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A practical introduction to solar irrigation

Training manual and reference guide with exercises to support the learning process of training participants in Mozambique

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Printed and distributed by:

Practica Foundation
The Netherlands, June 2022

www.practica.org

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Acknowledgement

This manual has been developed with support from Green People's Energy Mozambique (Africa Regional), in order to promote the productive use of clean energy by smallholder farmers in Mozambique.

Green People's Energy Mozambique is a project implemented by GIZ on behalf of the German Federal Ministry of Economic Cooperation and Development (BMZ).

PRACTICA Foundation promotes affordable technologies for water supply, irrigation and renewable energy in low- and middle-income countries.



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Preface

Approach

This technical training is a practical step-by-step guide for sizing small-scale solar irrigation. It includes practical methods and tips to design solar-powered irrigation systems up-until 1Ha and provides the basic steps to design larger irrigation systems.

It is a tool aiming at building the capacity of the actors of the solar irrigation ecosystem, and was designed as a part of a training provided by Practica to technicians, vocational trainers, and end-users.

Sizing an irrigation system is a long term investment. Some recommend to make very precise calculations to have the highest efficiency possible. In this training booklet, we adopt a more practical approach based on the idea that resources and needs vary. Within a year, water availability and crop requirements evolve continuously. Additionally, surfaces cultivated, labour available or market demand might evolve from one year to the next.

Because of that, we believe that building the capacity of the farmer by providing simple tools and skills is more efficient than building extremely precise and efficient irrigation systems that lack flexibility or adaptability. In this guide, we intend to make a simple and yet, safe estimation of the resources available and irrigation needs during the most critical period of the year, and to provide the necessary tools and knowledge allowing users to make choices and adaptations according to their preference.

For Who?

It aims to be a practical guide for:

- **Farmers** that wish to gain insight in solar irrigation and assess if solar irrigation is suitable for their farming practices;
- **Technicians** that want to have a quick reference guide on how to design a solar irrigation scheme;
- **Vocational trainers** that want a short guide that can be used during trainings as reference material for students.
- **Extension workers** that want to advise or support farmers on solar irrigation.

Basic calculation skills (multiplying, dividing) are needed to prepare the data and ensure a supplier can select the right pump. Selecting the right pump also requires (assistance of) a reader who is able to understand graphs.

Going further

If you are interested in following a training about solar irrigation or have questions about this guide, contact us at : info@practica.org
For those who wish further, more in-depth, information we suggest to use the online toolbox on Solar Powered Irrigation Systems (SPIS) developed by GIZ. This can be found on https://energypedia.info/wiki/Toolbox_on_SPIS

Explanations of words

This manual is a technical manual and introduces certain concepts and terms that might be new to the reader. The following list is an overview of the technical terms with a short explanation. The explanation will be more elaborate in the manual itself.

Application system: the set of technologies or practices used to bring the water from the conveyance system to the plants. For example, furrow irrigation is an application method.

Conveyance method: the way water is transported from the pump to the field.

Dynamic & static water level: The **static water level** refers to the level of the water in a well – measured from the ground surface – when the level is stable and no water is pumped.
When you start pumping water from a well (at a reasonable yield), the water level will start to go down. The more you pump the more it goes down, until a level where it might stabilize. This is the **dynamic water level**.

Fuel pump: A pump that runs on either petrol or diesel. Generally these are surface pumps.

Over-pumping a well: This is the point where a pump extracts more water than the well can provide. As a result the well runs dry.

Pump curve: a graph that shows how much water a pump can provide at a given head. Each pump has its own pump graph.

Pump discharge: The pump discharge indicates how much water the pump provides. Often expressed in m^3/h.

Yield test: Yield means 'to produce' per unit of time. Testing the yield of a well means pumping water at a certain flow, and observing how the water level reacts (how fast it decreases when pumping, and how fast it rises after stopping).

Safe yield of a well: The amount of water that a well can provide without over-pumping it.

Solar pump: A pump that runs on solar energy. This can be a submersible or surface pump.

Submersible pump: A pump that is lowered into the water: it is submersed. It runs on electricity (not fuel). Electricity can be provided by solar panels, the grid or a generator.

Surface pump: A pump that is placed on the ground and the inlet hose attached to the pump is inserted in the water. A surface pump can be a solar pump or petrol/diesel pump.

Total head: the force that the pump needs to provide in order to overcome the pressure in the system (column of water and friction forces). In irrigation, it refers to the pressure the pump needs to provide to let the irrigation system run the way it is designed.

Water efficiency: it shows which part of the water put into a system is not lost and can be used effectively. This can apply to conveyance and application methods. For example, when the water efficiency of an application system is 75% it means that for every 4 liters of water pumped in the system 3 liters of water reaches the plant.

Introduction

What is irrigation?

Irrigation is the practice of pumping water from a water source (like a lake, river or well) to water crops. Irrigation allows to grow plants in periods when there is not enough rainfall to naturally grow crops and to generate additional revenues during the off-season.

What is smallholder solar irrigation?

Solar irrigation is the practice to use **solar energy** to pump water from a source and bring it to the plants (to irrigate). The pump is powered by solar panels.

This guide explains the use of solar powered pumps to irrigate small plots (up to 1 ha) – also called smallholder solar irrigation.

How does solar irrigation differ from fuel powered irrigation?

Solar pumps are an alternative to manual pumps (like treadle pumps & rope pumps) and fuel pumps. But there are differences. The most important ones for a farmer are:

1. Solar pumps provide a relatively **low flow over the course of the day.** This flow varies depending on the intensity of the sun. The more sun the higher the flow. In comparison, fuel powered pumps provide a high & stable flow during a short amount of time.
2. **Energy from the sun is free**! So running costs are much lower than for fuel pumps. However, solar pumps are often more expensive to buy.
3. Submersible solar pumps allow access to water deeper than 7-8m, therefore they can be used in conditions where it is not possible to use fuel pumps.

	Solar pumps	Fuel pumps	Human powered pumps
Investment	Expensive	Less expensive	Cheapest
Running costs	Very cheap	Expensive	Very cheap
Labour	Time consuming with most application methods	Limited	Physical energy and time consuming
Maintenance	Little	More often	Little
Lifetime *Depends on the type of pump and use	3-10 years*	3-5 years*	3-5 years*
Water depth	Depending on pump	Most of the time suction pumps so less than 6-8 m	Depending on pump
Average plot size	Generally less than 1Ha (< 10,000 m^2)*	More than 2 acres (> 8000 m^2)	Up to 0.1 acre (< 400 m^2)
Pumping time	Daytime only	No restriction	No restriction
Power, pressure, flow	Variable	High	Very low
Typical use	Optimised systems	Pump for a short time,	Pump for a short time, linked to labour

Human powered pumps



Cheap, robust but labour intensive – so only a very small plot can be irrigated



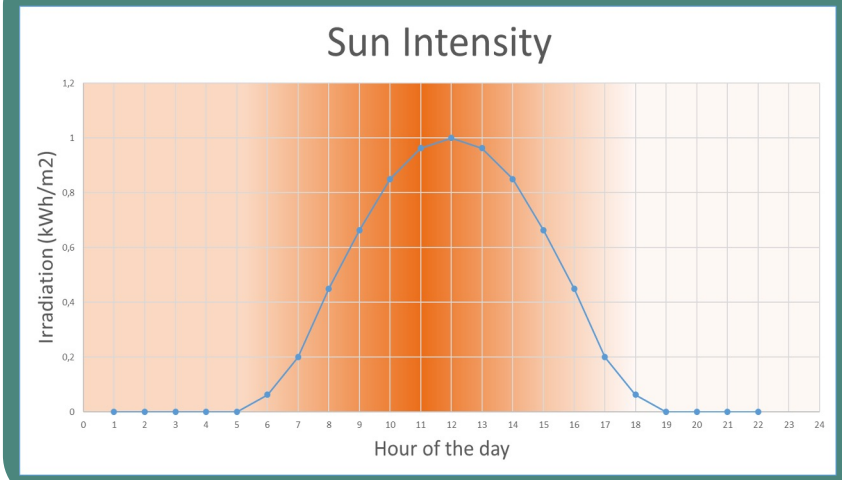
Fuel pumps

High flow of water, allows for quick irrigation. Lower investment than solar pumps yet high fuel costs

Solar pumps



Low water flow throughout the day– so it can be time consuming to irrigate. More expensive to buy than petrol pumps yet no running costs. Also – submersible pumps can reach deep water that is out of reach for fuel pumps.



Variable flow of solar pumps

Solar pumps do not have a constant water flow. This is because the power supplied to the pump depends on solar energy. And solar energy changes during the day. In the early morning the solar energy is low. At noon It peaks. After noon it slowly starts to become less until the sun sets. It is also affected by shade from clouds or dust.

How to design a solar irrigation system?

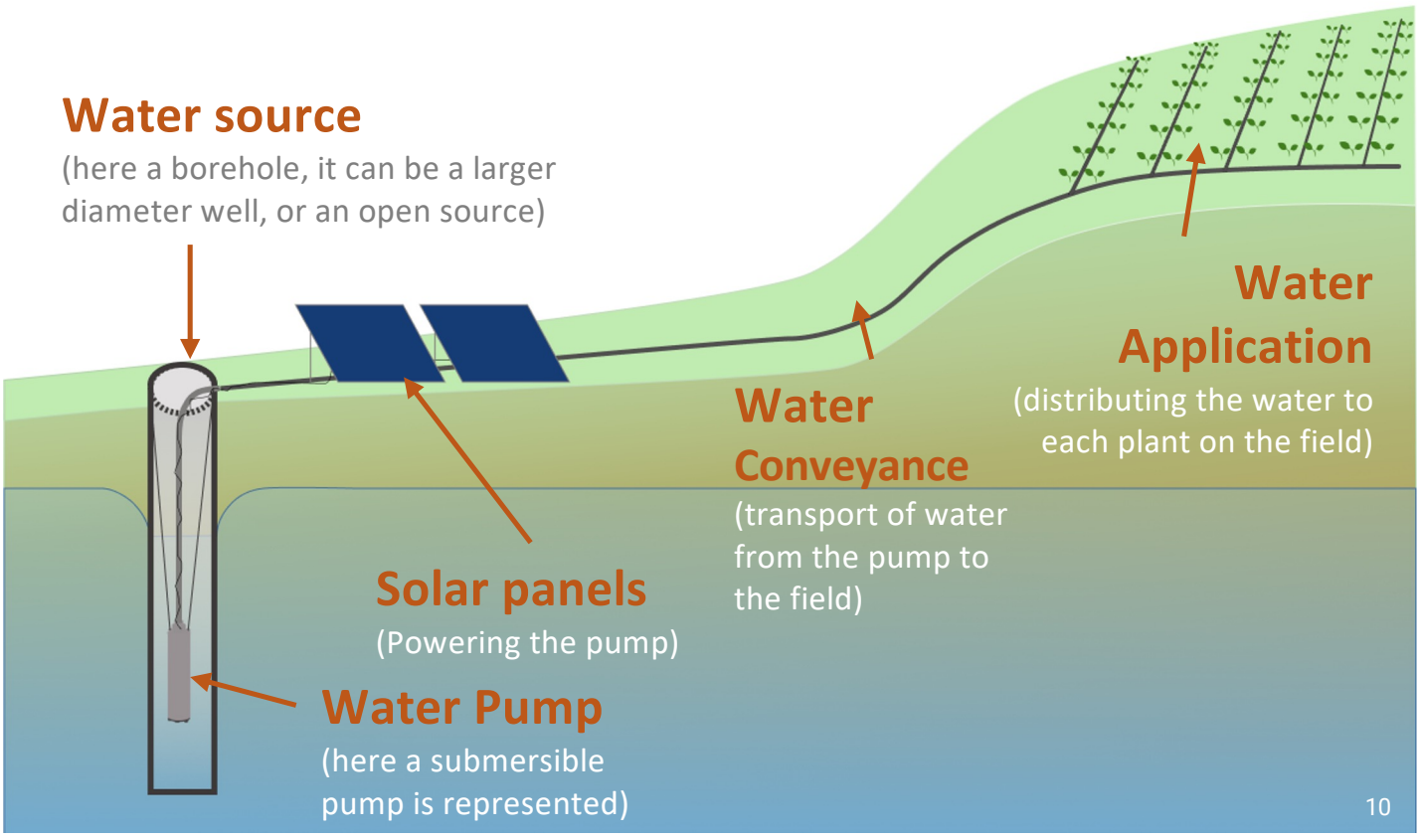
This manual presents a method to select solar irrigation technologies. There are several steps to take, in order to select a solar irrigation system adapted to your situation:

1. Determine the capacity of the water source, and measure the depth of the water
2. Determine how much water is needed to irrigate
3. Choose your application & conveyance system and determine your pump yield
4. Calculate the total head: a technical term that represents how much pressure the pump will need to provide
5. Select the pump that fits the identified needs
6. Identify the financial resources needed to buy the pump
7. Analyse the risks and other feasibility criteria

This manual will guide you through each step. First read the theory, then read the example. You can make the calculations for your specific situation. Don't hesitate to fill in your information directly in the manual.

This guide uses mostly m^3/h as a unit for water flow. Some pump suppliers use liters per second (L/s). Or liters per minute (L/min). In appendix 1, a conversion table is available.

Components of a solar irrigation system:



Form

This manual uses a step by step approach to gather the most important data to select the right solar pump. Each step will be explained in the right order.

As you go through the different steps of the guide, please fill in the following form, it will be useful to select the right solar pump. (A more complete form is also available in Appendix 2 of this booklet to guide you through the calculations.)

This manual belongs to: ……

Region: ……

Information	Outcome	How
Dynamic water level (Step 1):	1) ……meters	Measure water level while pumping from the well at safe yield
Yield of your water source (Step 2):	2) …… m^3/h	Do a bucket test
Pump dischrage needed (Step 3):	2)…… m^3/h	Calculate based on location, crop and field size and efficiency of irrigation scheme
Total head system (Step 4):	3) …… m	The sum of the total vertical elevation of the water plus losses in pipes and application method

The information in the table above are the most critical numbers for selecting a pump. It is because:

1) If the dynamic water level is below 8 meters only a submersible pump can pump water from the well;
2) The yield of the well has to be larger than the pump discharge otherwise the well will run dry and you won't be able to irrigate your field.
3) To select a pump one will need to know how much water needs to be pumped at which total head. This capacity differs per pump and number of panels used.



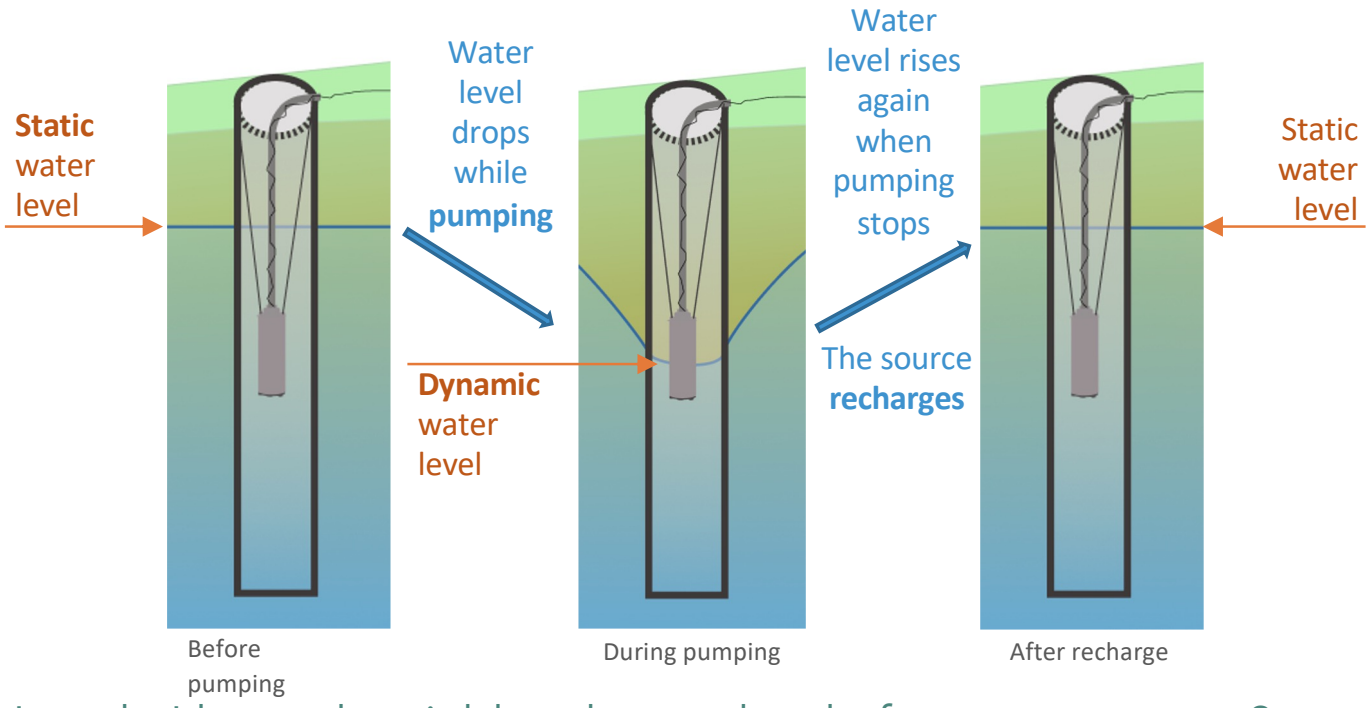
STEP 1: Yield & water level of the water source

There are 2 types of water sources used for irrigation:
- **Surface water**: river, lake or pond
- **Groundwater**: an open well or a borehole (also called tube well)

What are the yield and level of my source and why is it important?

/!\ Pumping water from a water source may cause the water level to drop.
- If more water is pumped from a well than the well can provide, the well will run dry.
- The lower the water table, the harder the pump needs to pump. If the level of the water source drops, more energy will be needed for the pump to bring water to the surface.

To design a productive and efficient system, it is important to measure these two factors:
1. How much water can the source safely provide. This is called the **safe yield** and is expressed in m^3/h. Yield means: 'how much can the source produce'.
2. How deep does the water level drop when the pump is pumping at a certain motor speed. This is called the **dynamic water level**.



How do I know the yield and water level of my water source?

- With large reservoirs or **surface water** you only need to know if it contains more water than what is needed for the whole growing season. Experience from previous years is often the best source of information. With surface water it is easy because the water level is visible: did the river ever run dry or did the reservoir dry up in the dry season?
- With **wells and boreholes** this is more difficult because you can't always see the water. Therefore a '**yield test**' is advised. The next infosheet presents a simple method to test how much water the well can provide. It is described in the next page.

When should I test the yield of my source?

Ideally you should test it during the driest period of the year. It is when your crop will need the most water and when your source has the lowest water level during the year.

Infosheet: How to test the yield of a tube well?

This infosheet explains how to test the yield of a tube well. In the paragraph after it is explained how this same principle can be used to measure the safe yield of an open well.

Material needed:

- Large capacity pump (that pumps more water than needed or than the well is expected to provide) with hoses
- Put a valve at the end of the hose to control the flow of the pump when using submersible pumps. For petrol pumps the throttle can be used to control the flow. Make sure that the hose and the valve can handle the pressure of the pump when the valve is nearly closed.
- Bucket (preferable volume at least 15-20L)
- Timer

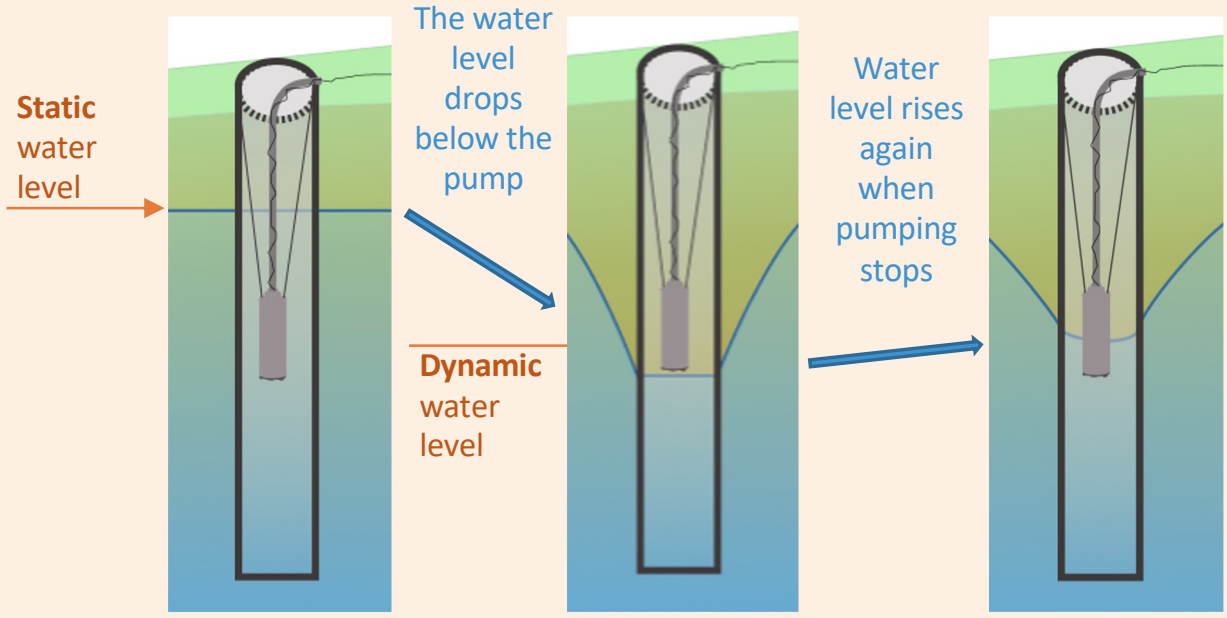
Procedure:

Step 1:

- For a tube well this means about one meter above the screen (the area where little slots have been made that let the water enter into the casing).
- In an open well this means, place the pump into the water but above the ground to ensure dirt/sand is not sucked into the pump. Dirt and sand will damage the pump.

Step 2: Start pumping at a slow rate. When using a submersible pump, this can be done by partially closing the valve at the end of the hose. Don't close it completely. Just enough to reduce the flow to a small steady flow. When using a petrol pump, use the throttle.

Step 3: Now find the speed of pumping where the well is over-pumped. This is the point where the pump pumps more water out than the well can provide. Do this by slowly opening the valve/throttle. This will increase the amount of water extracted from the well. Continue to do this until the pump is unable to provide a continuous water flow. Often you can see that the pump pumps water for a a few seconds and then it stops again. This is the moment you are 'over-pumping' the well.



Step 4: Once you found the moment you are slightly over-pumping the borehole, slowly close the valve/throttle, to reduce the water flow and find the point where the pump starts providing a continuous flow again. This is the maximum yield that the borehole can provide. Don't wait too long to reduce the water flow and restore a continuous flow, because the pump can get damaged when pumping dry for too long.

Step 5: Let the pump run at this setting for at least 30 minutes to ensure the flow can be sustained for a long period of time. For more certainty about the sustainability of the well yield let the pump run even longer than 30 minutes. In 'professional' well testing the well is sometimes tested over 1 or 2 days by continuous pumping. The longer the well is pumped the more certain one can be of the result.

Step 6: When you found the maximum yield of the borehole, measure the **depth of the water** table when still pumping. Write this down in meters. It is the **dynamic water level**.

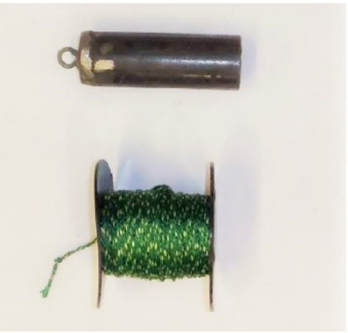
Tips for water level measurement:

Measurement devices:

- *Dipper*: A special device called a 'dipper' can be used. It makes a beeping sound when it hits the water, allowing easy measuring of the water level.
- *Traditional technique*: An alternative is to attach a small metal cup to a chord and lower it into the well. When the cup hits the water it makes a 'plopping' sound. This indicates it has hit the surface of the water. Make a small knot in the chord at the level of the ground surface. Pull out the chord and measure the length between the knot and the metal cup. It can be hard if the pump is making a lot of noise so you might need to turn it off to do the measurement very quickly once the pump stops – beware this will result in a less accurate result.



Dipper



Chord & metal cup

Prefer the use of a submersible pump:

Using a petrol pump might keep you from hearing the sounds of the metal cup hitting the water, and will cause the suction hose to be in the way when using the dipper.

Although the method is quite simple, in some cases it might be very difficult (or impossible) to measure the dynamic water level. This is particular difficult when a large suction hose is inserted into a small diameter well. If it proves practically impossible to measure the dynamic water level when using a suction pump than it is advised to use an assumed dynamic water level of 7 or 8 meters.

Step 7: **Keep pumping at the maximum yield.** Measure how much water is pumped out of the well by doing a 'bucket test'. This is done by timing how long it takes to fill a bucket with water. **The yield can be calculated by the following method:**

$$\text{Borehole yield } (\frac{m^3}{hr}) = \frac{Size\ of\ bucket\ (in\ liters)}{Number\ of\ seconds\ it\ took\ to\ fill\ it} x\ 3{,}6$$

Repeat the test 3 times and calculate the average to get an accurate number.

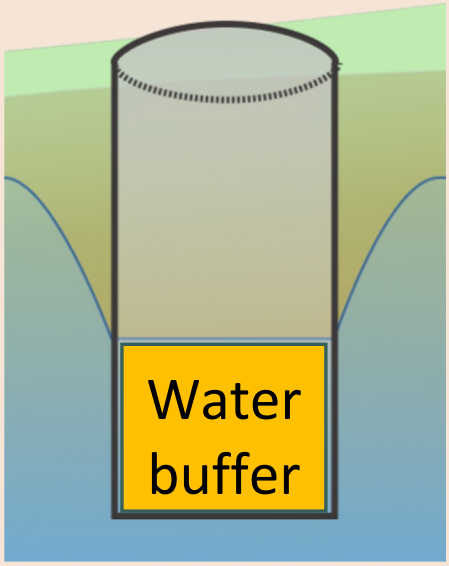
A	B	C	D	E
Test	Size of the bucket (in L)	Numbers of seconds it took to fill it with the constant flow	Nb of liters/s (B/C)	Nb of m3/h (D*3.6)
1st				
2nd				
3rd				
Average (Sum of first, second and third tests divided by 3)				



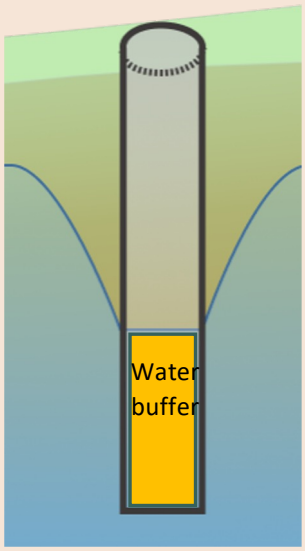
Infosheet: How to test the yield of open well?

To test the yield of an open well you need the same material as to test the yield of a tube well. See page 13.

Ground water can be accessed by either a tube well or a hand dug well. In principle they are the same: an opening in the ground is made to reach the water.



Open well



Tube

However, an open well has a much larger diameter than a tube well. This has an important effect: **open wells can store water inside, while with a tube well, water buffer/storage is not possible because the volume is too small.**

When testing the yield of an open well one has to take this into account that:

- When pumping from an open well it is possible – at the beginning – to pump high quantities of water. This gives the impression that the well can provide a lot of water. However, it is only the buffer water being pumped.
- The inflow of water is dependent on the level of water in the well. And that is because contrary to a tube well, there is no screen. The water can infiltrate in the open well from the whole surface of the walls.

Therefore testing the yield of an open well must be done with a slightly different approach than a tube well:

1. Measure the diameter of the well in meters.
2. Place the (hose of) the pump in the well.
3. Start pumping until the level of the water is lower than the level where the inlet of the solar pump will be placed (being either the submersible or the suction hose)
4. Stop pumping and measure how long it takes for the level to rise to a certain height (h). Depending on the well, you can choose a height of a few centimeters, for instance, between 5-30 cm.
5. Then calculate the yield as follows :

$$\text{Open well yield } \left(\frac{\text{m}^3}{\text{h}}\right) = \frac{Volume\ of\ water\ to\ fill\ a\ known\ hight\ (in\ liters)}{Number\ of\ seconds\ it\ took\ to\ fill\ it} x\ 3{,}6 =$$

$$\frac{\left(diameter\ well\ (in\ meter)\right)^2 * height\ (in\ m)\ * 785}{Number\ of\ seconds\ it\ took\ to\ fill\ it} x\ 3{,}6$$

Example of Mr. Langa:

Mr Langa is a farmer in the Gaza region in Mozambique. He currently uses a manually drilled borehole to irrigate his crops with a treadle pump, But he considers adopting solar irrigation because he wants to increase the surface he cultivates during the dry season. He will follow the steps in this guide to know what type of technologies he needs to invest in.

Procedure for the yield test

Material

Mr. Langa uses a diesel pump from a neighbour to test the yield of his well. He knows that he can use this pump because his borehole is 8 meters deep, and always has at least three meters of water in it throughout the year when no water is being pumped from it. That means he can use a suction pump.

Yield testing

He has a bucket of 25L that he will be using later to determine the safe yield. For now he proceeds to testing the well. First he pumps slowly, and little bit little he opens the valve and increases the water that is being pumped. When he notices that the water level starts to drop a little bit he closes the valve again a little bit until he obtains a continuous water flow and a continuous water level.

Water level measurement

That is the point when the water is 6,20 meter deep in the well. He writes down a **dynamic water level of 6,20 meters**.

Safe yield measurement with bucket test

Without changing anything, he proceeds to the bucket test to determine the yield. The bucket of 25L takes 12 seconds to fill. He measures 3 times in a row in order to make sure there was no mistake. He obtains more or less the same number of 12s. That's good.
He calculate the yield:

$$\text{Borehole yield } \left(\frac{m^3}{h}\right) = \frac{25}{12} x\ 3{,}6 = 7{,}5\ \left(\frac{m^3}{h}\right)$$

Now, Mr Langa knows that his well has an approximate **safe yield of 7,5 m^3/h**.

STEP 2: Water need for irrigation

What is the irrigation water need and why is it important?

The second step in the design process is to determine the irrigation water need. It is the maximum amount of water needed per day (in m^3/day) to irrigate all plants on the field.

It is important to know how much water is needed by your crop so you can select the right pump size. If the pump is too small, there won't be enough water to irrigate all the land.

How should I calculate it?

To calculate it, follow the next steps:

1. Measure the plot that you want to irrigate: ……m^2
2. Now you need to calculate the daily water needs. They are usually expressed in mm/day (= L/m^2/day). In Mozambique, the water needs for vegetable crops during the dry season and during the most critical period (September-October), can be estimated at 5-6 L/m^2/day. For tree crops, it is around 4-5L/m^2/day *(see the note on water availability and need page 18).*

Multiply the surface that you want to irrigate (in m^2) by 6 (inL/m^2/day). You obtain the crop water requirement in L/day for your farm.

Crop requirement (for vegetables) = …….. m^2 x 6 = …… L/day

Convert it into m^3/day by dividing the result by 1.000.

Water requirement per day = ……L/day / 1.000 = …… m^3/day.

This results needs to be converted into m^3/h because that's the unit used to determine the required discharge of the pump. Solar pumps run during the day, when there is sunshine. To obtain the water need per hour, we divide the water need per day by the number of hours of sunshine per day. On average, there is 5h of effective sunshine per day in Mozambique (during the critical period - see note on sunshine hours).

Required pump discharge = ……m3/day / 5 **=…… m^3/h**

/!\ Warning! No irrigation system is perfect and 100% efficient. If you use pipes (like PVC pipes) to conduct the water in your system, the losses will be neglectable. But there will always be losses in the connections and in the application system.

The efficiency of the application and the calculation of the losses will be explained during the next step. For now you just need to understand that the required pump flow that you just calculated is not final yet because it doesn't take into account the efficiency and the losses in the system.

Note: Why you should always estimate the water availability & needs during the most critical period of the year

- Water availability in the source and in the soil varies depending on the season. Water levels get higher during the rainy season, and reduce during the dry season.
- Crop water need vary during the crop cycle. Fully grown and productive plants have larger water needs than sprouts.

The safe yield of the water source and the water need of the crop should always be **determined during the period of the year when water supply for irrigation is the most critical**. It means that it should be determined when the water availability is the lowest, and the crop water need the highest.

In Mozambique, this period is during the months of September and October. The water availability in the soil is the most limited and the crop stage is usually advanced. Based on data from this period the water needs are calculated from the ETo and Kc. In Mozambique, we consider the number of 6L/m2/day to be a safe estimation of the crop needs for the design an irrigation system.

Source: Eto (Evapotranspiration): Climate Info Tool. (https://aquastat.fao.org/climate-information-tool/)
Kc (Crop coefficient): FAO (http://www.fao.org/3/bc824f/bc824f.pdf)

Example of Mr. Langa:

Mr. Langa wants to irrigate 0,65 Ha (= 6,500m^2) and grow vegetables during the dry season. He needs to calculate how much water is needed to irrigate his land.

He knows that the water needs in Mozambique, during the most critical period are about 6 L/m^2/day.

He multiplies the surface of his land (6,500m^2) by the water needs, and obtains a crop requirement of 39.000L/day. He converts this number in m^3/day, by dividing the previously obtained number by 1.000.

He obtains a crop requirement of 39m^3/day.

He would like to know how much water he needs to pump per hour in order to provide his plants with the 39m^3/day that they need.

In order to do this he divides the crop requirement per day by the number of hours of sunshine in a day (during the critical period). It is usually estimated at 5h/day.

So he divides 39m^3/day by 5 and obtains a required **pump discharge of 7,8 m^3/h**.

He needs to find a pump that can pump, from his water source to his field at least 7,8m^3/h, but first he needs to take into account the losses in his system.

In-between check n°1

What do we want to check?

In the previous steps the maximum yield of the well has been calculated (Step 1). And the irrigation water need has been determined (Step 2).

A first check can show if the well can provide sufficient water to irrigate the land. If the daily water needs are higher than the yield that the well can provide within the hours of effective sunshine, the surface of land indented for irrigation needs to be reduced (or the number of wells could be increased).

Note that we need to do a second similar check once we have selected our irrigation system in the next steps. This is because of the losses in the system, some water might be lost in the transport from the pump to the plant. This will be taken into account at a later stage.

How should I calculate it?

To make sure that the well can provide a sufficient amount of water to irrigate the surface that you have chosen, you need to compare the **safe yield of your well** (that you have measured at step 1, with a pump test) to the **required pump discharge** (calculated at step 2, in m^3/h).

- ❑ If the required pump discharge is **lower**, then proceed to the next steps.
- ❑ If the required pump discharge is **higher**, then reduce the size of the land to irrigate.
  Otherwise, digging a new additional well on the land can be considered.
  /!\ But an extra well might require an extra pump, so an extra investment.

Example of Mr. Langa:

At step 1, Mr Langa measure a safe yield of 7,5 m^3/h.
At step 2, Mr Langa calculated a required pump discharge of 7,8m^3/h to irrigate 6.500 m^2.

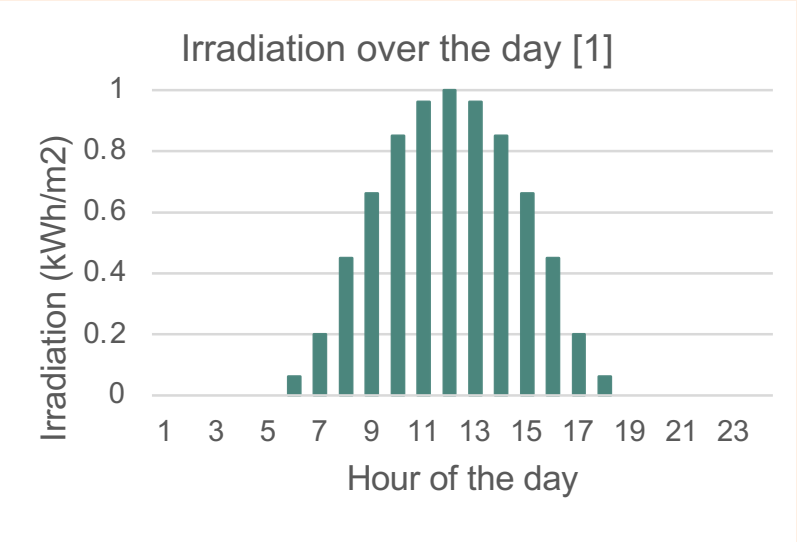
He realises now, that the required pump discharge is higher than the safe yield of the borehole. This means that Mr. Langa will not be able to irrigate his entire field with his well. He also knows that he has to account for some losses in the pumping and application system, so he understands that he has no other solution but to reduce the surface to be irrigated (doing another well would be too expensive for him).

He decides to reduce the surface he wants to irrigate to 0,45 Ha. He does the calculation again. He needs to irrigate 4.500 m^2, and for that he calculates that he needs **27 m^3/day,** and a pump discharge of 27/5 = **5,4m^3/h**.

This is lower than the safe yield of his borehole of 7,5m^3/h, so he proceeds to Step 3.

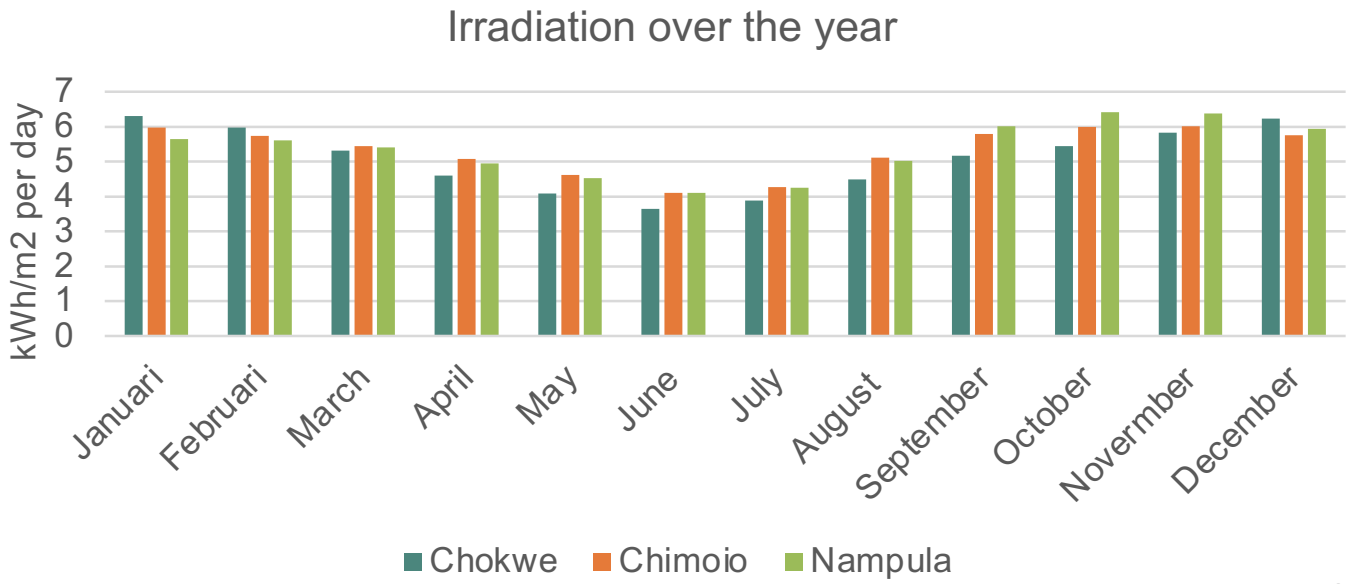
Infosheet: Hours of sunshine

At step 2, to calculate the required yield of the pump the daily water need was divided by 5. The number of 5 is derived from the concept of '**peak sunshine hours**'. 5h is a safe estimation of the minimum average irradiance in Gaza during the months of September, October, where the need of water for irrigation is the most important (https://power.larc.nasa.gov/data-access-viewer/)



The total amount of energy received from the sun in one day is an important number because it allows to determine how much water can be pumped during this day. This varies over the course of the day. In the early morning or late evening, the sun is less strong than at the middle of the day.
You can also notice that in the graph [1] above.

It is important to look at the hours of sunshine during the critical period for irrigation. In Mozambique, the irrigation season is during "winter" where the days are shorter. So in June and July, the sunshine available is about 4h/day. But the most critical period in terms of water needed by the plant and irrigation is during the months of September and October, where the days are longer. The average during this period is slightly above 5h/day. We will consider 5h.



STEP 3: Water conveyance & application method

What is water conveyance and application?

When the pump extracts water from the well it needs to be transported to the field. And from that point it needs to be transported to the plant.

- The first part, from pump to field, is called the **conveyance method**. Often this is done by using a pipe or a hose. Open channels are also used but are NOT recommended, because they are a lot less efficient.
- The second part, within the field, is called the **application method**. The most common practices of water application are furrows, sprinklers, drip, buckets, hose or spray cans.

Determining which conveyance and application method you will use is the third step.

Why is it important to know this when I choose my pump?

It is important because different methods have **different water efficiencies**. When a method is water efficient it means very little water is lost.



For example, if an application method has an efficiency of 75% it means that of every 4 liters of water pumped into the systems only 3L reach the plants. And 1L is lost.

At step 2, we determined the amount of water needed by the plants. To size the pump we need to take into account the water losses from the pump to the plant. The higher the losses are, the larger the pump capacity needs to be. Or, if a well provides a limited amount of water it means less land can be irrigated.

How to select the application method?

In this step you must adopt an entrepreneurial approach. Try to find technical and financial optimizations and combine them with your personal preferences. Some methods are cheap to use but are labor intensive (for example a spray can). Others have a high water efficiency but are relatively expensive (for example drip). Also the needed pressure should be considered: sprinklers need a certain pressure to be efficient. This takes energy that a pump could also use to generate a larger water flow. Some pumps provide a large flow even with a high pressure, but they are more expensive.
You can find examples of water application methods on pages 26 to 29 of this booklet.

For the conveyance we always recommend to use a pipe or hose to reduce the losses to a minimum. Therefore we assume a conveyance efficiency of 100% in the next examples.

How do I know the pressure & water efficiency of my application?

For small scale farmers who cultivate less than 5.000m^2, irrigation kits are available on the market. For instance drip kits, sprinkler kits, etc. In this type of kit the set up is already arranged and therefore the pressure and efficiency are pre-defined. You can find it on the box of your kit, and you can already have an indication in the table below.

For farmers cultivating larger areas, you might want to adapt your application system to your needs. Therefore you need to design the ideal set up and calculate the pressure needed and the efficiency it will have. We recommend you to reach out to a technician who will help you take these steps.

The following table provides an indication of the characteristics of different application methods.

	Drip kit	Misters & spray tubes	Low pressure sprinkler kit	Hose or pipe	Furrow / Basin	Bucket/ spray can
Water saving	Very high	High	Medium	High	Low	High
Labour intensity	Very low	Low	Medium	Very high	Very high	Very high
Price	Very high	High	Medium	Low	Low	Low
Ease of adoption	Difficult	Easy	Medium	Easy	Easy	Easy
Sensitivity to silt	High	Low	Low	Very low	Very low	Very low
Pressure needed	2 m	5 m	10 m	2-5 m*	0 m	0m
Water efficiency**	90%	75%	70%	75%	60%	75%
Solar compatibility	Good	Good	Medium	Medium	Low	Good

* Depending on the diameter and length of the hose and whether the farmer squeezes it to spray.
**Source: http://www.fao.org/3/t7202e/t7202e08.htm

Be aware that these efficiencies only apply if one uses the application method correctly. Over-irrigating by for example not replacing sprinklers or hoses in time will result in a loss of water and therefore a reduction in efficiency.

Note: Furrow & basin [for technicians]

For furrow and basin irrigation to be used effectively one will need a certain minimum flow of water. If the flow is too low the water will not reach the end of the irrigation plot. The smaller the flow, the more water is lost by infiltration in the first part of the furrow. How much water is needed at the beginning of a furrow depends on the length of the furrow and the soil type. For basin irrigation this depends on the size of the basin and the soil type.
In appendix 3 you can find a more detailed explanation to determine the minimum flow needed.

In-between check n°2

Relation between application, pump and well yield

As mentioned previously, no matter the application system you decide to use, there will be losses in your system. They will be expressed in percentage. We call it the efficiency of the application system.

For example, in an application system with an efficiency of 75%, for each 4L that enters the application system, 3L reaches the plant, and 1L is lost (in the air, the soil, etc.)

Note that when using a higher efficiency application method either (a) a larger plot can be irrigated compared to low efficiency applications or (b) a smaller pump can be selected.

How to calculate it?

Irrigation method	Efficiency (%)
Surface irrigation (Furrow, bassins, etc.)	60%
Overhead irrigation (Sprinklers, spray tubes, misters, etc.)	75%
Drip irrigation	90%

Source: http://www.fao.org/3/t7202e/t7202e08.htm

1. Select the efficiency of the application system that you have chosen in the table on the left or page 21.

2. In order to apply the efficiency to the required pump discharge that you have calculated, divide the required pump discharge by the corresponding efficiency.

$$Required\ pump\ discharge\left(\frac{m^3}{h}\right) = \frac{Pump\ discharge\ (\frac{m^3}{h})}{Efficiency\ of\ the\ application\ system\ (\%)}$$

Now check:

- ❑ If the required pump discharge is **still lower than the safe yield** of your water source measured at step 1, everything is fine. Your water source can supply enough water to irrigate your field. You can go to the next steps.
- ❑ If the required pump discharge you calculated now in m^3/h is **high than the safe yield** be careful! You need to reduce the area that you plan to irrigate or you need to select a more efficient application method (with the highest possible efficiency).

/!\ In these calculations we supposed that the losses in the conveyance system were neglectable because we used a closed pipe system to transport the water to the field.



Underground pipes can be used to transport water from the pump to the field.
It is called 'a Californian system'

Infosheet: Types of conveyance systems





There are 2 ways of transporting water from the pump to the field. An open channel, or via pipes and hoses.

Open channels have 4 considerable downsides compared to pipes and hoses:

1. Water cannot be transported uphill via an open channel.
2. Water losses are **very high**. These can go up to half of the water being lost during transport.
3. Most application methods are not possible with open channels – for instance drip and spray tubes are not compatible with open channels.
4. Open channels require a large water flow in order to be used, otherwise most of the water will be lost in the soil before reaching the plots. This is not always compatible with solar pumps (especially small pumps).

Because of the much higher efficiency it is advised to **always use pipes or hoses to transport water to the field when using solar energy**. If well installed, well maintained and used correctly, the water losses can be negligible (0-10%). Buried pipes have a lower risk of being damaged by cattle, sunlight etc.

Infosheet: Types of application technologies

Drip irrigation

Water is pumped into small pipes that lay in the field. Even smaller tubes can bring the water exactly where the plants needs it. It is therefore very efficient.





Sprinkler

A sprinkler 'splashes' the water to the plants in a circular pattern. Is uses the pressure of the water to rotate.



A tube with small holes in it sprays water on the field. It is relatively easy to use, has a high efficiency and is less expensive than drip irrigation.

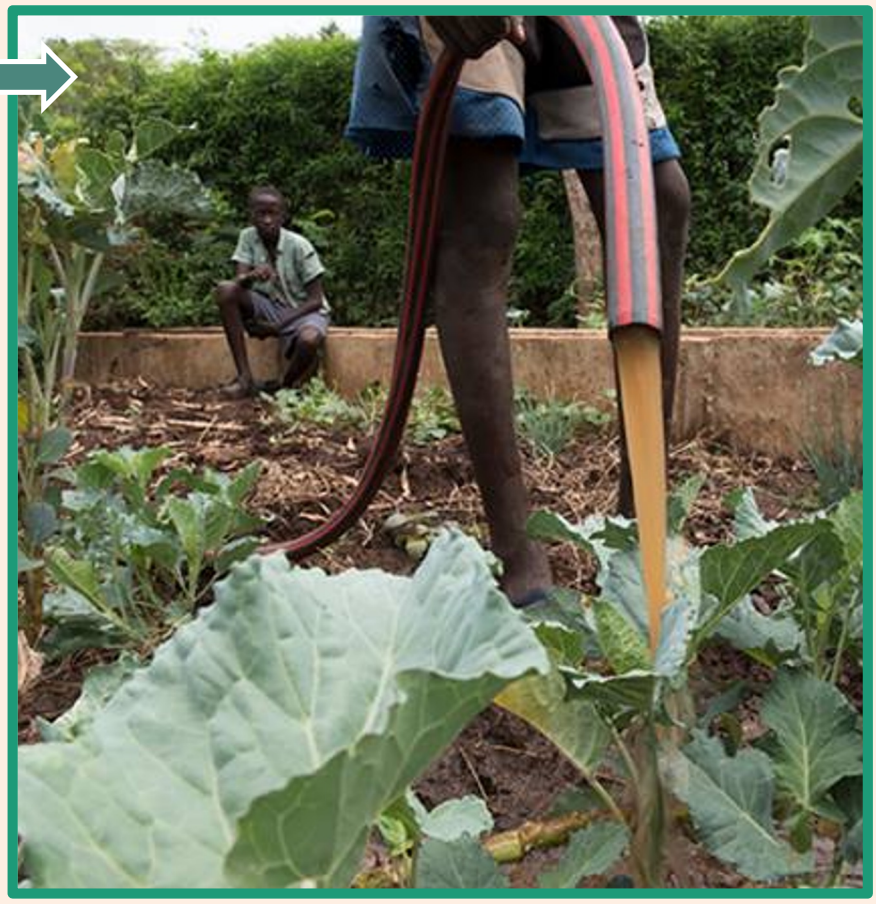
Misters / Spray tubes

Furrows are probably the most common application method in Sub Saharan Africa. Channels are dug in between plant rows. A pump is used to fill these channels. The biggest downside of this method is that it is very inefficient (a lot of water is lost) in combination with solar pumps.

Furrows



Pipe/hose



A pipe or hose is directly attached to the pump. Sometimes the hose is squeezed to let it spray further.

A bucket or watering can is used to transport the water and to water the plants.

Watering can



Both irrigation methods shown on this page are very labour intensive. This can, in some cases, mean that only a small plot can be irrigated.

Example of Mr. Langa:

Mr Langa. has a borehole that provides 7,5 m^3/h and he needs 27 m^3/day to irrigate his field. There is about 5h of sunshine during the critical time of the year, so he needs to pump 5,4 m3/h to apply sufficient water to his plants.
He hesitates which application method to choose for. To make a decision he makes an overview of the options.

Efficiency of furrows / basins

The first option he explores is using furrow irrigation. It is used a lot by other farmers and it is cheap. So it sounds attractive. He calculates the maximum pump flow when using furrows. Furrows have a water efficiency of about 50%, so the calculation is as follows:

$$Maximum\ pump\ flow\ with\ furrow\ irrigation\ \left(\frac{m^3}{hour}\right) = \frac{5,4}{0,6} = 9\ m^3/hr$$

Using furrows to irrigate the area he currently wants to irrigate would require a flow of 9m^3/h. Unfortunately his water source can only provide 7,5 m^3/h. Therefore, this option can only be used if he reduces his irrigated land by at least one sixth of its current size. But he doesn't want to do that.

Efficiency of spray tubes & drip

He decides to check if improving the efficiency of the application method can help him out. He calculates the consequences of using drip and of a spray tube. Spray tubes have a water efficiency of about 75% and drip irrigation about 90%, so the calculation is as follows (figures are rounded to higher number):

$$Maximum\ pump\ flow\ with\ spray\ tubes\ \left(\frac{m^3}{hour}\right) = \frac{5,4}{0,75} = 7,2\ m^3/hr$$

$$Maximum\ pump\ flow\ with\ drip\ \left(\frac{m^3}{hour}\right) = \frac{5,4}{0,9} = 6\ m^3/hr$$

By comparing the pump yields with the safe yield of the water source he sees that both options are feasible. With drip irrigation he can even irrigate more land than he planned. However, being new with irrigation he wants to limit the complexity of his irrigation and limit his investment. Spray tubes are cheaper and easier to install than drip. For that reason **he opts to use spay tubes**, the maximum pump yield is then **7,2 m3/h**.

It means that for every 7,2m3/h that he pumps and enters the irrigation system, only 5,4m3 will reach the crops.

Optional step: Water storage & batteries

What is a water storage?

Water storage is a reservoir or tank that stores water. It serves as a 'water battery': by storing water to be used at another point in time.

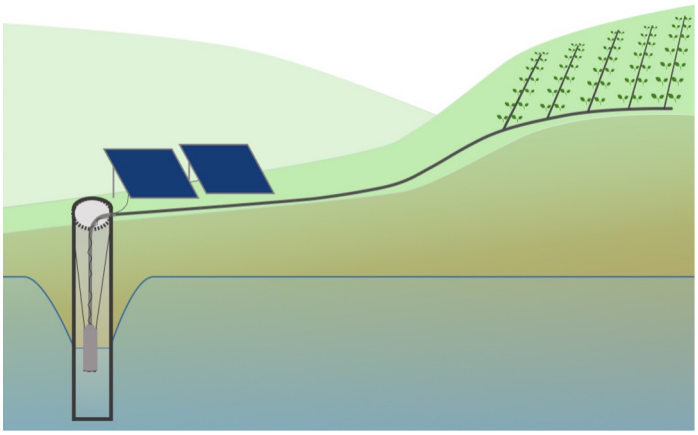
It is not necessary to have a water storage for irrigation. In specific situations it might be convenient.

What type of water storage are possible? *(Pictures page 32)*

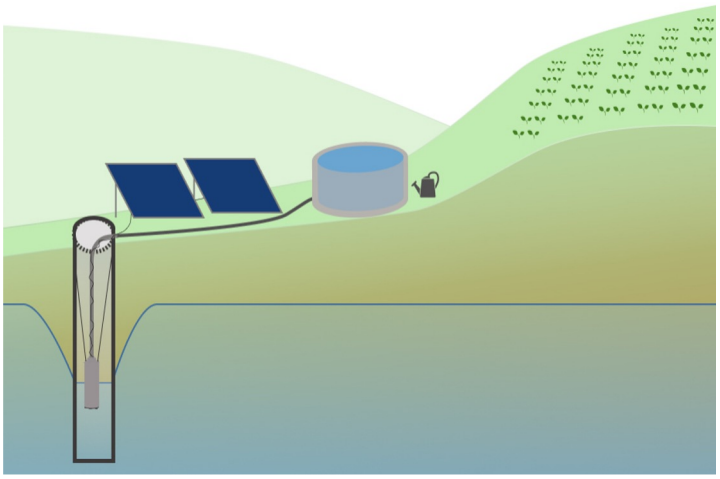
- **A small water reservoir/drum (picture B)**: the farmer can use drums on the ground to pump the water to. From there it can be fetched and applied with a bucket or spray can. It is labour intensive and can only be applied to very small surfaces or communal gardens. Yet, in this way water spillages are avoided compared to not using the drums.
- **Low sun intensity reservoir/drum (picture C)**: when the pump is connected directly to the application system (see explanation later in this manual), the intensity of the sun, 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.
- **Large reservoir/tank (picture 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 to make maximum use of the well and prevents that the farmer needs to come to his field every day. Note that to do this tanks can be very big – the size of the daily water production of a pump, multiplied by the number of days when irrigation is not needed!



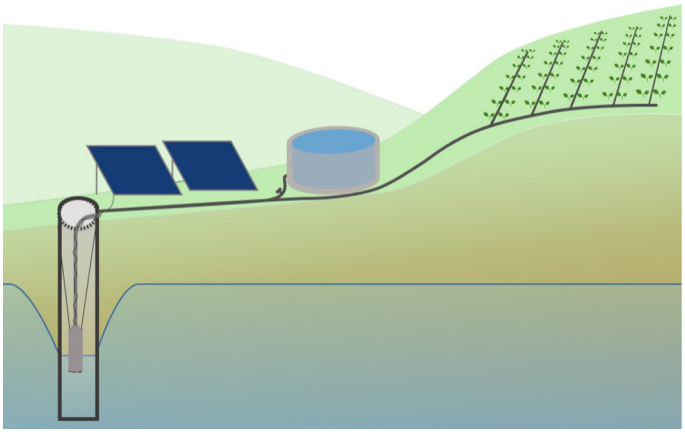
Bucket irrigation can be used in combination with small barrels to buffer the water. This set-up is common for communal gardens, since it enables multiple people to irrigate at the same time.



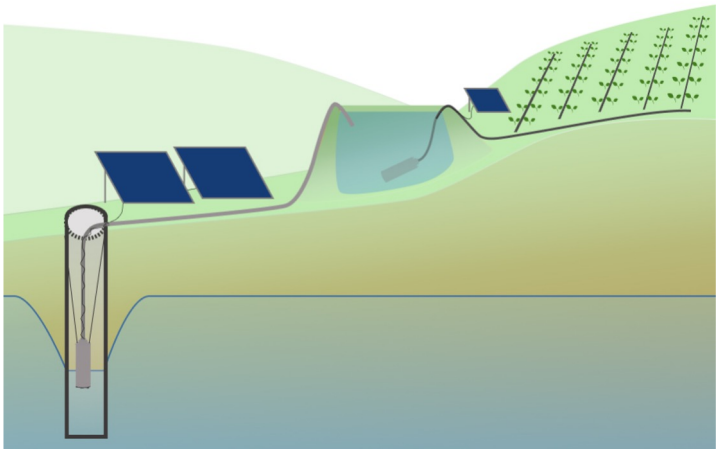
A- Direct connection from the pump to the application system



B- Small reservoir/drum for manual application



C- Low sun intensity reservoir/drum OR large tank



D- Large reservoir with second pump

Elevated storage or not?

Pumping water up requires energy. Water storages often adds extra height (and cost) in the system. The higher the water needs to be pumped (head), the lower will be the flow provided by the pump. And less flow means less water and less irrigated plants. **It is therefore often more efficient to pump the water directly into the application system**, rather than pumping it first into an elevated water storage and then using the gravity to transfer it into the application system.
If water storage is needed, it does not necessarily need to be elevated. It can be placed on the floor, and from there, the water can be fetched manually (for instance in the case of a low-intensity reservoir) or with a second pump. A low reservoir is a lot less costly than an elevated reservoir.

Storing water or using a battery?

Using a battery makes it possible to irrigate early morning and late evening. Nevertheless, it is better to invest in (low) water storage than batteries for several reasons:

- Batteries have a smaller lifetime and need more maintenance than water storage, because of the high temperature conditions and the control of the charge;
- Water storage also allows to irrigate early mornings and late evening;
- Batteries are less efficient than water storage. When transferring energy from the solar panel to the battery and then from the battery to the pump, a lot of energy loss occurs. While with a closed water storage, there are very little water losses. Efficient batteries are currently very expensive.

Example of Mr. Langa:

Mr Langa is wondering whether he should invest in a battery or a water storage. Mr Langa is a full time farmer. He spends most of his time in his field, and uses the harvest to feed his family and sells the surplus. He calculated at Step 2 that the surface that he can irrigate is 4.500 m^2. He needs to irrigate his plants every day.

Mr Langa decides to make an overview of all the pros and cons of water storage for his specific setting.

Small reservoir/drum	
Pros	**Cons**
- Can grow some additional herbs at a small plot at his house - Relatively low investment	- Can only buffer small amounts of water when the sun is still low in the morning and in the afternoon.

Large elevated tank	
Pros	**Cons**
- Can irrigate at night - Saves some time per day as the water flow can be faster from a reservoir than the pump normally would provide	- High investment but very limited extra profit - Lower pump yield

Since Mr Langa spends most of his time on his farm, he decides that a large tank has no major advantage. Because they are so expensive it makes no sense to buy one. However, he knows that he can buy two cheap old oil barrels. He decides to place them next to his house and fill them in the early mornings and late evenings to see if he manages to plant some extra plants around his house.

STEP 4: Calculating the head of the system

What is the total head?

Head is a technical term for calculating the pressure that the pump needs to provide to let the system function as it was designed to do. It is expressed in meters. So if a total head is calculated to be 10 meters it means the pump needs to work as if it has to pump the water 10 meters high.
Determining the total head of the system is the fourth step in the design process.

Why is it important?

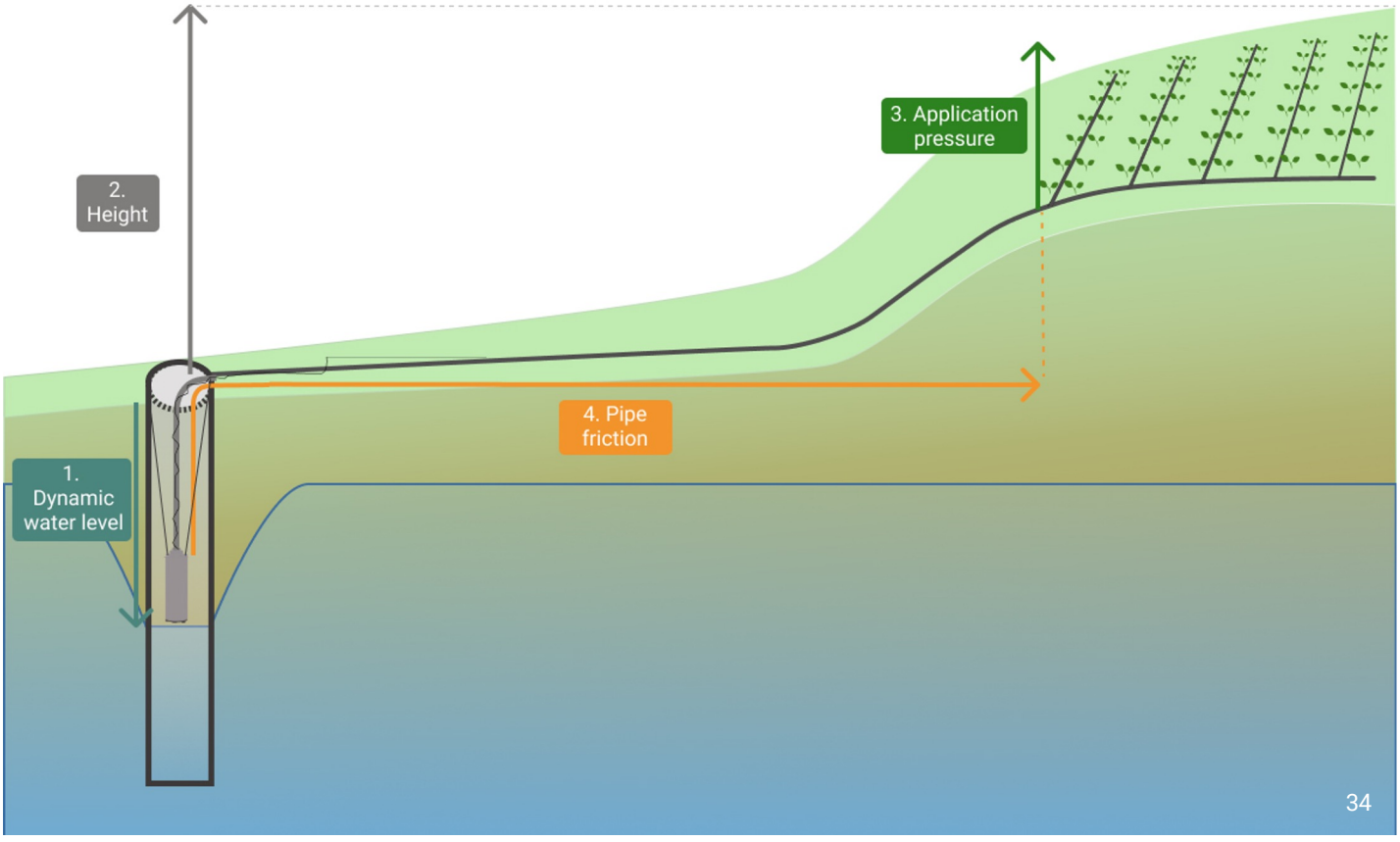
Pumps can be very different from one each other. It depends on the design of the pump. Some pumps can provide a high flow and provide very little pressure (head). Some pumps provide a very low flow but a very high pressure (head). Knowing the head in combination with the required flow allows you to select the right pump. Not calculating the head might result in a situation where you will not get any water at the field.

How to select the right method?

To calculate the head you will need to collect the following data:

1. The **dynamic water level** at the well measured (in meters – see step 1)
2. The **height** difference at highest point in the path from the well to the field (in meters)
   /!\ if you use an elevated reservoir, this might be the highest point!
3. The required pressure of the **application method** (in meters – see table step 3)
4. The **friction losses** of the pipes in your conveyance system (in meters)

The sum of point 1 to 4 is the total head.



Infosheet: Friction losses and how to calculate them

The friction losses are the losses of pressure due to the circulation of the water in the pipe. They are the fourth component of the head calculation and they depend on 4 parameters:

- The volume of water that flows through the pipe: more water is more friction;
- The length of the pipe: the longer the pipe the more friction;
- The internal diameter of the pipe: the smaller the diameter the more friction;
- The material of the pipe: the rougher the material the more friction.

In order to increase the efficiency of your system and optimize the use of your pump, you need to reduce the friction as much as possible. Ideally, for small irrigation systems, up to 1Ha, try to keep the friction losses below 1,5 or 2m.

Based on the required pump discharge that you calculated at step 3, use the table below to determine the ideal pipe diameter that you should buy.

Note on pipe diameter

Be careful! When you calculate the pipe friction you consider the internal diameter, which is different from the commercial diameter that will be given to you at the shop. Usually we talk about the commercial diameter, so check this line to know which type of pipe you should buy. But keep in mind that you calculate your friction losses from the internal diameter.

Determine the pipe diameter that you need and the friction losses in your system.

1. Select in the table below the ideal pipe diameter depending on the pump discharge calculated at step 3 (only applicable if your pipe is shorter than 50m) .

Pump discharge	=< 1m³/h	=< 2 m³/h	=< 4m³/h	=< 6,5m³/h	=< 12m³/h	=< 20 m³/h
Minimum internal diameter	22mm	29mm	35mm	45mm	57mm	68mm
Corresponding commercial diameter	**25mm**	**32mm**	**40mm**	**50mm**	**63mm**	**75mm**

1. Report this internal diameter, and the required pump discharge, that you calculated at step 3 in the table appendix 4, or on this website: https://www.nationalpump.com.au/calculators/friction-loss-calculator/
2. You obtain friction losses per meter. Multiply this figure by the total length of your conveyance pipe (in m)

Try to limit the total friction loss in the conveyance and application system – the easiest way to reduce the losses is to **choose a larger diameter pipe or hose**.

Example of Mr. Langa:

Mr Langa needs to calculate the head of his system:

1. At step 1 he already measured the dynamic water level. The depth is **6.20m**.
2. He measures the height difference between the top of his borehole and the highest point of his field. The difference of elevation is **8m**.
3. He decided to use spray tube irrigation from a kit. He looks at the table of step 3 and sees that the pressure needed to irrigate his field with spray tubes is **5m**.
4. He now needs to determine the friction losses of the pipes.
   He checks the table of the previous page and sees that for a discharge of 7,2m3/h he should use a pipe of commercial diameter 63mm. He goes to the website to see how much friction losses he will have. He is careful to enter the internal pipe diameter in the calculator. According to the table in the infosheet, in his case, the internal diameter of a 63mm pipe is 57mm.

National Pump & Energy - Pipe Friction Loss

Flow Rate	m^3/hr 7.2
Diameter	mm 57
Pipe Length	m 50
Pipe Material	uPVC
	Calculate Clear Fields
Friction Loss	m 0.5767143963681515

Pipe Friction Loss - In this example, calculate the total friction loss in a pipeline. Enter the flow rate, internal pipe diameter, and the type of pipe from the list supplied. Leave pipe length as 100 to get the friction loss per 100 m/ft of pipeline.

The total length of the pipes is 50m. As a result, he obtains friction losses of 0.6m. For the calculation of the head he rounds the number up at **1 m** of pipe friction.

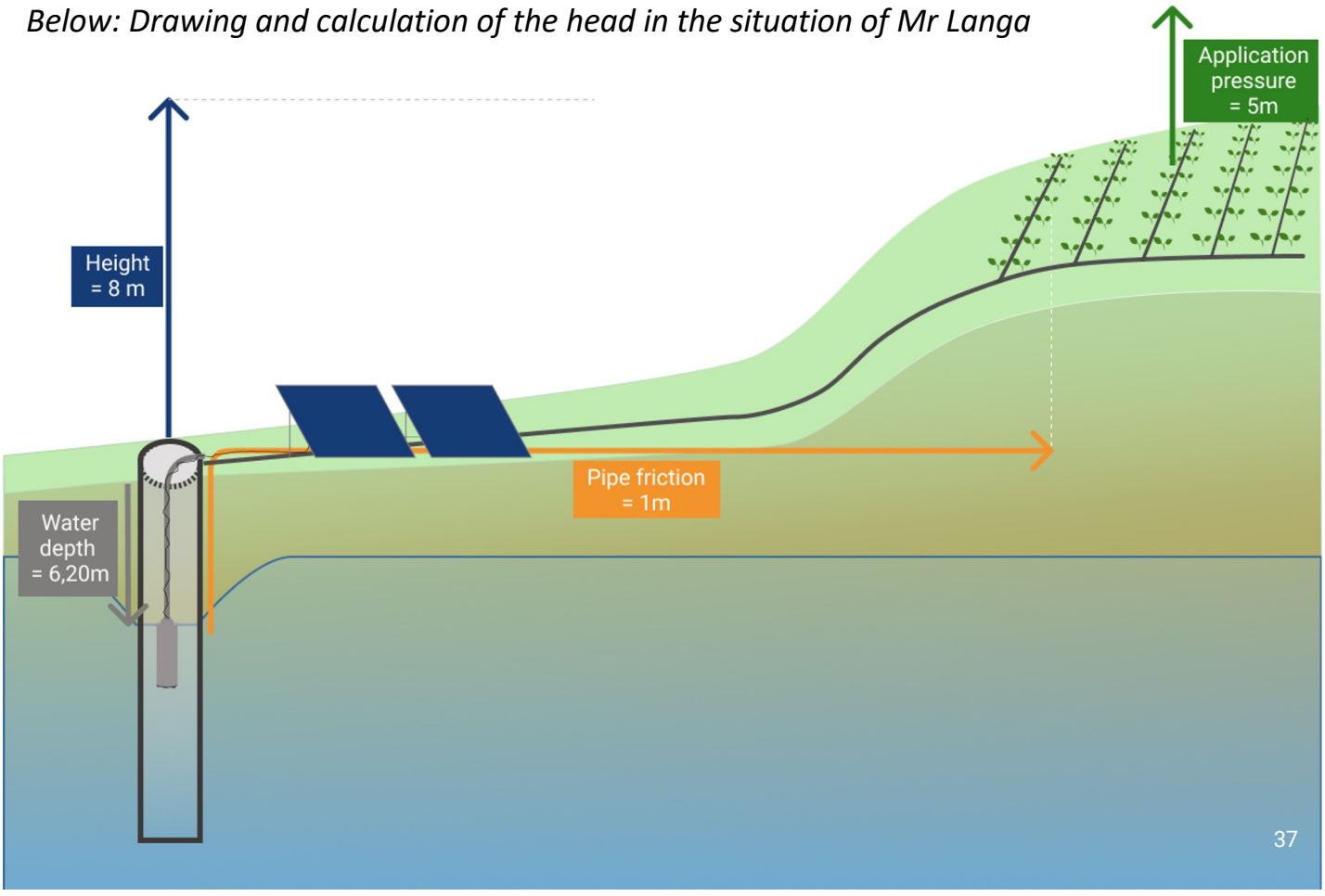
He adds up all the results = 6,2 + 8 + 5 + 1 = **20,2 m**
The total head of his system is rounded to 20 meters.

He now knows the pump that he will select needs to be able to provide **a discharge of around 7,2m³/h at a head of 20m**.



Above: a landscape in South Africa

Below: Drawing and calculation of the head in the situation of Mr Langa



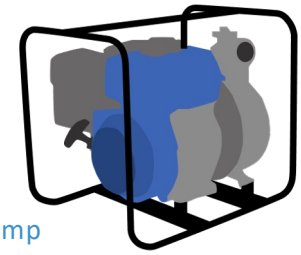
STEP 5: Pump selection [technical]

Suction or submersible pump?

By knowing the total head and the maximum daily water production of the pump we know what the pump needs to be able to do. We can now select a pump. The first selection is to determine the type of pump needed. Pumps fall in 2 main categories:

1. Suction pump: this means the pump sucks up the water first and then pushes it up. In order 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 suggest the pump is submersed in water. That means the pump is actually in the water. Therefore it does not need to suck up the water first. It just needs to push the water up. This means it can pump water even from great depths.



Suction fuel pump

There are **solar submersible pumps** and **solar suction pumps**. However all fuel pumps are suction pumps. But remember:

- Solar suction pumps usually have a much lower output than fuel pumps;
- With solar submersible pumps one can access water at far greater depths than with fuel pumps!



Submersible pump

Suction solar pump (here Futurepump)



	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 7m)	(Hand dug well), borehole
Resistance to silt/sand 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.

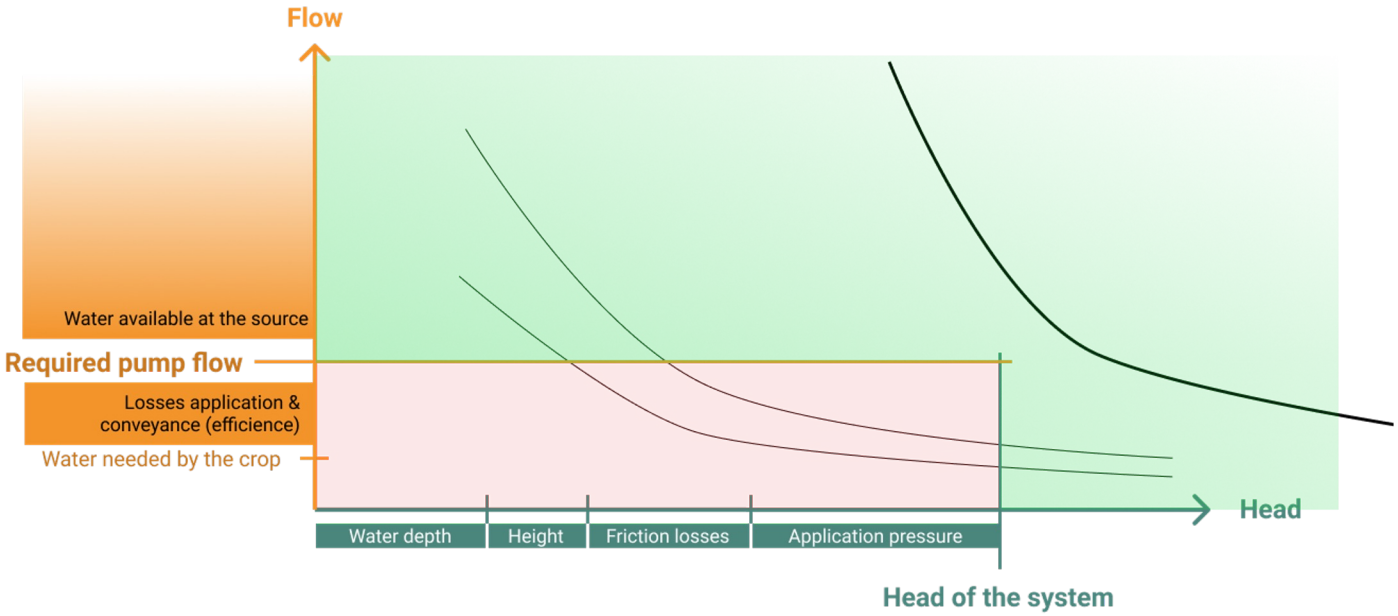
Remember that you measured the dynamic water level at Step 1?
If the dynamic water level that you measured is more than 6-7 m, ***you have to select a submersible pump***. If the water depth is less than the 6-7 meters you can select either of the two types of pump according to your preference.

How to select the right pump for your farm?

Whether you selected a suction or a submersible pump, the second step is to find a pump with the right pump characteristics for your situation. These characteristics depend on 2 factors. And without knowing we already determined these 2 factors in the previous steps:

1. **The required pump discharge** (step 3)
2. **The total head of the system** (step 4)

Different pumps provide different amounts of water at different heads. This relation is shown in a pump curve. Each pump on the market has his own graph. Here is an example with 3 curves and a method to read the graph:



The vertical axis shows the amount of water that the pump has to provide (the pump discharge). It varies with the total head, represented on the 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 **at more than a certain head the pump is no longer able to provide any water**: the curves stop.
- If you draw a crossing point with the required pump flow (= pump discharge) and the head that you calculated (as demonstrated in the graph above), the curve must be located in the **green (top, right) part of the graph**. The curves that cross the red part do not provide enough discharge at the head considered.

Once you have selected the solar pump that you want to buy, you need to buy the solar panels. Sometimes, depending on your supplier, the solar panels are supplied together with the pump. Read the infosheet on solar panels for more information.

Some solar pump suppliers also produce more complicated graphs where the power input is on the horizontal line. And multiple lines are in the graph for different heads. Or in some cases use different units and/or place the total head on the vertical axis. Beware of this – however these graphs have the same principle as above. They show the relation between head and discharge depending on the amount of solar panels.

Infosheet: Buying a pump from the market

- Calculating the power -

In theory, the head of your system, and your required pump discharge is all you need to know in order to buy a pump. You should check the pump curve of the pump, and see whether the pump is a good solution for you or not.

In practice, especially if you go to the local market, it is different. The pump curves are rarely available directly on the packaging of the pumps, suppliers are not always aware of it, so you need to do some internet research to find it.
In general, only the maximum head and the maximum flow are shown on the pump package so that's not enough information for you to know if this pump will be adapted to your situation.

We have developed a method to help you narrow down the ranges of pumps that you will check from your supplier:

Although suppliers are rarely aware of the pump curves, they generally know the power of the pump. And it is always written on the packaging of the pump, in W or kW.
Luckily it is possible to estimate the power needed based on the required pump flow and the head of the system. You can download and use the app IRRIS to make this calculation, or use the formula below*:

$$Pump\ power\ (W) = 6{,}8125 \times Pump\ discharge\ \left(\frac{m^3}{h}\right) \times head\ (m)$$

*This formula is based on a pumping efficiency of 40%. The efficiency generally varies between 40 and 60%.

Download the app IRRIS on your Android smartphone:
Enter information about your farm and obtain all the information you need to go to your supplier: the power, head, pump discharge, and more.

Thanks to this formula or the app IRRIS, you can ask to see the pumps that have a similar power to the result you just obtained.
Note the names of these pumps and make a search on google to find the pump curves.
Once you found the pump curves you can check whether it fits your system.

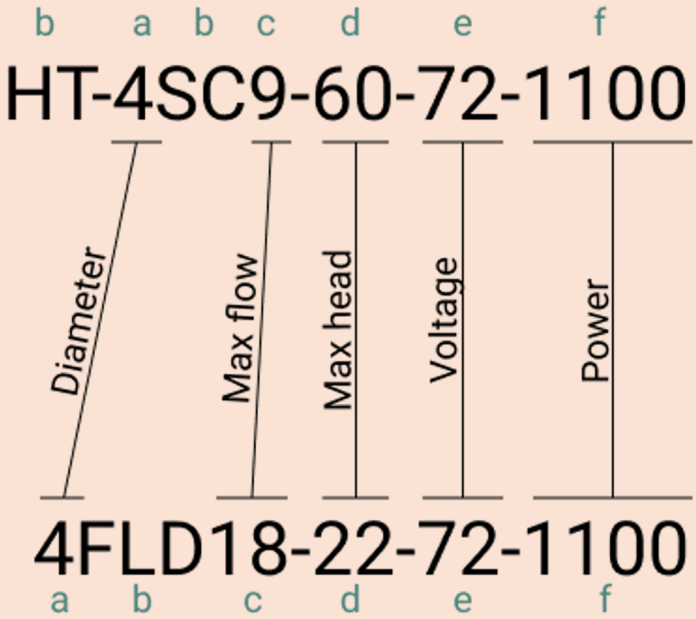
This method is especially useful when you want to buy pumps from Asian brands because less information is accessible. While they are generally cheaper, Asian pumps can have a quality and a yield as good as European brands.

The most well-known European pump brands are Lorentz and Grundfos. They have resellers in most African countries and the pump curves are available online.
For information on Lorentz pumps, check the table at the end of this link to see which pump is the most suited to your situation. /!\ The head is called "lift"
https://partnernet.lorentz.de/files/lorentz_ps2_product-brochure_en.pdf

- Reading pump names and description -

This infosheet includes tips to explore the pump market. This information is not always valid depending on the pump brand. Therefore use it only as a guide and always cross-check the information that you will find with your supplier or a technician.

Pumps from the brands Grundfos and Lorentz have clear names, and information about their pumps is easily accessible.
For Asian brands it first appears to be more complicated.
Pump names are usually a list of letters and numbers that do not always make sense at first sight, but there is a logic. Below you find an example with two pumps of similar capacities from different Asian brands. Here is how to read it:



a) Just before or after the letters, you will see the **pump diameter** in inches => useful to know if the pump will fit in your borehole.
b) A series of letters is a code for the constructor. You don't need it.
c) Right after the last letters you find the **maximum flow** in m3/h.
d) The following number is the **maximum head** in meters.
e) The second to last number refers to the voltage.
f) The last number refers to the **power of the pump** in watts.

Check the last number, and compare it with the pump power that you have calculated. Is it similar? Go check online if you can find the more detailed characteristics of the pump and the pump curve, to be sure it matches your situation.

- Reading the pump curve -

Search the internet for the name of the pump that you have identified. Once you found the pump curve, draw a line at the level of your required pump discharge. Draw a line at the level of the head of your system. **Check if the pump curve goes above, and on the right of the point that you drew. If it does, most likely the pump is good for you.** You can discuss the price and purchase conditions with your supplier.

Check if the pump has a diameter smaller than your borehole.
Now discuss the price, the warranty and the services that your supplier can offer you. You also need to choose your solar panels.

Example of Mr. Langa:

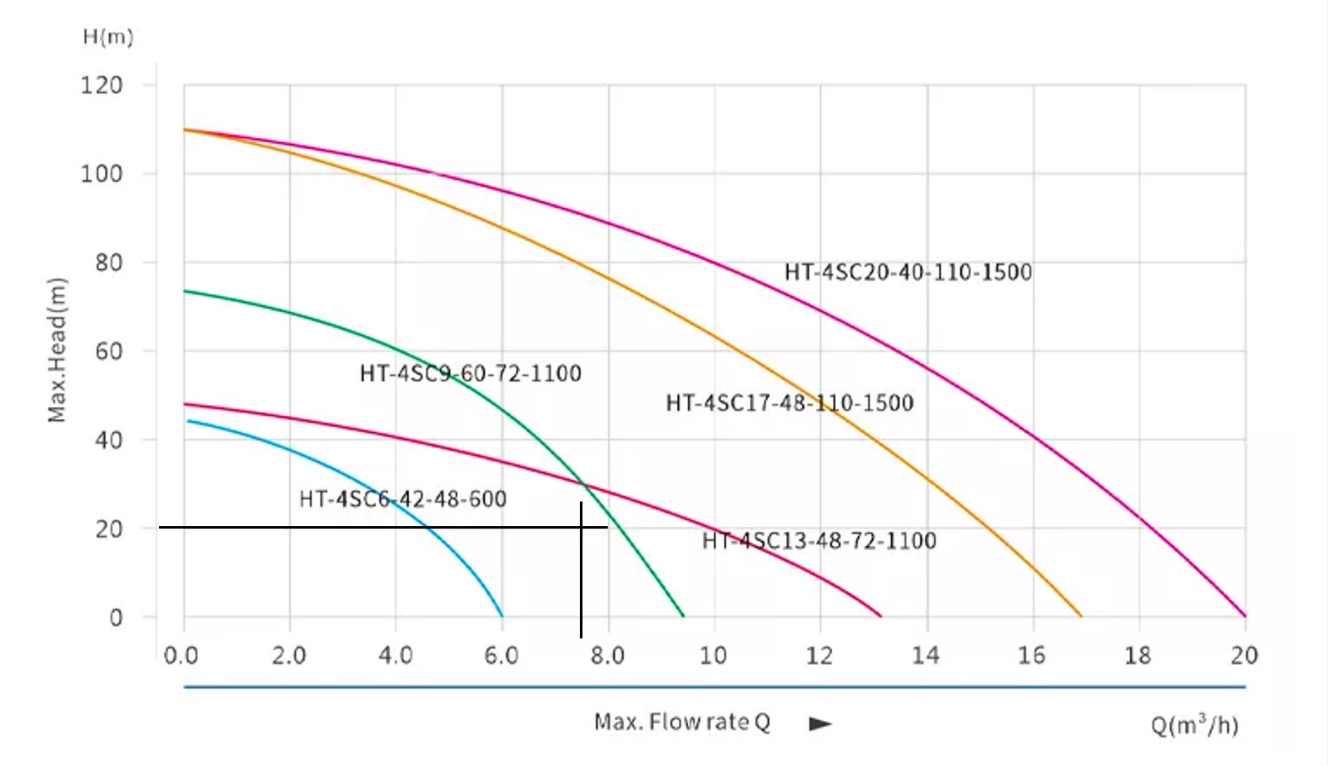
Mr. Langa is looking for a solar submersible pump. He calculates the pump power that he needs. He obtains 981W which he rounds up to 1kW. Thanks to the infosheet “Buying a pump from the market” he knows how to read the name of the pump, and where to find information on the power, diameter and maximum flow and head.

In the range of power that he needs, he finds a supplier who sells the solar pump HT-4SC9-60-72-1100 *(same as the infosheet)*.

He checks online. On the website Alibaba, the seller of the pump “HT” provides the curve of this pump. It is the green curve on the graph below. He draws the point corresponding to his situation:

- Head: 20 m
- Required pump discharge: 7,2 m^3/h

The curve goes above, and on the right of the point he drew. So he knows the pump can work in his field.



Now that he knows he can buy the pump, he can:

- Choose the solar panels (see infosheet “Solar panels”)
- Enquire the price of the pump from the supplier, and discuss the conditions: warranty, installation, after-sale services, repair, maintenance, etc.
- Find a way to finance the pump. He needs to get a loan in order to buy the pump and the spray tubes, but he first needs to make a financial planning.

The market of solar pumps is large. This method is an example of how to proceed to find a solar pump, but in case of doubt, it is better to ask for advice from a technician, an extension worker, or a supplier of technologies.

When you buy your pump, it is essential to pay attention to the technical characteristics (discharge and head) and make sure that they fit your situation. **But do not forget to take into consideration the other aspects like the price, service, warranty, etc. These are very important aspects that will play an important role in your solar irrigation experience.**

Sizing an irrigation system is usually a long term investment. Some recommend to make very precise calculations of the crop requirement and very specific estimations of the head, discharge, etc. **In this training booklet, we adopt a more practical approach based on the idea that resources, and agricultural and irrigation practices vary**. Within a year, water availability and crop requirement evolve consequently. Additionally, surfaces cultivated, labour available or market demand might evolve from one year to the next. This method to choose a pump and an application is a tool to increase your understanding of technical aspects of irrigation systems and build up your technical capacity.
Once the system in place, don't hesitate to make adjustments and changes based on your evolving needs and preferences.

IN SUMMARY, CHOOSE YOUR SOLAR PUMP DEPENDING ON:

- Water source (Step 1) → Safe water yield
- Total pressure needed (step 4) → Total head
- Volume/flow of water needed (Step 2 & 3) → required pump discharge
- Price (step 6)
- Access to warranty and after-sale services (step 7)
- Repairing and replacement of parts (step 7)
- Resistance to silt/sand in the water (step 7)
- Transportability (step 7)



Training on solar irrigation in Madagascar

Infosheet: Solar panels



The more solar panels you will have, the more (or higher) water can be pumped. But keep in mind that there is a limit to that. Each pump works with a certain amount of solar panels. If you have more than the recommended number this will damage your pump in an irreparable manner. Therefore, ask advice to your supplier before buying your solar panels.

Why do I need solar panels?

Solar panels provide the energy to the pump. They absorb the energy from the sun and convert it into electricity that allows the motor of your pump to turn. There are different types of solar panels. Its size is expressed in Watt-Peak (Wp) generated at full light. In theory, solar panels have a lifetime of about 10 to 20 years if handled properly.

How to choose the solar panels?

Generally a supplier will provide the pump and the panels as a set. If not, you can easily calculate the number of solar panels that you need thanks to the **app IRRIS.** Otherwise use the following formula* (expressed in Wp):

$$Power\ solar\ panels\ (Wp) = 11.35 \times pump\ discharge\ \left(\frac{m^3}{h}\right) \times head\ (m)$$

*In this formula we consider a 5h of sunshine and an efficient of the solar panels of 60%

The number of panels supplied depends on the unit power of the solar panels. Once you know which solar panels are available, divide the power that you calculated above by the unit power of the solar panels. Round it up, you know how many you should buy.

How to use and maintain my solar panels?

Solar panels use the energy of the sun to produce electricity. The more sun they receive the more electricity they are able to provide to the pump. To use them as efficiently as possible:

1. Let them face the sun directly. In Mozambique**, orient them towards the North**.
2. Use the **good inclination**. The correct inclination is more or less equal to the latitude of your location. In Mozambique, it is about **25°**. Use the level tool of your phone. Place it on the panels and measure a level of 25°.
3. Make sure that there is **never any shadow** on any area of the solar panels. Even a small piece of shade may cause the pump to stop pumping.
4. Make sure that they are **clean** (remove the dust and the stains regularly).

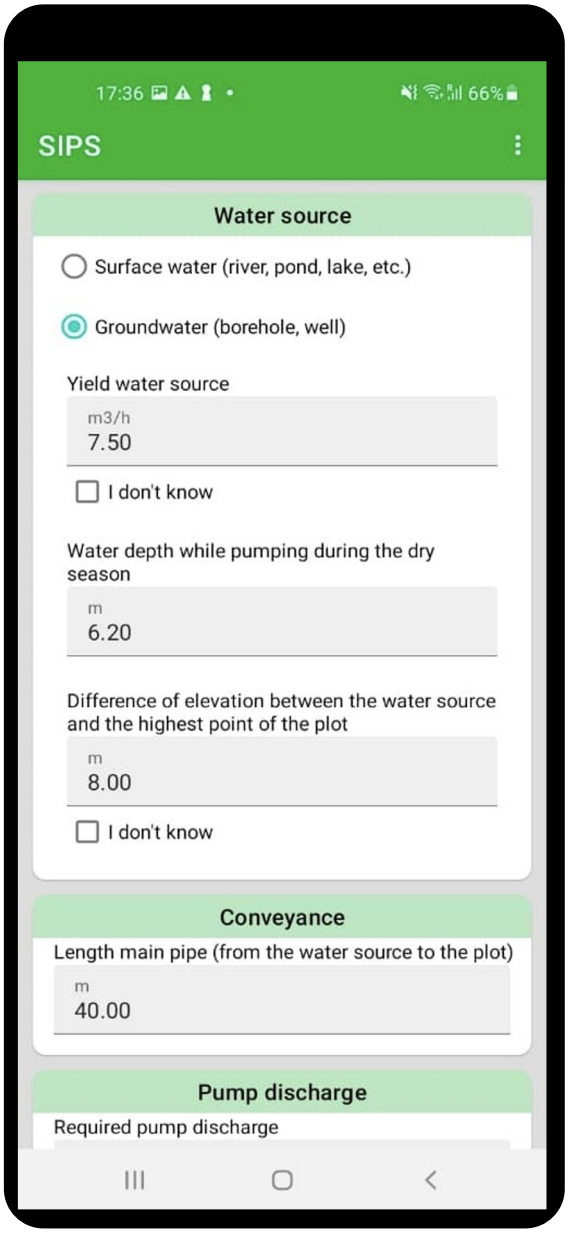
Download the smartphone app “IRRIS”

The app is meant to facilitate the sizing of solar irrigation systems.

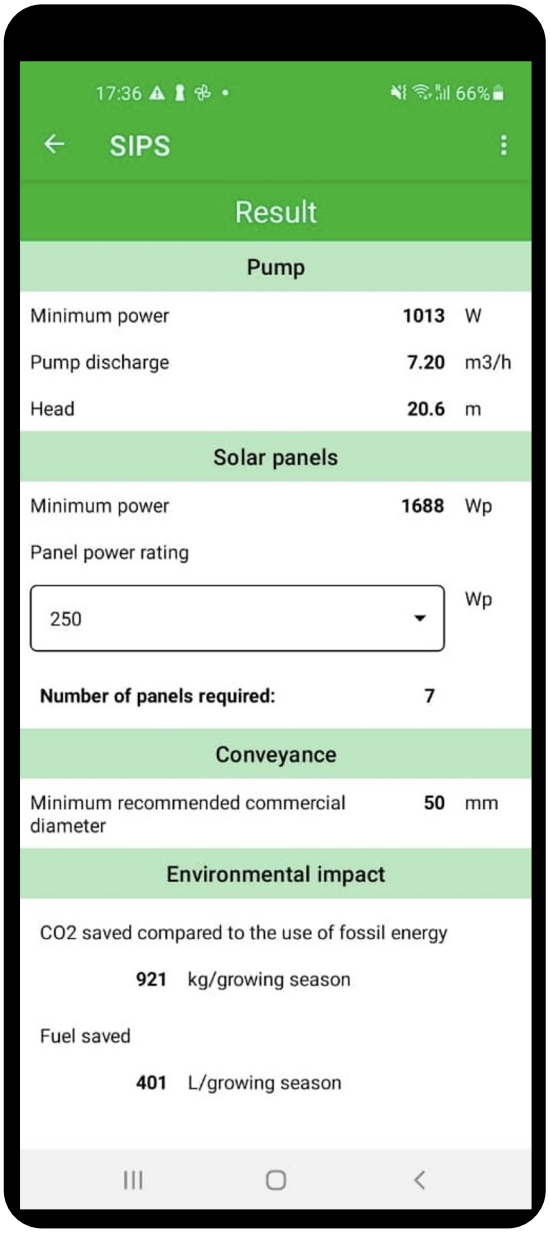
1. Download it from the google store on your Android smartphone or tablet
2. Enter the specifications of your farm (follow the same steps as this guide).
3. Click ”calculate” and get the results immediately: see the pump power, the pump discharge, the total head, the number of solar panels needed.
   You can even see how much fuel and CO_2 you save compared to petrol powered irrigation.
4. You can export and download the data to an Excel file or share it. You even have access to the details of the calculations.

Try it for free!

Enter the specifications of your farm



Get the results immediately



STEP 6: Financing solar systems

What is the cost of solar irrigation?

Contrary to petrol powered systems, which require fuel to function, energy from the sun is free. So the running costs of solar irrigation are very low.

However, solar irrigation systems are generally expensive compared to petrol powered irrigation systems for 2 reasons:

- Solar irrigation pumps are relatively new on the market. Even though the offer tends to diversify itself and the prices tend to reduce, at the moment, a solar pump is usually much more expensive than a petrol pump of a similar capacity.
- Solar irrigation system output depends on the sun. To limit the investment costs, and because there are zero running costs, it is preferable to buy a solar pump with a lower flow and to let it pump the whole day to irrigate the field. Over the day, you get the same amount of water but it takes 5h to irrigate, instead of 30 min with a petrol pump. However, because you don't want to spend 5h holding a hose in your field, that implies that you should also invest in an autonomous application system, like drip or spray tubes in order to irrigate the whole day. Sometimes, depending on the location and the social environment, someone needs to stay close to the farm the whole day to make sure the pump is secure. This means, that there are additional costs to consider from the beginning, such as the investment in the application system, and the cost of labour.

How to secure funding?

In order to invest in solar irrigation, farmers usually need to find an investor, or take a loan. Sometimes suppliers offer finance facilities.
The second step of investing in a solar irrigation system (after determining the technical feasibility) is to find out how to finance the system, and to plan for it.

Planning for financing solar irrigation

In order to make the plan to present to your investor you need to determine 4 things:

- What is **the cost of the investment**? (cost of the pump, panels, and irrigation system)
- What will be the **running costs** of your system? (expected maintenance and repair costs, expected labour costs, etc.)
- What is the **lifetime** of the technologies that you want to invest in? (this is used to determine the depreciation of the hardware)
  The depreciation is important. Planning for it allows you to make sure that you will save money in order to replace your hardware once it is broken and unrepairable.
- How much **revenue** do you expect to generate? Is it enough to balance the investment, recurring costs and depreciation of the hardware?

Make a list of all expenses and revenues. Divide the hardware costs by its lifetime to find its depreciation, and specify the running costs per month. Doing this analysis per month allows you to analyse all the items together. You can do it per month or per growing cycle.

Listing and presenting your expenses and revenues

As shown in the table below, list your expenses and your revenues. Indicate the payment terms or the lifetime of the hardware in months. In the last column divide the cost by the lifetime in order to calculate the depreciation per month (or by growing cycle).

	What?	Expected payment period	Cost per month
Investment	Pump Solar panels Application System (AS) Installation (labour & material)	Every 3 to 5 years Every 10 years Every 2 to 5 years Same as pump and Application System	Divide the cost of the item by the duration of payment terms (in weeks/months)
Running costs	Expected maintenance Expected repair costs Labour Agricultural inputs (seeds, pesticides, fertiliser)	Ask supplier Ask supplier Every week/month Per crop cycle	
Personal expenses		Per week/month	
Total of the expenses			Add up all the expenses per months
Revenues	Revenues from sales	Per crop cycle	Multiply by the number of crop cycles Divide by the duration of a crop cycle (in months)
Revenues per month – Expenses per month			**Here you determine the money available per month in order to pay back the loan**

With this information you can go to a financial institute or a pump supplier who also provides financial services.

- The amount that you need to lend is the sum of the row “investment”.
- The amount you can pay back per month (or at the end of each growing cycle) is the cell in yellow in the table.
- You can determine the time you will need to reimburse your loan by dividing the investment by the amount you can pay back per month.

Farmers do not generate revenues continuously. They gain revenue by selling their products at the end of the growing season. It is usually better to agree on payment terms for a loan after harvest (so per growing cycle) because this is the moment when farmers get money from their work..

STEP 7: Analysing risks/benefits

Apart from the technical and financial feasibility, what else to consider before investing?

Technical and financial feasibility are essential aspects to consider when planning to invest in solar irrigation. However, don't forget to consider other factors:

Financial risks

- **The warranty:** Does your supplier offers a warranty with the pump? With the solar panels? With the application system? What if one of them breaks down?
- **Financial risk:** What if the harvest is bad and you don't have money to pay back the loan? Make a plan.
- **Breakdown/theft**: What if the pump breaks down before harvest? Will you have access to an alternative to keep producing? (Can you borrow a pump from neighbour?)

Practical aspects

- **Transportability and security**: it is possible to move the pump and the solar panels? Will you be able to protect them from theft?
- **The repairability**: can your pump be repaired? If yes, do you know who can do that for you?
- **The sensitivity to silt/sand in the water:** some pumps are more sensitive than others to silt and fines. Does your water source contain a lot of particles? If yes, make sure that you choose a pump with a low sensitivity to silt. Does the warranty cover this damage?
- **The risk of running dry:** In general it is not good for pumps to run dry. But some are more sensitive than others. Make sure you are aware of the risks.
- **The maintenance**: does your pump need regular maintenance? Who can do it for you?

Markets

- **Access:** Do you have access to markets to sell your products after harvest?
- **Inputs:** Have you identified a supplier of seeds and inputs for farming?

Knowledge

- **Pre-requisite:** Do you have the necessary skills, knowledge and experience for irrigated farming? Otherwise, do you know who can help you start this activity?
- **Network:** If you have a problem, related to irrigation or agricultural practices, do you know where to get help?

Policy, rules

- **Permission:** Are you allowed to pump water and practice irrigation on these lands?

This is a non-exhaustive list of considerations to have before investing in solar irrigation in order to make it a successful experience. Keep in mind that most likely you will encounter some problems, but as long as you have planned well and considered the risks with attention, you are likely to find a solution.



Above, a small-scale solar irrigation system of 3,000m2 in Mauritania.

Below, a large scale solar irrigation system in Madagascar



Large-scale solar powered irrigation systems

This training guide has been tailored to enable practical decision-making on small-scale solar irrigation systems. The same steps could be used to develop large scale solar irrigation systems. This page includes the steps and references that can be used to this end.

1. Determine the available water volume

- What is the water source, its cost and dimensions?
- For groundwater : what is the safe well yield during the peak irrigation season (m3/h)?
- For surface water : what is the (agreed) water availablity during the most critical period (m3/day)?
- For rainwater storage : what is the available water volume for the season (m3), taking into account the losses through evaporation ?

2. Determine the gross peak water need

- Look for the maximum Kc (crop coefficient) value of the crop:
  Use 1 for vegetables
  Use 0.75 for fruit trees
  A complete overview is available in Annex 2 of
  http://www.fao.org/3/bc824f/bc824f.pdf
- Look for the highest monthly reference evapotranspiration (ET_0) in mm on your location
  https://aquastat.fao.org/climate-information-tool/ . This is the peak irrigation month.
- Divide the montly ET_0 value of the peak irrigation month by 30 to get the daily ET_0 (mm).
- Multiply the daily ET_0 value with the Kc value to obtain the crop water need (L/m2/day)
- Multiply by the irrigated area to get the total gross water need (m3/day)
  This is the daily volume of water that needs to arrive at the crop. The pumped water volume needs to be higher to accommodate for losses on the way.

3. Determine the net peak water need :

- For solar powered irrigation systems a piped conveyance system with 100% conveyance efficiency is recommended.
- Select the application technology and corresponding water efficiency:
  Drip : 90%, Spray : 75% , Furrows : 60% provided that maximum length is respected (Appendix 3) http://www.fao.org/3/t7202e/t7202e08.htm
- Multiply the gross water need by (1+ (1 - X% efficieny)) to calculate the Nett water need (m3/day). E.g. for spray irrigation, Nett water need = Gross water need x 1.25.
- Divide the daily Nett water need by 6 to determine the required pump capacity (m3/h). Check if this can be sustained by the water source. Otherwise reduce the irrigated area accordingly.

4. Determine the available irradiation

- The next step is to determine het available solar irradiation at your location
- Go to https://power.larc.nasa.gov/data-access-viewer/ and fill in the following:
  1. Choose a User community : SSE-Renewable Energy
  2. Choose a temporal average : Climatology
  3. Enter Lat/Lon or Add a point to the map : select your location on the map
  4. Select time extent : not required
  5. Select output file formats : CSV
  6. Select parameters : Click on the folder : Tilted solar panels
     Check the box : Solar irradiance for equator facing tilted surfaces (set of surfaces)
  7. Submit
- Open the downlowded excel file. Search for the row with parameter: SI_EF_TILTED_SURFACE_LATITUDE and select the value of the peak irrigation month. This is the expected solar irridation (kWh/m2/day) received on a panel that is directed towards the equator.

 Alternatively you can also use 4 or 5 kWh/m2/day as a safe estimate for Mozambique.

5. Calculate the required pump and panel capacity

- Calculate the total dynamic head (TDH) by collecting the following data and adding it up (see explanation in chapter 4)
  - Dynamic water level (m)
  - Height difference from well to field (m)
  - Pressure application system (m). Careful as the pressure in large-scale systems can increase substantially compared to small systems.
  Drip : 10 m, Sprinkler : 15 m, Spray : 5 m, Californian and furrow : 2 m
  - Friction losses (m) (see infosheet)
- Determine the combined pump and motor efficiency.
  A safe estimate for solar submersible pumps is 40% (< 2hp) or 60% (> 2hp)
- Determine the solar panel efficiency.
  For fixed installations: generally 40% in dusty conditions and 60% when regular cleaning takes place.
- Recall the following elements calculated above:
  - Daily Nett water need (m^3/day), pump discharge (m^3/h)
  - TDH Total Dynamic Head (m)
  - Expected solar irradiation (kWh/m2/day)
- Calculate the pump power needed.
- Calculate the required solar power in Wc using the following formula:
  Required Power (Wc) =

$$\frac{(2{,}725 \times \text{Daily water need } (m^3/\text{day}) \times \text{TDH (m)} \times \text{Nb hours of sun} / \text{pump efficiency (\%)})}{(\text{Expected irradiation (kWh/m2/day)} \times \text{Panel efficiency (\%)})}$$

Appendix 1: Units

$$1\left(\frac{m^3}{hour}\right) = 1.000\ liters\ per\ hour$$

$$1\left(\frac{\mathrm{m}^3}{\mathrm{hour}}\right) = 16{,}6 \text{ liters per minute}$$

$$1\left(\frac{\mathrm{m}^3}{\mathrm{hour}}\right) = 0{,}277 \text{ liters per second}$$

$$1 \text{ liter per second} = 3{,}6\left(\frac{\mathrm{m}^3}{\mathrm{hour}}\right)$$

$$1 \text{ liter per minute} = 0{,}06\left(\frac{\mathrm{m}^3}{\mathrm{hour}}\right)$$

$$1 \text{ mm} = 10 \text{ m}^3\text{/jour/Ha} = 10 \text{ liters/day/m}^2$$

Appendix 2: Form to fill with the information you collected

Step 1: Yield & water level of my water source

S1.1 Dynamic water level (measured at page 17): …….. m

S1.2 Safe yield of your water source (measured at page 17): …….. m^3/h

Step 2: Water need for irrigation

S2.1 Surface to irrigate = …….. m^2 /10.000 = …….. Ha

S2.2Daily water need: = …….. m^2 x 6 $L/m^2/day$ = …….. L/day

Daily water need = …….. L/day / 1.000 = …….. m^3/day

S2.3 Pump discharge needed = …….. m3/day / 5h sunshine = ……m^3/h

In-between check 1

Is the pump discharge needed (S2.3) lower or higher than the safe water yield (S1.2) (tick the box below)

❑ **Lower** → Continue to the next step

❑ **Higher** → Reduce the size of the land you want to irrigate and start again at Step 2.

Step 3: Water conveyance and application system

S3.1 Which application system did you choose?

- ❑ Drip irrigation (from a kit) (90%)
- ❑ Spray tube / misters (75%)
- ❑ Sprinkler (75%)
- ❑ Hose or pipe (75%)
- ❑ Furrow (60%)
- ❑ Water can / Buckets (75%)
- ❑ Other:……

S3.2 Efficiency of the application system selected ……..%
(Check the table page 25 or calculate this yourself based on the characteristics of your application system)

S3.3 Required pump discharge (revised)……m^3/h
(Divide the water need you calculated at S.2.3 by the efficiency of your application system)

S3.4 Is it **lower** or **higher** than the yield of your water source calculated at the point S1.2? (tick the box below)

- ❑ **Lower** → Continue to the next step
- ❑ **Higher** → Reduce the size of the land you want to irrigate (start again at Step 2) **OR** select another type of application system that is more efficient (start again at Step 3)

Optional step: water storage & batteries

Pros of using water storage	Cons of using water storage

Step 4: Calculating the total head of the system

- You already calculated the dynamic water level at point S1.1;
- Go to your field and measure the height between your water source and the highest point of your field;
- You indicated the application system chosen at point S3.1. Find the head corresponding to your application system in the table page 25.
- Calculate the friction losses below

Friction losses

S4.1 Meters of pipe needed to convey your water (in m): ……

S4.2 Internal diameter of the pipe for water conveyance (in mm): ……

Report the length of your pipe (S4.1), the diameter (S4.2) and the flow that you calculated at point S3.3 on this website (or use the table in appendix 2 of this booklet) to determine your friction losses. https://www.nationalpump.com.au/calculators/friction-loss-calculator/

S4.3 Friction losses in your system (in m): ……

S4.4 Head calculation (everything in m)

Dynamic water level: ……m

Height / Elevation: ……m

Head of the application system: ……..m

Friction losses: ……m

SUM of the 4 elements above = Head ……..m

You now know the dynamic water depth of you water source, the yield of your water source, the required pump discharge and the head of your system. You can bring all the information circled in orange to your pump supplier.

Step 5: Pump selection

Pump power (W) = 6.8125 x Pump discharge (S2.3) x head (S4.3) = …….. W

Solar panel power (Wp) = 11.35 x Pump discharge (S2.3) x head (S4.3) = …… Wp

Appendix 3: Furrow and basin irrigation

Water infiltration is an important issue when using the solar pump in combination with surface irrigation. A very uneven water distribution can be expected if a small amount of water is applied to the field due to infiltration. This is caused by the fact that at the beginning of the plot or furrow, water will infiltrate into the soil before the water reaches the end of the irrigated plot. With a small flow, which can be expected with the solar pump, this loss will be relative big.

The following table gives an overview of the recommended inflow per furrow of 50 meter length on a flat land. The inflow is divided in soil types as different soils will have a different infiltration rate. The data is for furrows that have a spacing of 1 meter. This means that every one meter that is a furrow. The relation with wider/smaller spacing is linear. This means that, if a furrow has a spacing of 1,2 meter, the furrow inflow should be multiplied by 1,2. Equally, for longer or shorter furrows, the inflow can be in- or decreased proportionally.

Soil	Furrow inflow L/s
Clay	0.015-0.075
Clay-loam	0.075-0.15
Sandy loam	0.25-0.4
Sand	0.4-1.35
Data based on 'Small scale irrigation, Peter Stern, 1997, ISBN 0 903031 64 7	

For basin irrigation, the flow of the pump determines the maximum recommended size of the basin. The following table gives an overview of the maximum recommended size of a basin for a flow of 0,5 l/s on a flat land. If the flow is larger or smaller, the size should be increased or decreased proportionally. So if the inflow is 0,25 l/s, the maximum size of the basin should be half the size indicated in the table.

Soil	Max size of the basin (m^2) for 0,5 l/s inflow
Clay	35
Clay-loam	20
Sandy loam	10
Sand	3,25
Data based on 'Small scale irrigation, Peter Stern, 1997, ISBN 0 903031 64 7	

Appendix 4: Friction losses in meter per meter of pipe

The friction losses in the table below are presented in meter per meter of pipe:

- Look for your flow and the commercial diameter that you want to use.
- **Don't forget to multiply the figure in the table by the length of your pipe!**
- Select the **cells in green**. The friction losses are very high in the cells coloured in yellow and red. It is not recommended to choose a pipe with a too small diameter.

Headloss in meter per meter of pipe						
Commercial diameter (PVC)	1 inch (25 mm)	1,25 inch (32 mm)	1,5 inch (40 mm)	2 inch (50 mm)	2.5 inch (63 mm)	3 inch (75 mm)
Internal diameter (mm)	22	29	35	45	57	68
Flow (m3/h)						
0.5	0.009	0.002	0.001	0.000	0.000	0.000
1.0	0.031	0.008	0.003	0.001	0.000	0.000
1.5	0.065	0.017	0.007	0.002	0.001	0.000
2.0	0.111	0.029	0.012	0.003	0.001	0.000
2.5	0.167	0.044	0.017	0.005	0.002	0.001
3.0	0.235	0.061	0.024	0.007	0.002	0.001
3.5	0.312	0.081	0.033	0.010	0.003	0.001
4.0	0.399	0.104	0.042	0.012	0.004	0.002
4.5	0.497	0.129	0.052	0.015	0.005	0.002
5.0	0.603	0.157	0.063	0.019	0.006	0.002
6.0	0.845	0.220	0.088	0.026	0.008	0.003
7.0	1.124	0.293	0.117	0.035	0.011	0.005
8.0	1.440	0.375	0.150	0.044	0.014	0.006
9.0	1.790	0.467	0.187	0.055	0.017	0.007
10.0	2.175	0.567	0.227	0.067	0.021	0.009
11.0	2.595	0.677	0.271	0.080	0.025	0.011
12.0	3.048	0.795	0.318	0.094	0.030	0.013
13.0	3.534	0.922	0.369	0.109	0.034	0.015
14.0	4.054	1.057	0.423	0.125	0.039	0.017
15.0	4.605	1.201	0.481	0.142	0.045	0.019
16.0	5.189	1.353	0.542	0.160	0.051	0.021
18.0	6.453	1.683	0.674	0.198	0.063	0.027
20.0	7.842	2.045	0.819	0.241	0.076	0.032
22.0	9.354	2.439	0.977	0.288	0.091	0.039
25.0	11.849	3.090	1.238	0.364	0.115	0.049
30.0	16.602	4.329	1.734	0.511	0.162	0.068
35.0	22.081	5.758	2.306	0.679	0.215	0.091