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A practical introduction to solar irrigation

Technical training manual with examples and pre-filled sheets to support the learning process of training participants

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Preface

For Who?

This technical manual is a practical step by step design guide for small-scale solar irrigation. It gives practical tips and actions to design a solar-powered irrigation system, up-until 5.000m^2 and provides the basic steps to design larger irrigation systems.
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.

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

Further reading

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 provides an overview of the technical terms with a short explanation. The explanation will be more elaborate in the manual itself.

Application method: the method that is 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 and static water level of a well: The static water level refers to the level of the water in a well – measured from the ground surface - when no water is pumped from this well and when it is stable (it does not rise). When you start pumping water from a well the water level will start to go down. The more you pump the more it goes down. The water level when water is being pumped from the well is called 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 means how much water the pump provides. Often expressed in m^3/hr.

Yield test of a well: Yield means 'to give or to produce'. Testing the yield of a well means to test how much water the well can provide. Often expressed in m^3/hr.

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

Solar pump: A pump that runs on solar PV 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). The 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 amount of pressure the pump needs to provide when it runs. 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 for 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

Irrigation is the application of water to the soil to meet the daily water needs of crops/plants. The source of water for irrigation includes; surface water (e.g lakes, rivers, streams) and ground water (e.g tube wells, open wells). Irrigation provides the environment for all year-round crop production; especially in areas of low rainfall.

What is small holder solar irrigation?

Solar irrigation uses solar energy from the sun to pump water from a source to 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 small holder solar irrigation.

How does solar irrigation differ from fuel/diesel 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 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 8-6 m	Depending on pump
Average plot size	Generally less than 1 acre (< 4000 m²)*	More than 2 acres (> 8000 m²)	Up to 0.1 acre (< 400 m²)
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

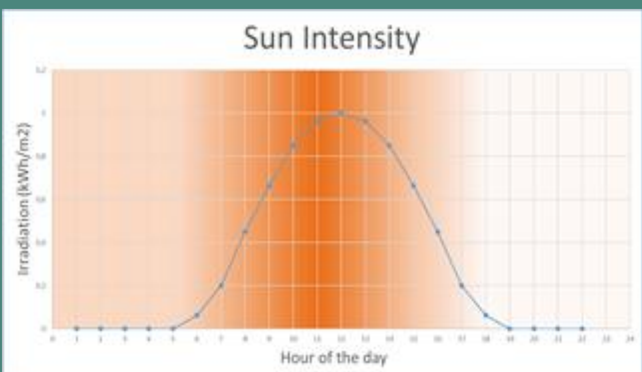
Cheap, robust but labour intensive – so only a very small plot can be irrigated

Fuel pumps

High flow of water so allows 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 of 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?

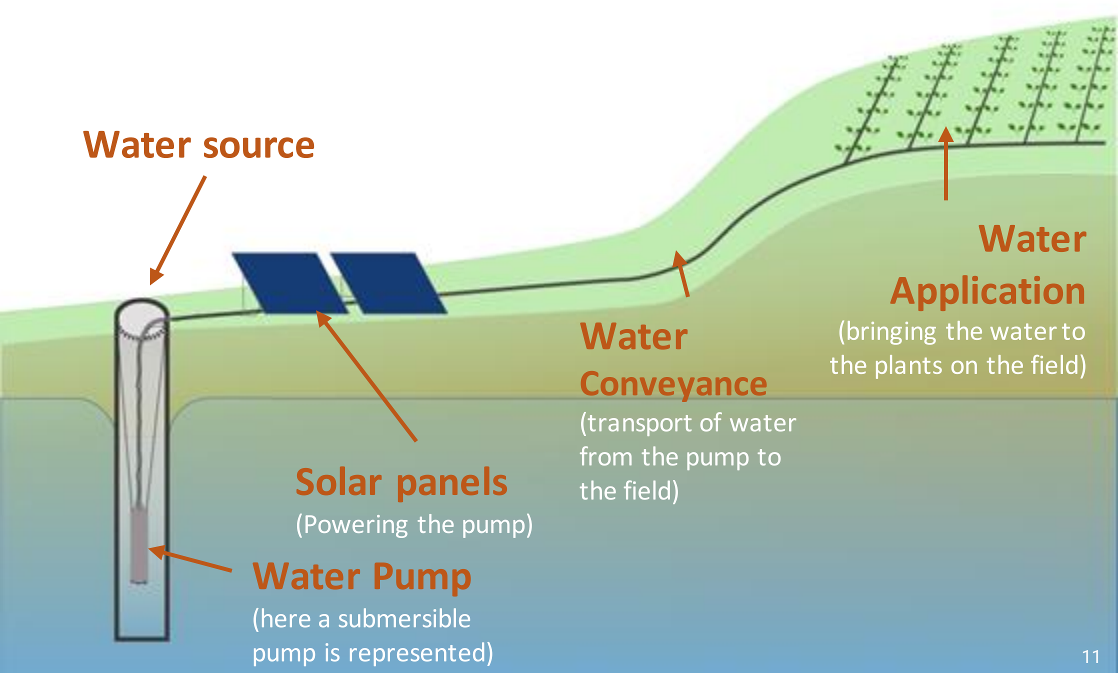
This manual shows how one can select and compare solar pumps. There are several steps to take in order to select a solar irrigation system adapted to your situation:

1. Determine the quality of water in the source for optimum crop production.
2. Determine how much water the water source can provide and measure the depth of the water
3. Determine how much water is needed to irrigate
4. Choose your application & conveyance system and determine your pump yield
5. Calculate the total head: a technical term that shows how much pressure the pump will need to provide
6. Select the pump that fits the need;
7. Compare it with alternative pumps
8. Buy the right pump and irrigation equipment

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 on the manual.

This guide uses mostly m³/h or day as a unit for water quantity. Some pump suppliers use liters per second. Or liters per minute. In appendix 1 an overview is provided how to switch between these different units.

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.

As you go through the different steps of the guide, 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):	................................meter	Measure water level while pumping from the well at safe yield
Yield of your water source (Step 2):	.... m^3/h	Do a bucket test
Pump yield needed (Step 3):	.... m^3/day	Calculate based on location, crop and field size and efficiency of irrigation scheme
Total head system (Step 4):	.... 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:

- If the dynamic water level is below 8 meters only a submersible pump can pump water from the well;
- The yield of the well has to be larger than the pump yield otherwise the well will run dry;
- 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: Quality of the water source

- Water quality refers to the characteristics (chemical, physical and biological properties) of a water supply that will influence its suitability for a specific use (e.g irrigation, drinking).
- In irrigation water, emphasis is placed on the chemical and physical characteristics of the water rather than biological.
- Irrigation water quality can vary largely due to the type and quantity of dissolved salts. Sources of dissolved salt include; weathered rocks and soil, dissolution of lime, gypsum and other soil minerals. Increase in total salts will lead to challenges in the soil and crop environment affecting soil water available for plant use, and crop a drastic decline in yield. High salts will corrode and rust metallic parts of irrigation systems e.g pumps, sprinkler heads.
- Test the quality of your water source by taking water samples to the laboratory . Laboratory results should be compared with credible guidelines (Table 1) for proper interpretation and necessary action. Alternatively, one can ask other farmers using the same water source to what extent the water quality is an issue for irrigation.

Table 1: Chemical properties needed to evaluate common irrigation water quality problems

Water parameter	Symbol	Unit	Range
SALINITY			
Salt Content			
Electrical Conductivity	EC_w	dS/m	0 – 3
(or)			
Total Dissolved Solids	TDS	mg/l	0 – 2000
Cations and Anions			
Calcium	Ca^{++}	me/l	0 – 20
Magnesium	Mg^{++}	me/l	0 – 5
Sodium	Na^{+}	me/l	0 – 40
Carbonate	CO^{--}_3	me/l	0 – .1
Bicarbonate	HCO_3^-	me/l	0 – 10
Chloride	Cl^-	me/l	0 – 30
Sulphate	SO_4^{--}	me/l	0 – 20
NUTRIENTS			
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2
Potassium	K^+	mg/l	0 – 2
MISCELLANEOUS			
Boron	B	mg/l	0 – 2
Acid/Basicity	pH	1–14	6.0 – 8.5
Sodium Adsorption Ratio	SAR	(me/l)	0 – 15

STEP 2: Yield & water level of the water source

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

There are 2 types of water sources used for irrigation:

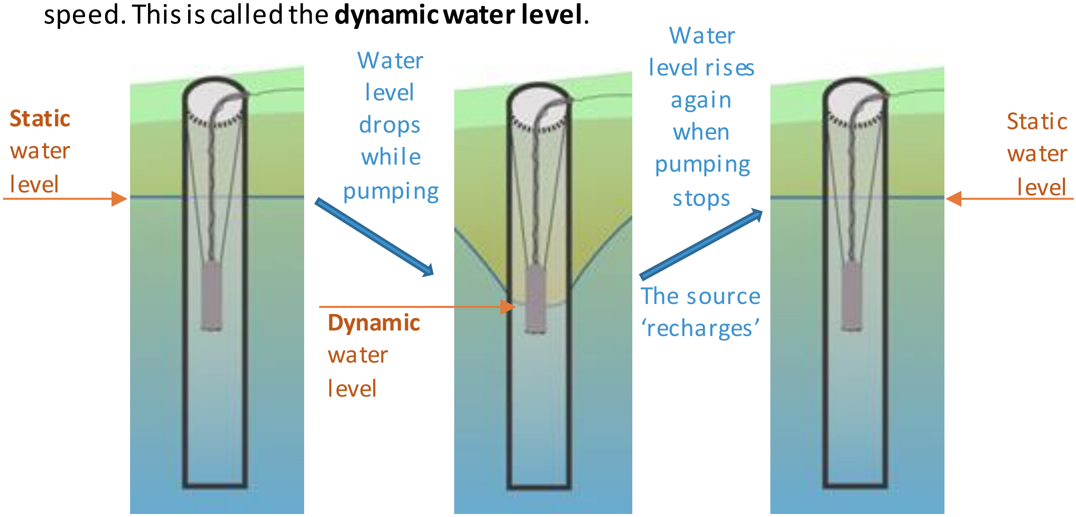
- **Surface water**: river, lake or pond
- **Groundwater**: an open well or a borehole (also called tube well)

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.

It is therefore important to measure these two factors:

1. How much water can my source safely provide. This is called the **safe yield** and is expressed in m³/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**.



Before pumping During pumping After recharge

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. This is a test to see 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.

Procedure to test the yield of a tube well

This paragraph shows 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

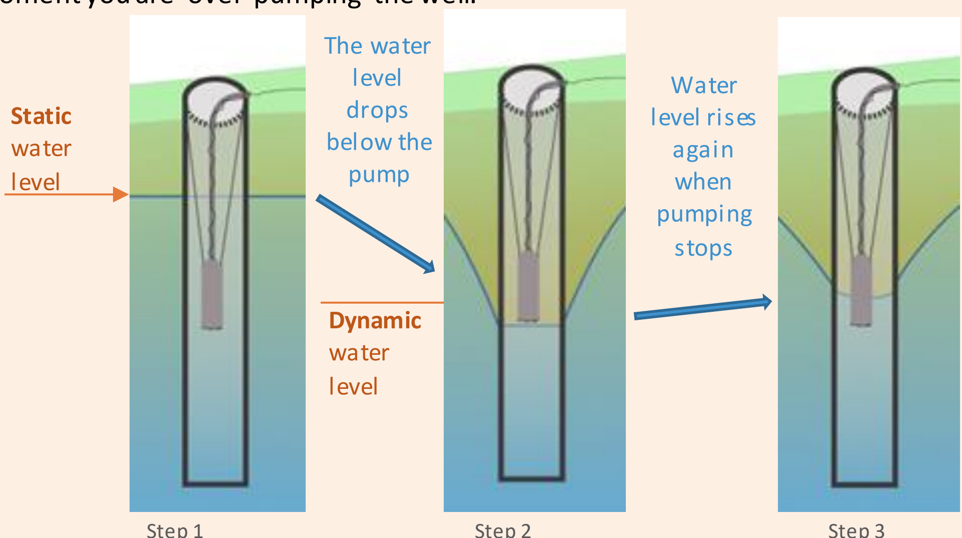
Procedure:

Step 1: Insert the pump in the well. Make sure it is placed deep inside the well.

- For a tube well this means about one meter above the area where little slots are made that let the water into the casing.
- In an open well this means well 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. Use the throttle when a petrol pump is used.

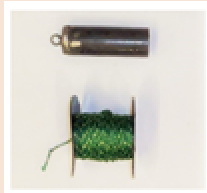
Step 3: Now find the speed of pumping where the well is over-pumped. This is the point where the pump pumps more water out than the well can provide. Do this by slowly opening the valve/throttle. This will increase the amount of water extracted from the well. Continue to do this until the pump is unable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



Step 4: Slowly reduce the water flow when this happens to find the point where the pump starts providing a continuous flow again. This is the maximum amount of water that the well 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.

Let the pump run at this setting for about 30 minutes to ensure the flow can be sustained for a longer period of time. For more certainty about the sustainability of the well yield let the pump run even longer than the 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 5: When you found the maximum yield of the well, measure the **depth of the water** table when still pumping.



- a special device called a 'dipper' can be used. It makes a beeping sound when the dipper hits the water.
  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. 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! 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. Both methods work best in combination with a submersible pump. Using a petrol pump will cause the suction hose to be in the way when using the dipper.

Write this down in meters. It is the **dynamic water level**.

(Report it at page 9 of this booklet)

Note that 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 in 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 6: **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:**

$$\text{Borehole yield } \left(\frac{m^3}{h}\right) = \frac{\textit{Size of bucket (in liters)}}{\textit{Number of seconds it took to fill it}} \times 3.6$$

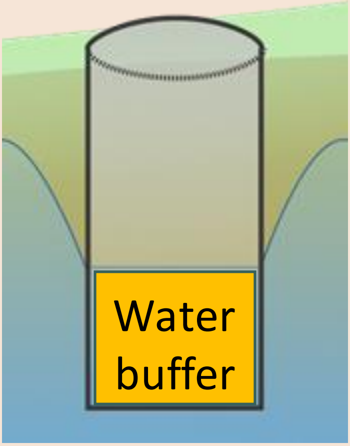
(Report it at page 9 of this booklet)

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

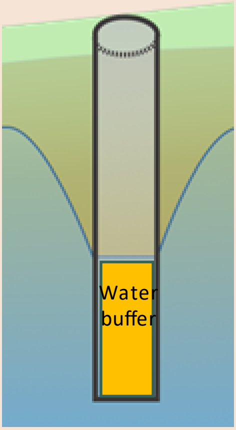
A	B	C	D	E
Test	Size of the bucket (in L)	Numbers of seconds it took to fill it with the constant flow	Nb of liters/s (B/C)	Nb of m^3/h (D*3.6)
1st				
2nd				
3rd				
Average (Sum of first, second and third tests divided by 3)				

Testing yield of open well:

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 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: when pumping from an open well it is possible – at the beginning – to pump high quantities of water. Depending on the well size this can result in the impression that the well can provide a lot of water! However, what happens is that the water buffer is used to pump this water. What further complicates the process of measuring the yield is that the inflow of water is dependent on the level of water in the well. Therefore testing the yield of an open well must be done with a slightly different approach than a tube well.

To determine an estimate of the maximum (safe) yield a tube well (step 3 and 4 in the procedure of testing a tube well) one has to adopt the procedure. Determining (an indication of) the safe yield is done by:

- Measure the diameter of the well in meters.
- Place the (hose of) the pump in the well.
- Start pumping until the level of the water in the well is lower than the level where the inlet of the solar pump will be placed (being either the submersible or the suction hose)
- 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.
- Then calculate the yield as follows :

$$\text{Open well yield } \left(\frac{m^3}{h}\right) = \frac{\text{Volume of water to fill a known hight (in liters)}}{\text{Number of seconds it took to fill it}} \times 3.6 =$$

(Report it at page 9 of this booklet)

$$\frac{(\text{diameter well (in meter)})^2 * \text{height (in m)} * 785}{\text{Number of seconds it took to fill it}} \times 3.6$$

Example of Ms. Faridatu:

Faridatu is a farmer in the Northern region of Ghana. She currently uses a hand dug well to irrigate her tomato crop with a spray can. But she considers adopting solar irrigation because she wants to increase the land area she cultivates during the irrigation season. She will follow the steps in this guide to know what type of technologies needed to invest in.

Procedure for the yield test

Faridatu uses a diesel pump from a neighbor to test the yield of her well. She knows that she can use this pump because her well is 7 meters deep, and always has at least two meters of water in it throughout the year when no water is being pumped from it.

First, she measures the diameter of the well. This is 80 cm (= 0.8 m). Next she figures out where she would place the inlet of the solar pump: about 80 cm above the bottom of the well. So at 6.20 meter deep. At that level no dirt from the bottom is sucked up, and yet the inlet is well below the water level.

She starts pumping her well until the water level lowers to 6.20 meter deep. She then stops pumping and measures how long it takes for it to refill 20 cm (= 0.2 m). That is the point when the water is 6 meter deep. This takes 350 seconds. She calculate the yield as:

$$\text{Open well yield } \left(\frac{m^3}{h}\right) = \frac{0.8^2 * 0.2 * 785}{350} x\ 3.6 = 1.0 \left(\frac{m^3}{hr}\right)$$

She now knows that her well has an approximate yield of 1 m^3/hr. And she takes 6.20 as the dynamic water level.

The bucket test shows that the *safe yield* of Ms. Faridatu's borehole **is 1.0 m^3/h**

STEP 3: Water need for irrigation

What is irrigation water need?

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.

Why is it important to calculate the water need?

It is important to know how much water is needed by the plants so you can select the right size of pump. 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. Determine the reference evapotranspiration (ETo in mm/d) of your farm's location from climatic data (i.e: minimum and maximum temperature, humidity, wind speed, sunshine hours) using the ETo calculator function of CROPWAT Model Software developed by FAO. See Table 2.
2. Select the peak crop coefficient (kc) value for your crop in Table 3 provided at the right side.
3. Determine the daily water need (ETc in mm/d) by multiplying the peak Kc value by the peak ETo (March: Table 2) value (Kc x ETo). This is done easily using the CROPWAT Model, by providing climatic data mentioned earlier and defining the crop parameters.
   Alternatively, for Northern Ghana you can use a max daily water need of 6 mm/day = 0.006 m/day.

This crop need is the maximum water need of the crop. At the beginning and end of the growing cycle of the plant it will be less. By using the peak of the most water demanding crop you ensure there will be enough water throughout the irrigation season, independent of the type of crop

Table 2. Average Monthly Evapotranspiration values for Northern region

Month	ETo (mm/d)
January	4.46
February	5.16
March	5.36
April	5.18
May	4.72
June	4.08
July	3.90
August	3.60
September	3.82
October	4.27
November	4.43
December	4.03

Table 3. Peak Kc values for selected crops

Crop	Peak Kc
Small vegetables	1.05
Vegetables (Solanum family)	1.15
Vegetables (Cucumber family)	1.00
Roots and Tubers	1.10
Legumes	1.15
Cereals	1.15

Note: Adjustment of kc values with respect to the crop's developmental stage will be required for more precise computation of daily water needs.

4. Measure the length (m) and width (m) of the field you want to irrigate. Use meters to do so. Multiply them to determine **the surface (area) of the plot**. *You can use the table in appendix 2-Step 2 to guide you in the calculations.*

5. Calculate the **daily water need** by using the following formula:

$$Maximum\ water\ need\ for\ crop\ \left(\frac{m^3}{day}\right)$$
$$= Area\ of\ plot\ (m^2)\ x \max daily\ water\ need\ (m/d)$$

Remember to convert ETc (mm/d) to ETc (m/d)

Note: This calculated maximum water need of the crop represents the net irrigation water requirement – without losses.

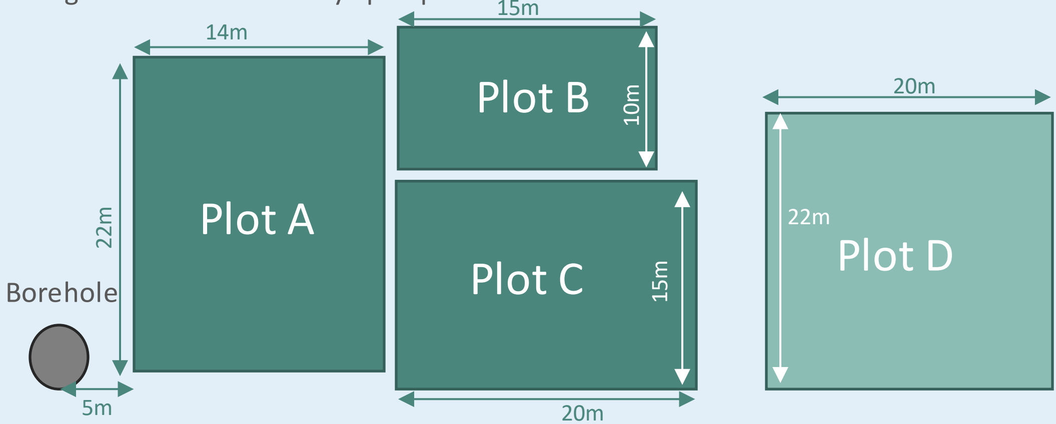
6. Do this for every plot you want to irrigate with the same pump in case there are multiple smaller plots and add all the number up. *You can use the table in appendix 2 to guide you in the calculations.*

Sources:

- Information on water quality guidelines (Table 1) for interpretation was obtained from https://www.fao.org/3/t0234e/T0234E01.htm#tab1
- Information on ETo for Northern region in table 2 was computed from historical (45years) climatic data obtained from the CSIR-SARI Meteorological station. These values might differ slightly for distant areas - far away from station. For such areas, online tools could be explored to determine ETo.
- Information on crop coefficient values in Table 3, was obtained from FAO Irrigation and Drainage Paper retrieved from; https://www.fao.org/3/X0490E/x0490e0b.htm

Example of Ms. Faridatu:

Faridatu has multiple plots of land. The crop is Tomato (Solanum family) with a Kc value of 1.15 (Table 3) and critical/peak ETo value of 5.36 mm/d for march (Table 2). Here is a drawing –seen from a birds' eye perspective– of her situation:



She fills in the table below (also available at the end of this booklet)

Plot number	A Water needed (mm/ day) (Kc x ETo)	B Water needed (m/ day) (A/1000)	C Length (in m)	D Width (in m)	E Multiply the length & width to obtain the surface area (in m^2) (C X D)	F Total water need for the whole farm (m^3/day) (B X E)
Plot A	*6.164*	*0.00616*	*22*	*14*	*308*	*1.90*
Plot B	*6.164*	*0.00616*	*15*	*10*	*150*	*0.92*
Plot C	*6.164*	*0.00616*	*20*	*15*	*300*	*1.85*
Plot D	*6.164*	*0.00616*	*22*	*20*	*440*	*2.71*
Plot E	-	-	-	-	-	-
Plot F	-	-	-	-	-	-
Total	*6.164*				**1,198**	**7.38**

The total land area Ms. Faridatu wants to irrigate is approximately **1,200 m^2** and for that her crop needs to receive **7.38 m^3** of water per day at the peak of the season.

So the daily water need for her entire land to irrigate is rounded at **7.4 m^3/day**. Note that this is the amount of water the plants need. The pump will need to pump more water than that! It will be explained in the next chapters.

In-between check 1

What do we want to check?

In the previous steps the maximum yield of the well has been calculated (Step 2). And the irrigation water need has been determined (Step 3).

A first check can show if the well can provide sufficient water to irrigate the land. If the daily water need is much 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 needs to 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 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 will calculate the amount of water that your pump needs to extract from the well during each hour of sunshine. This is called the 'required pump discharge' because it is the the amount of water required to be pumped in order to irrigate your field according to its needs. You can calculate it like that:

$$\text{Required pump discharge}\left(\frac{m^3}{hour}\right) = \frac{\text{Maximum water need for plants}\left(\frac{m^3}{day}\right)}{6}$$

Now compare the safe yield of the well, with the required pump discharge that you just calculated.

- 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 that needs to be irrigated.
  Otherwise, digging a new additional well on the land can be considered. Depending on the mobility of the selected pump, an additional well may require an extra pump as well.

Example of Ms. Faridatu:

Ms. Faridatu calculated that she needs **7.4 m^3 of water per day.** The required discharge of the pump will then be 7.4/6 = 1.2 m^3/h. But she calculated at Step 2 that his water source can only provide 1.0 m^3/h. This means that Faridatu will not be able to irrigate her entire field with her well, since she also has to account for some losses in the pumping and application system. Therefore she needs to reduce the land surface to be irrigated.

She decides not to irrigate Plot D because it is the farthest from her water source. She does the calculation again. Without plot D she now needs to irrigate 760 $m^{2,}$ and for that she needs **4.67 m^3/day**. So she needs a pump discharge of 4.67/6 = **0.78m^3/h**. Her borehole can provide this.

Hours of sunshine [Note for technicians]

To calculate the required yield of the pump the daily water need was divided by 6. The number of 6 is derived from the concept of '**peak sunshine hours**'. 6h is the average irradiance in Ghana during month of March, 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 changes over the course of the day, because 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] below.

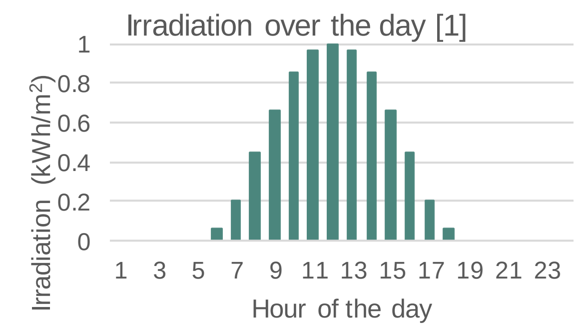
In the end, what matters, is the total amount of sunlight received. But it is difficult to calculate.

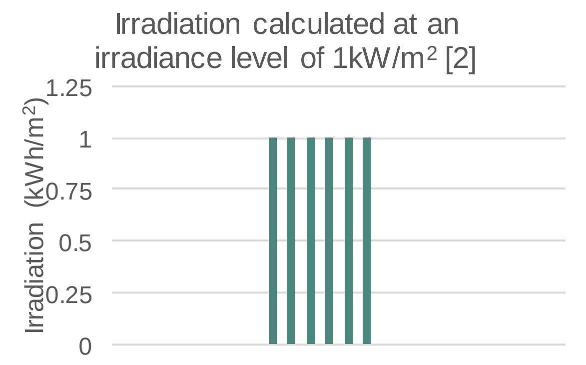
To make it easy, we look at the graph and we simply add the small bars to the bigger bars until the reach 1 kWh/m². We obtain the graph [2] below. As you can see, we were able to make 6 full bars out of it. It means this day would have 6 peak sunshine hours. So **peak sunshine hours are the number of hours, at an irradiance level of 1 kW/m², required to produce the energy received during one day.**

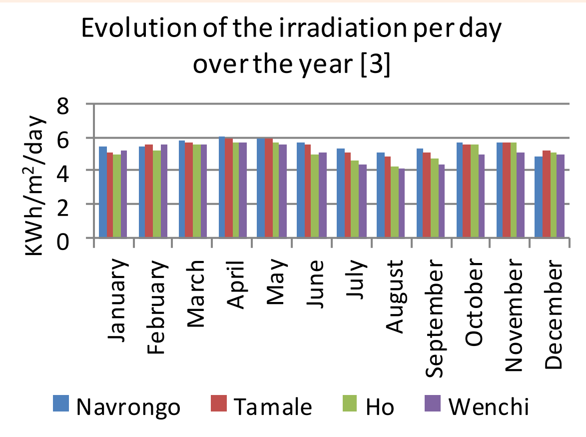
The figure of **6 peak sun shine hours is a common standard to be used in calculations with solar panels**. It gives a good indication of how much energy we can expect per square meter. You will see, we often use this number in the calculations. This can change depending on the location, the season and the weather. It can be a bit more or a bit less.

It is important to look at the peak sunshine hours **during the irrigation season**. In the graph below [3] you can see the irradiation for four random locations in Ghana. You can see that during the irrigation season the peak sunshine hours are likely to be 6 hours.

Therefore, 6h appears to be quite a safe assumption to make a first assessment.







STEP 4: 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 brought 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 they are 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 method will be used is the third design 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 is 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 3 reach the plants. And one liter is lost.

In step 3 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 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 higher water flow. You can find examples of water application methods on page 29 and 30 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.

Relation between application, pump and well yield

It is very important to assess the required pump discharge and compare it to the discharge of the water source. You did a first calculation at Check 1. Yet the efficiency of the application system was not taken into account. Therefore your calculation must revised by adding in the formula the efficiency of the application system, as follows:

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.

$$Required\ pump\ discharge\left(\frac{m^3}{hour}\right) = \frac{Maximum\ water\ need\ of\ plants\ \left(\frac{m^3}{day}\right)}{6} x \frac{1}{application\ efficiency\ (\%)}$$

Again, a new check is needed to determine if the required pump discharge is higher than the well of the water source. If so, your well cannot provide enough water. You have to reconsider the design of your system. It can either be done by improving the efficiency of the application; or by reducing the size of the irrigated plot. A third option would be to create a second well and possibly purchase multiple pumps.

In these calculations we assumed the water losses at the conveyance system to be neglectable.

Secondly once you have chosen your application system, and in order to select a pump, you need to calculate how much water needs to be pumped.

If you chose a very inefficient irrigation scheme, you will need to pump more water into the system compared to using a very efficient application method.

How much water the pump needs to supply on a **daily basis** can be calculated as follows:

$$Required\ pump\ discharge\left(\frac{m^3}{day}\right) = Maximum\ water\ need\ of\ plants\ \left(\frac{m^3}{day}\right) x \frac{1}{application\ efficiency\ (\%)}$$

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

How do I know the pressure needed & 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 but 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	Sensible	N.S.*	N.S.*	N.S.*	N.S.*	N.S.*
Pressure needed	2 m	5 m	10 m	5 m	0 m	0m
Water efficiency**	90%	75%	70%	75%	50%	75%
Solar compatibility	Good	Good	Medium	Medium	Low	Good

*N.S.: Not sensible
**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.

Additional note 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.

WHICH CONVEYANCE SYSTEMS EXIST?

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

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

1. Water can't be transported uphill via an open channel.
2. Water losses are **very high**. These can go up to 1/3 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.

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 the water losses can be neglectable (0-10%) if installed and used correctly. Buried pipes have the advantage that the chance of damage by cattle, sunlight etc. is reduced.

WHICH APPLICATION TECHNOLOGIES EXIST?

Drip irrigation

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

Sprinkler

A sprinkler 'plashes' the water to the plant 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

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

Example of Ms. Faridatu:

Ms. Faridatu has a borehole that provides 1.0 m^3/h and she needs 4.67 m^3/day to irrigate her plots. She hesitates which application method to choose. To make a decision she makes an overview of the alternatives.

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

$$Maximum\ flow\ rate\ pump\ with\ furrow\ irrigation\ \left(\frac{m^3}{hour}\right) = \frac{4.67\left(\frac{m^3}{day}\right)}{6} x \frac{1}{0.5} = 1.6\ m^3/h$$

Using furrows to irrigate the area she currently wants to irrigate would require a flow of 1.6m^3/h. Unfortunately her water source can only provide 1.0 m^3/h. Therefore, this option can only be used if she reduces her irrigated land by a third of its size. But she doesn't want to do that.

So she decides to check if improving the efficiency of the application method can help her out. She 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):

$$Required\ pump\ discharge\ with\ spray\ tubes\ \left(\frac{m^3}{hour}\right) = \frac{4.67\left(\frac{m^3}{day}\right)}{6} x \frac{1}{0.75} = 1.0\ m^3/h.$$

$$Required\ pump\ dischargewith\ drip\ irrigation\ \left(\frac{m^3}{hour}\right) = \frac{4.67\left(\frac{m^3}{day}\right)}{6} x \frac{1}{0.90} = 0.87\ m^3/h.$$

By comparing the pump yields with the safe yield of the water source she sees that both options are feasible. Meanwhile, with drip irrigation she can irrigate more land than she now intents. However, being new with irrigation she wants to limit the complexity of her irrigation and limit her investment. For that reason **she opts to use spray tubes**, though the maximum pump yield of **1.0 m^3/h** equals safe borehole yield. Ms. Faridatu's decision has a tendency to run dry her well due to the equal pump discharges. She is further advised by an expert to use the **drip irrigation system** with maximum pump yield of **0.87 m^3/h**, though technical support will be required from Extension officers to help run the system.

Knowing this allows her to calculate how much water the pump needs to pump on a daily basis.

$$Required\ pump\ discharge\left(\frac{m^3}{day}\right) = 4.67\left(\frac{m^3}{day}\right) x \frac{1}{0.90} = 5.2\ m^3/day$$

Optional step: Water storage & batteries

What is a water storage?

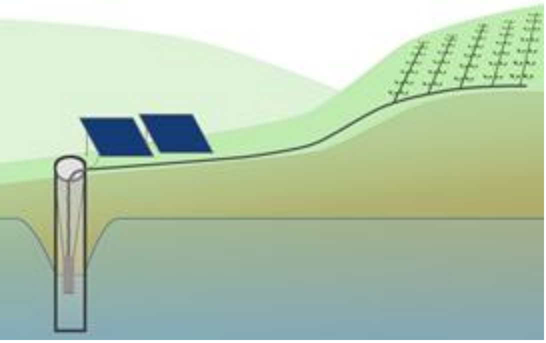
Water storage is a reservoir or tank that stores water. It serves as a 'water battery': by storing water to be used at another point in time.

It is not always necessary to have a water storage for irrigation. In certain situations it can be convenient.

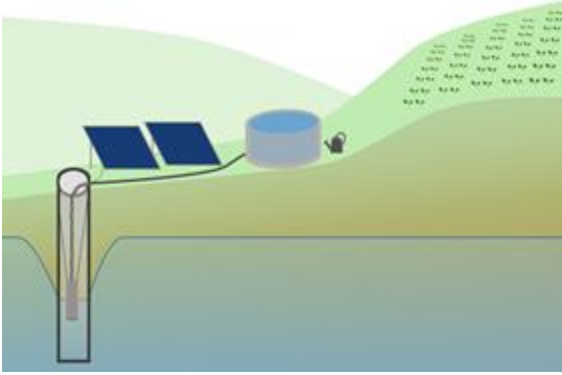
What type of water storage are possible?

- **A small water storage/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. However, in this way water spillages is avoided compared to not using the drums.
- **Low 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 loosing 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 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!

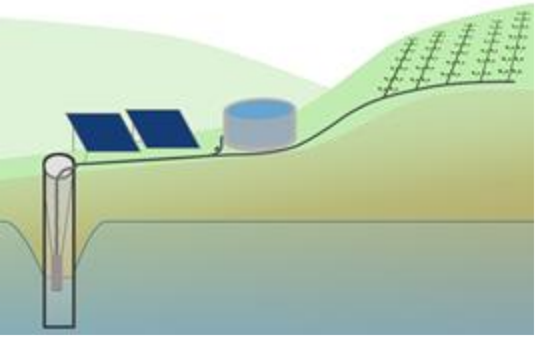
Bucket irrigation can be used in combination with small barrels to buffer the water. This set-up is common for communal gardens, since it enables multiple people to irrigate at the same time.



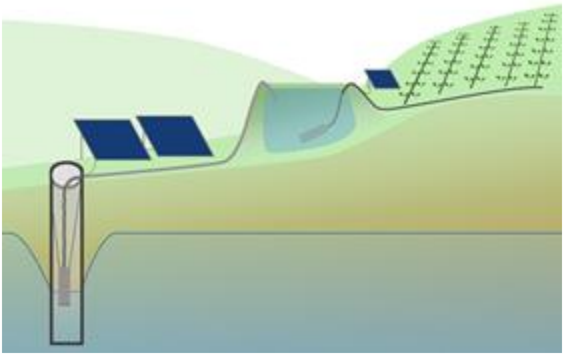
A- Direct connection from the pump to the application system



B- Small drum for manual application



C- Low intensity drum OR large tank



D- Large drum 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 in 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 a 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 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. But efficient batteries are currently very expensive.

Example of Ms. Faridatu:

Ms. Faridatu is wondering whether she should invest in a battery or a water storage. Faridatu is a full time farmer. She spends most of her time in the field, and uses the harvest to feed her family and sells the surplus. She calculated at Step 3 that the surface that he can irrigate is 760 m^2. She needs to irrigate her plants every day.

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

Small drum		Large elevated tank	
Pros	**Cons**	**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.	- 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 Ms. Faridatu spends most of the time on her farm, she decides that a large tank has no major advantage. Because they are so expensive and it makes no sense to buy one. However, she knows that she can buy two cheap old oil barrels. She decides to place them next to her house and fill them in the early mornings and late evenings for a year to see if she manages to plant some extra herbs around her house.

STEP 5: Calculating the total head of the system

What is the total head?

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 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?

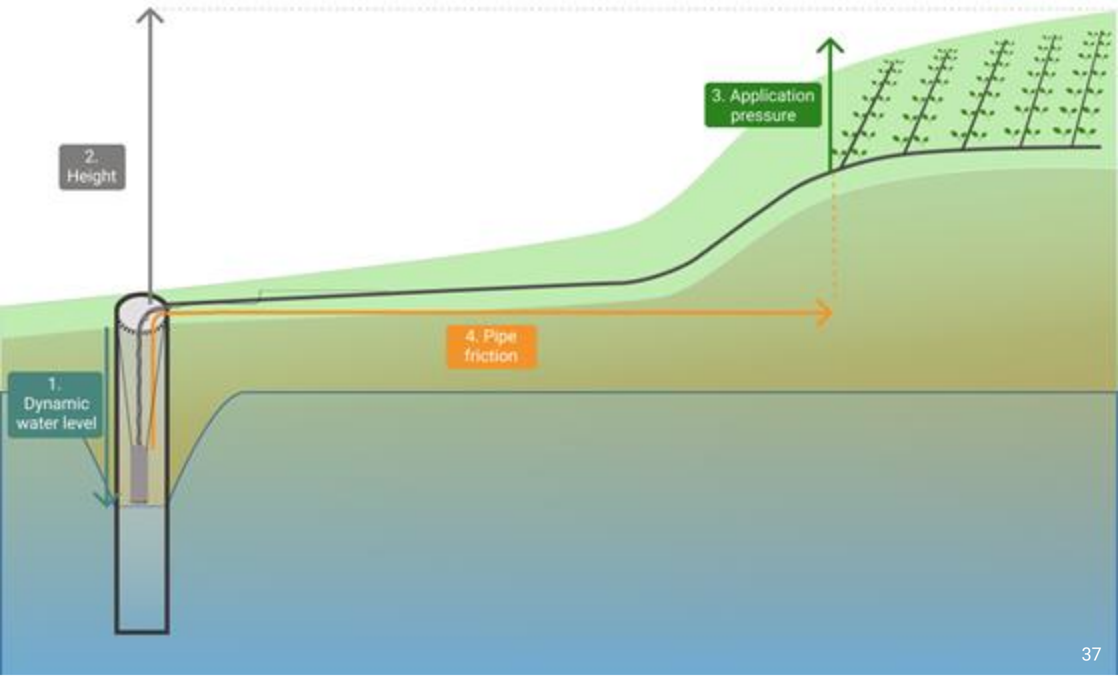
Pumps can be very different from one each other. It depends on the design of the pump. Some pumps can provide a high flow and provide very little pressure (head). Some pumps provide very low flow but a very high pressure (head). Knowing the head in combination with the needed flow allows you to select 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 2)
2. The **height** difference at highest point in the path from the well to the field (in meters)
3. The required pressure of the **application method** (in meters – see table step 3)
4. The **friction losses** of the pipes in you conveyance system (in meters)

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



Friction losses and how to calculate them:

The friction losses mentioned in point 4 depend on:

- The amount 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.

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

1. Select in the table below (only applicable if you pipe is shorter than 50m) the minimum pipe diameter.

Flow	=< 2m³/h	=< 3,5 m³/h	=< 5m³/h	=< 8,5m³/h	=< 13m³/h
Minimum internal diameter	25mm	32mm	40mm	50mm	63mm

1. Report this diameter, and the required pump discharge that you calculated at step 3 in the table appendix 4, or on the following 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 pipe.

Try to limit the total loss of the conveyance – the easiest way to reduce the losses is to choose a larger diameter pipe.

Example of Ms. Faridatu:

Ms. Faridatu needs to calculate the head of his system:

1. At step 2, 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 **7.70m**.
3. He recommended to use drip irrigation from a kit. He looks at the table of step 3 and sees that the pressure needed to irrigate his field with drip irrigation is **2m**.
4. He now needs to determine the friction losses of the pipes. He would like to buy pipes of 1.25 inch for the conveyance system. The pump discharge calculated at step 3 is 0.87 m³/h. So he opens the website mentioned above, enters the flow of 1.0 m³/h and the 1.25 inch pipe *(be careful to select the good units!)*. His friction losses are 0.005 m per m of pipe. There are 40m between his borehole and the furthest plot that he needs to irrigate. So he calculates the total friction loss = 0.005x40 = 0.21m. It is acceptable. For the calculation of the head he rounds the number up at **0.2 m** of pipe friction.

He adds up all the results = 6.2 + 7.7 + 2 + 0.2 = **16.1 m**
The total head of his system is rounded to 16 meters.

She now knows the pump that she will select needs to be able to provide a discharge of around 1m³/h at a head of 16m.

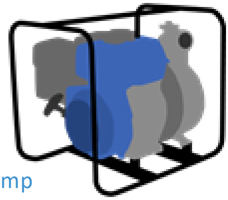
STEP 6: Pump selection - technical

What is the first selection step?

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

1. Suction pump: this means the pump sucks the water up 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 the water up 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 2?

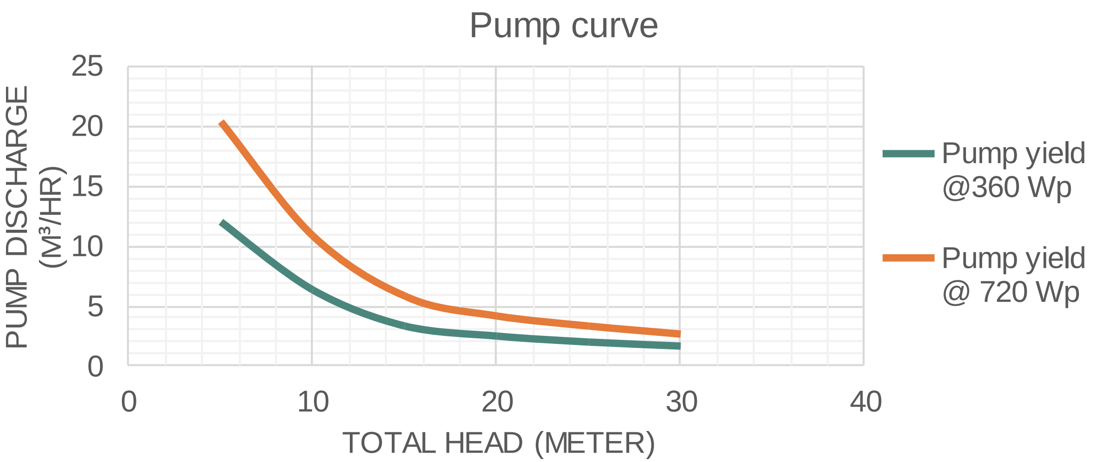
If the dynamic water level that you measured is more than 7-8 m, *you have to select a submersible*. If the water is shallower than the 7-8 meters you can select either of the 2 types of pump according to your preference.

What is the second selection step?

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. A random pump curve looks like this:



The vertical axis shows the amount of water that 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** (the curve is going down as we go towards the right of the graph, so towards higher heads). **This is true for all pumps**. So for example, take the orange line. If the head is 10 meters the pump can provide about 11 m^3/hr. But if the total head is increased to 20 meters then the pump will be only be able to provide 5 m^3/hr.
- This graph also shows that **at more than a certain head the pump is no longer able to provide any water**. On this graph it is at 30m. This means that if the total head of the system is 30 meters or more, the pump will not be able to provide any water.
- Also there are 2 lines in this graph: the red line shows the amount of water will provide with double the amount of panels compared to the green line.

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.

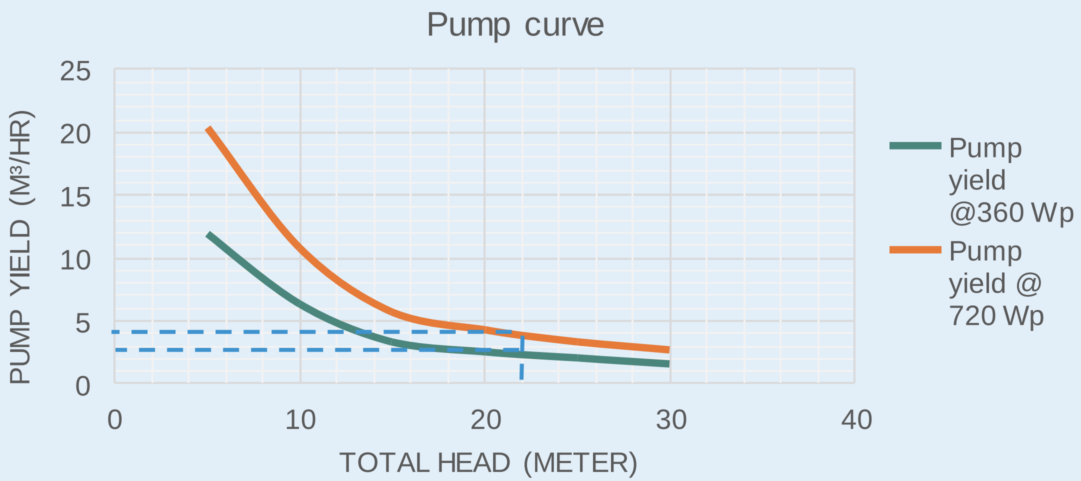
Because of the very large amount of pumps available on the market and the very large differences between regions, we advise to take all the data calculated at step 1, 2, 3 and 4 to a local pump supplier and ask for advice there.

Example of Ms. Faridatu:

Ms. Faridatu walks on the market and sees a solar pump. She is interested! Knowing that her system has a total head of 16 m and her borehole has a yield of 1 m³/h, she starts looking at the pump. On the pump curve below he sees that:

- With 2 solar panels (of 360Wp each) that provide in total 720 Wp she could have a flow of about 4.0 m³/h. But in this case the capacity of the pump would be larger than the capacity of her water source and the pump would run dry. So she doesn't need a second solar panel.
- With 1 solar panel of 360 Wp, the pump can provide a flow of about 2.5m³/h. That is still more than her well can handle!

Even at a total head of 30 meters this pump still provides too much water. Therefore it is too big, and most likely too expensive for her system. She decides this pump is not for her and seeks further for better options.



In summary you need to know that each pump differs from another. But the market is large, so you should ask your local supplier for advice (you can also visit 2 or 3 suppliers).

When you buy your pump, it is essential to pay attention to the technical characteristics and make sure that they fit your situation. But 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.

IN SUMMARY, CHOOSE YOUR PUMP DEPENDING ON:

- Water source (Step 2)
- Total pressure needed (step 4)
- Volume/flow of water needed (Step 2 & 3)
- Price
- Repairing and replacement of parts
- Resistance to silt/sand in the water
- Transportability

Solar panels

Why do I need solar panels?

Solar panels are the device that will provide the energy to your 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. Their size is expressed in Watt-Peak (Wp) generated at full light.

How to choose the solar panels?

Generally a supplier will provide the pump and the panels as a set. The number of panels supplied depend on the power of the solar panels, the needed amount of water per day and the total head. You can use the following formula to calculate the size of the solar panels needed (expressed in Wp):

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 a irreparable manner. Therefore, ask advice to your supplier before buying your solar panels.

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. The pump will then pump the most water. Therefore – if possible – change the position of the panels over the day towards the sun.
2. 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.
3. Make sure that they are clean (remove the dust and the stains regularly).

Solar panels have a lifetime of about 10 to 20 years if handled properly.

Example: Ms. Faridatu goes to the pump supplier

The data she has collected and brings to the supplier:

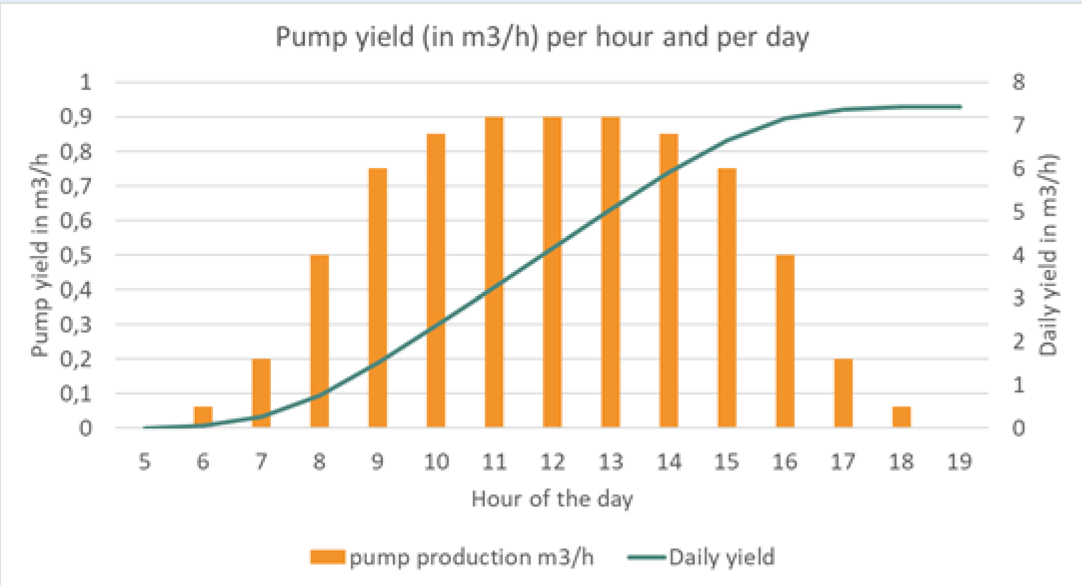
- Pump yield: 5.2 m³/day
- Total head of the system: 16 meter
- Dynamic water depth is 6.2 meter
  (so both a submersible and a surface pump are possible)
- Safe yield of the water source: 1.0 m³/h.

Unable to find the right pump on the market Ms. Faridatu goes to a pump supplier who suggests two different pumps. The first is a submersible solar pump. It comes with 1 solar panel of 360 Wp. It can provide a maximum head of 40 meters. The shop provided advice that this extra head is convenient for her if she ever wants to change to a different application system like sprinklers that require more pressure.

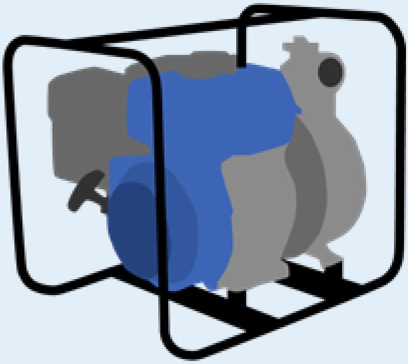
The shop uses modelling software of the pump provider to give her an overview of the amount of water the pump will produce in her situation. The orange lines show how much water is produced each hour of the day. During the day the pump never pumps more than the well can provide. The green line shows the daily production of the pump. At the end of the day about 7 m³/day have been produced.

The price of the pump including the panels is 35,000 GHC including the solar panels.

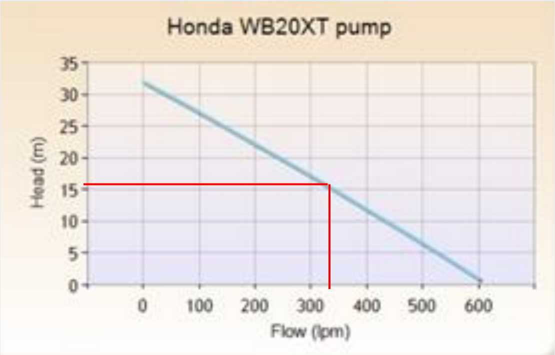
Submersible pump



The second pump Ms. Faridatu if offered is a petrol pump. It has a total head of 32 meters and consumes about 1.1 liter of petrol per hour at full speed. The staff of the shop do not know a lot about the pump but on the box of the pump the following graph is provided.



Although this graph is slightly different than the graph she has seen in a solar pump course, she understands it shows the relation between head and pump yield. She knows her system has a total head of about 16 meters. So the draws a red line where the head is 16 meters. And reads this pump would provide about 330 liters per minute at this head.



With 60 minutes in one hour she figures out that the pump yield is 19,800 liters per hour. But her water source can only provide 1000 L/h! So she would need to slow down the pump a lot during irrigation. In the end it would take him 6 hours to irrigate her entire field using the fuel pump. Which is the same as a solar pump.

The pump supplier provided her a quote of 12,000 GHC for the pump. The pump supplier also suggests that at such a slow rate of pumping the pump would consume 0.5L of petrol per hour.

Not knowing what to do she decides to take the information with her and make a comparison back home before deciding what to buy.

STEP 7: Pump comparison

To make an informed decision what to purchase it is advised to compare the solar pumps with the alternatives on the market. This chapter shows how one – in a simplified manner – can financially compare different pumps.

Which pumps can I compare a solar pump with?

The first step in comparing pumps is to determine which type of pump can be compared to the selected solar pumps in step 5. The 2 most common alternatives are:

1. **A hand pump**: To compare this with a solar pump one needs to have a very small plot because in general terms a hand pump is only able to provide water to irrigate up to 400 m^2 meters.
2. **A petrol pump**: This comparison is only applicable when the dynamic water level is in the range of 7 meters depth or less. If the water is lower than the 8 meters the petrol pump will no longer work and then it is of no use to compare it with a submersible solar pump.

Make a selection of the pumps that you would like to make a comparison with.
Make sure the performance is the same. It makes no sense to compare a high yielding solar pump with a hand pump.
It is possible to compare a certain type of solar pump with another type of solar pump.

How do I compare the pumps financially?

The easiest way to compare pumps is to calculate the expected yearly cost of each pump. For an entrepreneur like a farmer it makes sense to choose the cheapest option as long as the pumps can provide the same performance. Meaning: both pumps will result in the same amount of crop yield. This will be the assumption for the calculations made in this training guide.

To compare pumps you can consider the following costs:

1. **Fuel and lubricant costs:** this applies to petrol pumps. Solar pumps do not need any petrol or lubricants.
2. **Maintenance & repair cost pump**: small parts needed to keep the pump running.
3. **Depreciation cost pump**: a pump wears when it is being used. The yearly depreciation costs is the amount of money the value of the pump loses over a year due to the wearing. This is not an out-of-pocket cost, but a theoretical cost that can be accounted for to save money for replacing the pump after its average lifespan.
4. **Other/divers cost**: For each farmer his/her situation will be different. Maybe a farmer will have weekly transportation costs for fetching petrol. Or a loan is used to pay for the pump. This will need to be taken into account too.

By making a yearly overview of the cost you can compare the different pumps financially in a very simple way. More advanced financial comparisons are possible – for example taking interests rates into account. This – however becomes quite complicated and often does not change the conclusion of the comparison.

Depending on the farmer and the setup one can also take into consideration:

- **Maintenance, depreciation & repair costs of the irrigation system**: this is only relevant if a farmer compares different pumps in different irrigations setups. So for example, if a farmer uses a petrol pump in combination with furrow irrigation. And wants to switch to a solar pump using drip irrigation.
- **Labor costs**: solar irrigation is usually more time consuming than petrol pumps. This is caused by the low discharge of solar pumps compared to petrol pumps. It implies that the farmers may need to spend more time in the field (depending on the storage and application system) with a solar pump. Taking this additional time input might come at a cost that needs to be taken into account as well.

What else should I take into account?

Along with technical aspects, financial aspects are very important while choosing your pump, but don't forget to compare other practical factors such as:

- **The warranty offered by your supplier**: is it the same for the two types of pump that you are trying to compare? Do you know what is included in each situation?
- **The practical aspects like 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 sensible than others to silt. Does your water source contain a lot of particles? Does your supply offer a warranty for this?
- **The risk of running dry:** In general it is not good for pumps to run dry. But some are more sensible than others. Make sure you are aware of the risks.
- **The maintenance**: does your pump needs regular maintenance? Who can do it for you?
- **Fuel independence**: solar pumps do not use any petrol. In times of scarcity prices can increase or fuel availability might reduce. When relying on petrol this might be a reason to change to solar.
- **Environmental impact**: fuel pumps have a larger environmental impact than solar pumps.
- **Other use for solar panels**: – when the irrigation season is over – solar panels can be used for other purposes. Like providing charging telephones or batteries to run small lights. Ask advice on the correct setup – never just connect electronics to a solar panel as it might damage your electronics!

Example of Ms. Faridatu:

On the way back from the market, Faridatu realizes that she forgot one option she wants to explore: the rope pump. It is used a lot in her direct surrounding and many people are using it to irrigate. She asks her neighbor if she can test her rope pump with the same setup as Faridatu envisions.

She tests the rope pump by following the steps in this guide from the end to the beginning.

- **Step 4**: She already has a rope pump, she needs to calculate the discharge in her set up because this rope pump does not have a pump curve.

The first thing she does is measuring how much water the rope pump can provide. She starts pumping and fills a bucket of 20 liters. She measures that this takes 80 seconds. Knowing this she calculates the pump yield as follows:

$$\text{Pump discharge } \left(\frac{m^3}{hr}\right) = \frac{\textit{Size of bucket (in liters)}}{\textit{Number of seconds it took to fill it}} x\ 3.6 = \frac{20}{80} x\ 3.6 = 0.9\left(\frac{m^3}{hr}\right)$$

Her pump discharge is 0.9 m^3/h. Faridatu thinks she can pump for 2 hours per day. To this would result in a total of 1,800 liters pumped per day.

- **Step 3**: The most logical option would be to use a bucket to bring the water to her field. With a 75% efficiency she calculates this will result in (0.75x1,800=) 1,350 liters at the plants.
- **Step 2**: These plants need 6.2 liters per m^2. Making it possible to irrigate a plot (1,350/6.2) = 218 m^2. This is much less than her intended field size of 760m^2.

She concludes that the rope pump cannot deliver enough water to fit the needs of her crop. Therefore she decides to compare the petrol pump with the solar pump only. For that she makes a financial comparison.

Because both the petrol pump and the solar pomp will take most of the day to irrigate the field she does not include any cost for labor.

Also, no matter the choice of pump, Faridatu decided she would use drip irrigation. So she does not include cost differences related to the application system either.

Financial comparison:

She first makes the overview for her petrol pump.

She takes into account the travel costs of fetching fuel. She comes up with the following cost items:

- **Fuel costs**: during the 6 hours per day that the pump will run at low speed she will need to pay for 3 liters of petrol per day. She estimates the irrigation season is about 45 days.
- **Lubricant costs**: She wants to replace the oil of the pump each year which takes about 3 liters.
- **Maintenance costs**: She reserves 500 GHC for small repairs.
- **Depreciation costs**: based on experience she thinks the pump will last for about 5 years.
- **Other:** She lives very far away from the nearest petrol station. A round trip fetching fuel would cost him 75 GHC.

She puts all the cost in a table, creating the following overview resulting in an estimated yearly cost for a fuel pump of 5,046.5 GHC:

Factor	A	B	C	Total costs (GHC/year)
PETROL PUMP				
1. Fuel cost (only applicable for fuel pumps)	Fuel consumption (liters per day)	Fuel price (GHC per liter)	Number of irrigation days per year	(AxBxC)
	3	6.9 ghc/ltr	45	931.5
2. Lubricant cost (only applicable for fuel pumps)	Needed liters of lubricant per year	Liter price (GHC per liter)		(AxB)
	3 liter	30 ghc/ltr		90
3. Maintenance & repair cost pump	Cost per season (GHC)			
	500			500
4. Depreciation costs of pump	Investment cost of pump (GHC)	Expected lifespan of pump (years)		(A/B)
	12,000 ghc	5		2,400
5. Other/divers	Number of trips to fetch petrol per year	Travel costs (GHC/return trip)		
	15	75		1,125
Total (sum of parts)				5,046.5

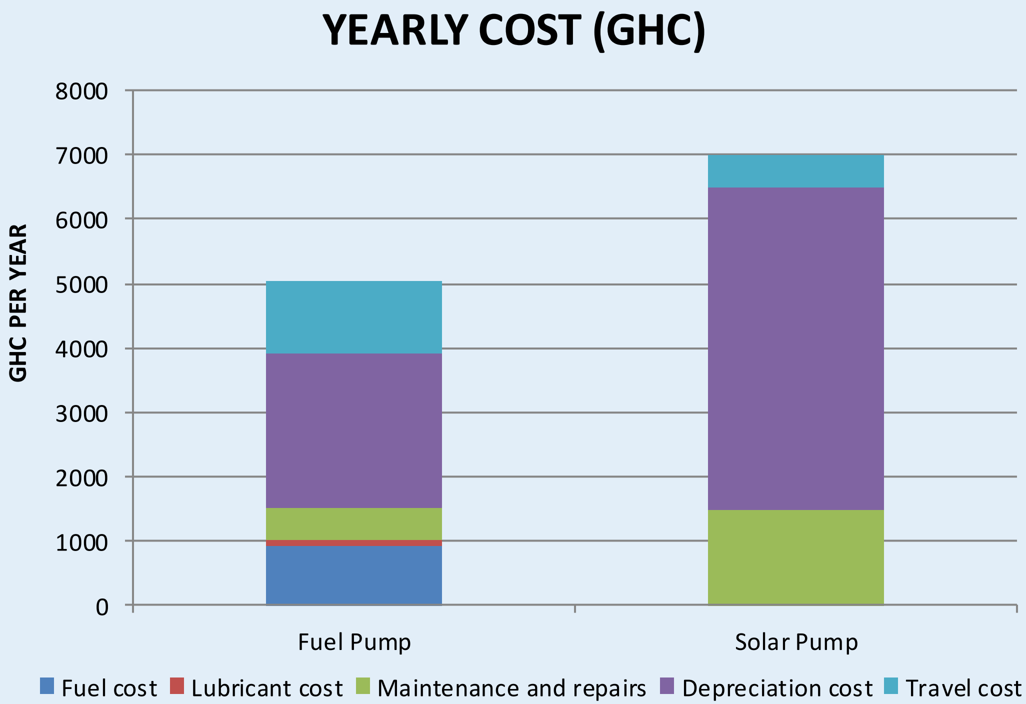
Secondly she makes the same calculation for the solar pump. For her solar pump she makes the following overview of the expected costs per year:

- **Fuel costs:** no fuel costs as the pump will run on solar energy
- **Lubricant costs**: a submersible does not use any lubricants.
- **Maintenance costs**: She expects fewer repairs but expects them to be more costly when they are needed. She therefore decides to save 1,500 GHC per year for repairs after the warranty period.
- **Depreciation costs:** the shop attended advised her to assume a life span of 7 years.
- **Other**: as she does not need to travel up and down for petrol she does not include any daily travel costs. She – however – knows the pump supplier is located in the next major town. For spare parts she needs to pay 250 GHC round trip. She therefore reserves 1 round trip for just in case. And another 250 GHC to buy her an old drum.

He puts all the cost in a table, creating the following overview resulting in an estimated yearly cost for a solar pump of 7,000 GHC:

Factor	A	B	C	Total costs (GHC/year)
		SOLAR PUMP		
1. Fuel cost (only applicable for fuel pumps)	Fuel consumption per hour (liters per hour)	Fuel price (GHC per liter)	Number of irrigation hours per year	(AxBxC)
	ZERO – solar pump uses solar energy			
2. Lubricant cost (only applicable for fuel pumps)	Needed liters of lubricant per year	Liter price (GHC per liter)		(AxB)
	ZERO – solar pump does not need lubricants			
3. Maintenance & repair cost pump	Cost per season (GHC)			
	1,500			1,500
4. Depreciation costs of pump	Investment cost of pump (GHC)	Expected lifespan of pump (years)		(A/B)
	35,000 ghc	7		5,000
5. Other/divers	Supplies & drum	Cost per item		
	2	250		500
Total (sum of parts)				7,000

The following graph shows the comparison between the 2 systems. Left are the costs of the fuel pump. And right is the cost of the solar pump.



Ms. Faridatu now hesitates. The solar pump is more expensive due to its investment cost. About 2,000 GHC per year over that of the Fuel pump.

She decides to go for the solar pump.

Being fuel independent – and reducing the hassle of travelling for petrol – is very important for her. She perceives it as a entrepreneurial risk: not having petrol for a few days could ruin his whole irrigation season. Moreover – she thinks the petrol prices will continue to go up. Making the solar pump more attractive in the end.

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 quality, cost and dimensions?
- For groundwater : what is the safe well yield during the peak irrigation season (m^3/h)?
- For surface water : what is the (agreed) water availability during the most critical period (m^3/day)?
- For rainwater storage : what is the available water volume for the season (m^3), 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 1.1 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/m^2/day)
- Multiply by the irrigated area to get the total gross water need (m^3/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% efficiency)) to calculate the Nett water need (m^3/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 (m^3/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 downloaded 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 irradiation (kWh/m²/day) received on a panel that is directed towards the equator.
- Alternatively you can also use 6 kWh/m²/day as a safe estimate for most African countries.

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 chapter 4)
- 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 50% in dusty conditions and 60% in when regular cleaning takes place.
- Recall the following elements calculated above:
  - Daily Nett water need (m³/day)
  - TDH Total Dynamic Head (m)
  - Expected solar irradiation (kWh/m²/day)
- Calculate the required solar power in Wc using the following formula:
  Required Power (Wc) =

$$\frac{(2{,}725 \text{ X Daily Nett water need (m}^3\text{/day) X TDH (m) / pump efficiency (\%))}}{\text{(Expected irradiation (kWh/m}^2\text{/day) X Panel efficiency (\%))}}$$

STEP 8: Health and safety (SPIS)

This module is designed to equip trainees with knowledge and skills in health and safety issues relating to solar-powered irrigation systems. It introduces students to SPIS and safety, the basic fundamentals of safety, identification of safety and hazard, and how to mitigate hazards. Trainees will particularly be equipped with knowledge and skills of personal protective equipment (PPEs) usage.

1. Module Objectives:

- At the end of this module, the trainees will be able to:
- Demonstrate knowledge in OHS in SPIS
- Use PPEs appropriately
- Identify health and safety hazards related to SPIS
- Apply skills relevant to mitigating and eliminating identified SPIS hazards

2. Introduction

Installation of solar panels and systems can be risky. Workers in the solar industry face various risks. These may include:

Falls from high rooftops
Electrocution or other electric hazards
Repetitive stress injuries
Cuts or sprains
"When you think about workers in the solar industry who are working with large, heavy panels and tools from very high off the ground, the list of things that can go wrong is endless," said Stacie Prescott, The Hartford's chief underwriting officer for energy business insurance. "It can be a dangerous industry and that's why businesses providing installation of PV panels or other kinds of systems have to make sure they're protected."

Due to these, the risks that businesses and workers face, the Occupational Safety and Health Administration (OSHA) requires employers to have safety training and protection for their employees. Many solar installation companies have taken OSHA's requirements a step further and created their own manuals.

Ensuring due diligence is important as each worksite is unique and presents different risks. It's important for the installer to visit the site, identify safety risks and develop specific plans in addressing them.
Equipment to use for safe lifting and handling of solar panels
Type and size of ladders and scaffolding
Fall protection for rooftop work
Personal protective equipment (PPE) for workers

Health and Safety (SPIS)

The condition of being protected from or unlikely to cause danger, risk, or injury.
Safety issues are common for solar installations, but proactively putting preventive measures in place can help mitigate on-the-job injuries.

Understand the risks

Reduce workplace stress

Use the right tool for the right work

Take regular breaks

Use mechanical aids whenever possible

Wear protective equipment to suit the task

10

Lifting and Handling Solar Panels

Solar panels are heavy and awkward to lift and carry. Loading and unloading panels from trucks and onto roofs can cause:

- Strains
- Sprains
- Muscle pulls
- Back injuries

Solar panels also heat up quickly when exposed to sunlight. So, if PPE isn't worn or panels aren't handled correctly, they can cause burns.

When it comes to solar panel safety, workers can reduce injury risks by:

- Having two people lift panels with the correct lifting technique
- Using mobile carts or forklifts to transport panels onto and around the worksite
- Never climbing ladders while carrying solar panels
- Using properly inspected cranes, hoists or ladder-based winch systems to get panels onto roofs
- Covering uncovered panels with an opaque sheet to prevent heat buildup
- Always wear gloves when handling panels

Health and Safety (SPIS)

Ladder Safety

Solar installations often involve working on roofs from ladders. So, having the right type of ladder and using it correctly is essential to worker safety.

Select the ladder that best suits the need for access. This can include a stepladder, straight ladder or extension ladder. Be aware that straight or extension ladders should extend a minimum of 3-feet above the rung that the worker will stand upon.

Choose the right ladder material. Aluminum and metal ladders are commonly used, but they're a hazard near power lines or electrical work. Instead, a fiberglass ladder with non-conductive side rails may be a better option near power sources.

Place the ladder on dry, level ground. Make sure the feet of the ladder are away from walkways and doorways and at least 10 feet from power lines. Secure the ladder to the ground or rooftop for added stability.

Trips and Falls

Trips and falls are the second most common nonfatal injury in the construction industry.[8] In fact, there were over 25,000 nonfatal slips, trips and fall injuries in 2019.[9] Rooftop solar installations can pose a higher fall risk because there's less work space as more panels get installed.

To help keep workers safe while installing solar panels and systems:

Keep work areas dry and clear of obstructions
If employees are working six feet or higher, install guardrails around ledges, sunroofs and skylights. It may be a good idea to also use safety nets
Provide workers with a body harness anchored to the rooftop to stop a potential fall
Cover holes on rooftops, including skylights, as well as ground-level work surfaces

Health and Safety (SPIS)

Solar PV Safety

A solar PV system includes several components that conduct electricity. This includes the PV solar array, the inverter and other essential parts. This presents solar power safety concerns.

When these parts are live with electricity generated by the sun, they can cause serious injuries due to electric shock or arc-flash. Even in low-light conditions, systems can create enough voltage to cause injuries.

Be aware that electricity comes from two sources with PV systems:

The utility company
Solar array absorbing the sun's light
Even if the building's main breaker is shut off, the PV system still continues to produce power. This requires extra caution among solar workers.
of the ways you can keep workers safe include:

Covering the solar array with an opaque sheet to block the sun's light.
Treating wiring coming from a solar PV system with the same caution as a utility power line. That means assume all wires are live.
Using a meter or circuit test device to ensure circuits are de-energized before working on them.
Locking out power on systems that can be locked out. Tag all circuits you're working on at points where that equipment or circuit can be energized.
Never disconnecting PV module connectors or other associated PV wiring when it's under load.

Health and Safety (SPIS)

Personal Protective Equipment for Solar Workers

Personal protective equipment (PPE) is essential during every solar installation. Employers have to assess workplaces for hazards and make sure they provide workers with the necessary PPE for their safety. This can include:

Hard hats
Gloves
Steel-toed shoes with rubber soles
Eye protection, like glasses or goggles
Vests
Harnesses

Make sure employees know how to use the PPE, as well as how to maintain it so it is kept in safe and reliable condition. Workers should know the process to request replacement PPE if it's necessary.

The PPEs should be provided by the System Management and includes:
Hard Hats: to be used when climbing to heights above 2 m and when there is a danger of items falling from a high point.

Hearing protection: to be used when using loud equipment, like when inside the pumphouse.

Eye protection: to be used when working on electrical equipment, when working with chemicals, and to protect from dust.

Respiratory protection: to be used when working with chemicals like, fertilizers, pest and herbicides
Gloves: to be used to protect th
e hands when working with chemicals such as fertilizer, pesticides and herbicides.

Safety

A hazard is a potential condition that may cause injury, illness, damage or death.
The relevant hazard types include:
Physical hazards, Chemical hazards, Biological hazards, Mechanical hazards,, Psychological hazards, Ergonomic hazard , Electrical hazard

The critical types in the area of SPIS are Electrical, Mechanical, and Physical.
Electrical Hazards: Energized systems can be lethal when handled inappropriately, even if they appear to be unpowered. Always take extreme care and treat electrical systems with extreme caution.

Current	Reaction
Below 1 milliampere	Generally, not perceptible
0.5 milliampere	Faint tingle
1 milliampere	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6–25 milliampere (women)	Painful shock, loss of muscular control
9–30 milliampere (men)	The freezing current or " let-go" range. Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated.
50–150 milliampere	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1,000–4,300 milliampere	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10,000 milliampere	Cardiac arrest, severe burns; death highly likely.

Proper maintenance and safety procedures protect both maintenance personnel and individuals using the irrigation system. A quality electrical design always takes electrical hazards into account from the beginning and implements safe practices to eliminate electrical exposures. Appropriate training of operators and technicians is essential to maintain these safety practices.

Typical Electrical Hazards in SPIS systems

- Damaged or Bare wires
- Wires with worn or degraded insulation which may have no visible damage
- Partially connected electrical equipment
- Any operating equipment either powered ON or OFF
- Conducting material or standing water in contact with electrical equipment
- All electrical equipment is potentially hazardous and should be treated with extreme caution even when power appears to be OFF!

Safety

Some of the ways you can keep workers safe include:

Covering the solar array with an opaque sheet to block the sun's light.
Treating wiring coming from a solar PV system with the same caution as a utility power line. That means assume all wires are live.
Using a meter or circuit test device to ensure circuits are de-energized before working on them.
Locking out power on systems that can be locked out. Tag all circuits you're working on at points where that equipment or circuit can be energized.
Never disconnecting PV module connectors or other associated PV wiring when it's under load.

Personal Protective Equipment for Solar Workers
Personal protective equipment (PPE) is essential during every solar installation. Employers have to assess workplaces for hazards and make sure they provide workers with the necessary PPE for their safety. This can include:

Hard hats, Gloves, Steel-toed shoes with rubber soles, Eye protection, like glasses or goggles, Vests, Harnesses

Make sure employees know how to use the PPE, as well as how to maintain it so it is kept in safe and reliable condition. Workers should know the process to request replacement PPE if it's necessary.
The PPEs should be provided by the System Management and includes:
Hard Hats: to be used when climbing to heights above 2 m and when there is a danger of items falling from a high point.
Hearing protection: to be used when using loud equipment, like when inside the pumphouse.
Eye protection: to be used when working on electrical equipment, when working with chemicals, and to protect from dust.

Respiratory protection: to be used when working with chemicals like, fertilizers, pest and herbicides
Gloves: to be used to protect the hands when working with chemicals such as fertilizer, pesticides and herbicides.
Hazards
A hazard is a potential condition that may cause injury, illness, damage or death.
The relevant hazard types include:
Physical hazards
Chemical hazards
Biological hazards

Safety: Solar PV and Panels

Solar panels are unique in characteristics. It makes it difficult to work safely. Adherence to safety guidelines requires a lot of effort since solar panels are energized anytime the sun is up. Doing maintenance during night hours is not safe or practical.
It is essential to understand the grounding applied to the solar panels in order to safely operate the system. Panel frames that are connected mechanically to metal roofs are always connected to the grounding electrode using the required size of wire. In some schemes, the negative wire to the panels is grounded at some point to the grounding of these conductive surfaces and the positive conductor of the solar panels whether the breakers and/or safety switches are closed or not.

Recommendations on Solar PV

Do not work in bad weather.
Do not sit on the solar module.
Cover the solar modules while working on them.
Do not wear metallic jewelry when working around electrical components.
Work with someone.
Have a good ladder to reach the solar modules for cleaning and repairs

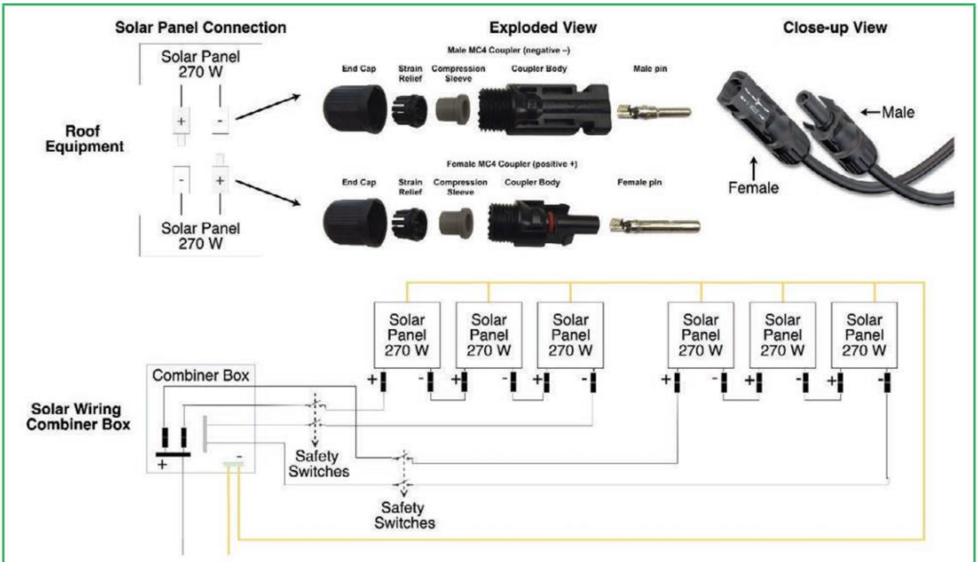


Image adopted from CC BY-SA 3.0, https://en.wikipedia.org/w/index.php?curid=44756814, CC BY-SA 3.0, https://en.wikipedia.org/w/index.php?curid=44756818, and Multi-Contact AG - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=23953040 by McKenna Roberts

Safety: Pumphouse/Pump Enclosure

Pump house/Pump Enclosure
This provides protection for electrical controls and equipment. Water should not be allowed to pool on the floor of the pump house since water is a conductor. Pump Motor and Pump are usually located within the dam. The role of the pump is to transform electrical energy from controller into mechanical and hydraulic energy. For metallic well casing or riser pipe, it is ideal to connect pump motor wiring to the ground.

⚠	Energized systems can be lethal when handled inappropriately even if they appear to be unpowered. Always take extreme care and treat electrical systems with extreme caution!
⚠	Although proper grounding helps remove shock hazards, operators and users of the SPIS should never remove any electrical equipment covers. If removed covers or uninsulated wiring are found, do not touch these components. Immediately contact a certified Technician for support!
⚠	Never service a SPIS during a lightning storm!
⚠	Intrusion of any foreign material into the well may result in sickness or death of system users or severe harm to the system equipment!
⚠	Solar panels have unique characteristics that make them difficult to work on safely. Adhering to safety guidelines is of utmost important since solar panels are energized anytime the sun is up. Doing maintenance during night hours is not safe or practical!
⚠	Never disconnect MC-connectors to break load or fault currents. Do not disconnect MC-4 connectors because they are not designed to interrupt any electrical current!


Helmet


Goggle


Hand Gloves

Multi meter

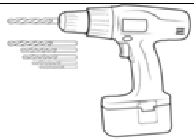
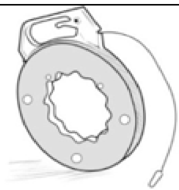
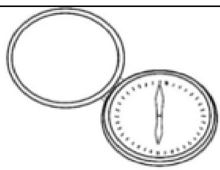

Boots

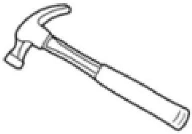
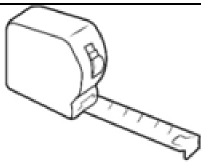
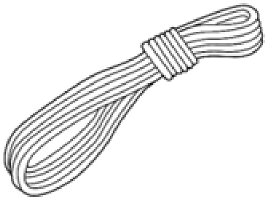
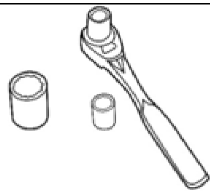
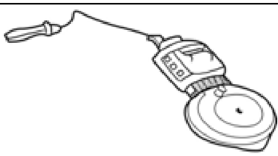
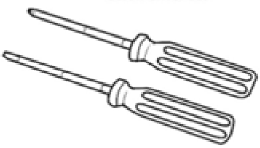
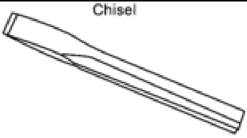

Harness

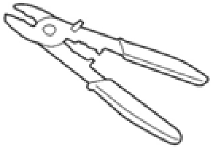
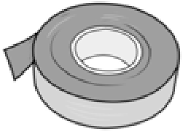
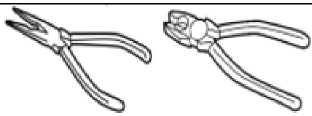
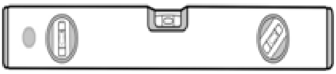
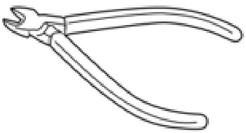
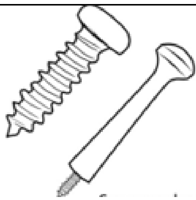
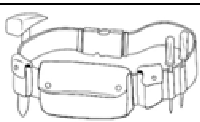
STEP 9: Installation and commission of solar powered irrigation system

This module presents relevant standard procedures of installation tools, safety procedures and installation requirements, protective devices and their installation, and commissioning procedure.

The table shows the required tools and materials for SPIS installation

Tool	Picture	Function	Maintenance and storage
Power drill with appropriate drill bit		Drilling holes in surfaces	Always keep power drill in its casing. The drill bits should also be secured in the tool box or casing
Extension cord		Connecting electrical installation equipment to a power supply. It is important to note that the full length of the cable has to be uncoiled when using it.	Always make sure the cord is folded onto its rim after use. Make sure cable is cleaned from dirt after use
Cable fishing tape		For running cables in conduits	Always make sure the cable fishing tape is folded onto its rim after use
Ladders		For work requiring access to high places/heights	Always make sure foldable ladders are well folded and put in horizontal position after use.
Compass		For determining the east-west, north-south directions for your solar installation relative to the sun movement	Clean compass from dust after use. Store compass in dust free environment

Hammer		For hammering nails into wooden platforms	Store hammer safely on its rack
Tape measure		For measuring distances	Clean from dust after use Make sure the tape is drawn into its casing after use and properly hanged in the storage room
Rope		Protecting workers; functions as a line when working on elevated surfaces (above 2 m)	Clean, fold and hang ropes after use
Ratchet wrench		For screwing in nuts and bolts	Clean ratchet wrench from dust after use. Store wrench in their casing after use
Electricians chalk line		For making straight-line and markings on installation surfaces	Keep it away from reach of children Keep in its box after use. Do not keep it close to liquids
Screw driver set		For fastening screws	Clean it from dust after use Keep them their tool boxes after use
Chisel	Chisel 	For punching holes in the installation surface, used together with a hammer	Keep it away from the reach of children Always keep it in a tool box after use

Crimping tool		For terminating cable lugs	Keep it in a tool box after use
Electricians tape		For insulating cables with broken insulation and terminating ends of electrical cables	Always keep it away from liquids
Different types of pliers		For cutting cables	Clean from dust after use Keep in tool box after use
Spirit level		Determining whether a surface is straight or slanted	Clean from dust after use Keep in its casing after use
Wire cutter		For cutting long wires	Clean from dust after use Keep in tool box after use
Screws and pegs		For fastening conduits and equipment to mounting surfaces	Do not leave remaining screws and pegs haphazardly on floors after work
Tool belt		Carrying basic installation tools. To be worn around the waist	Hang it after use

Personal protective clothing for installing SPIS

Personal Protective Equipment (PPE) is an essential part of every solar installation. It is the employer's job to assess the workplace for hazards and provide the PPE deemed necessary for the employee's safety. Some examples of PPEs for solar system installation are listed in the table below

Type of PPE	**Picture**	**Function**
Hard hats (**safety** helmets)		For protecting the head from falling objects
Gloves		For protecting the palm from sharp cutting edges and hot objects
Steel-toed shoes with rubber soles (safety boots)		For protecting the feet from falling objects. Heavy tools falling from the hand can hurt the feet if the installer is not wearing safety boots
Reflecting jackets		It helps to increase visibility of workers for easy identification especially during the nighttime.

Handling PV Modules

Solar photovoltaic modules are manufactured to withstand difficult weather conditions. Their aluminum frames and tempered glass covering further provide strength. However, they could be damaged if they are not handled properly during transportation and installation. Besides the health and safety measures listed above when installing a solar PV array, the following general precautions should be taken to prevent physical damage to solar PV modules.

- Transport the modules in their original packaging to prevent damage. Inappropriate handling may break the module.
- Hard objects can strike the back of a module and cause permanent damage.
- When one cell is broken, the whole solar PV module is unusable or permanently compromised and its use is limited to a low value and lower power application.
- Store PV modules in a cool dry place.
- Protect the PV modules against scratches and similar damage.
- Do not rest a PV module unprotected on its edges, as this can damage its frame.
- Ensure the solar PV modules do not bow under their own weight.
- Never move or lift the PV modules using the cables at the junction box
- Do not lay the solar PV module face down on any surface
- Do not subject the face of the PV module to mechanical stress
- Do not stand or walk on the PV modules
- Do not drop or place objects on the PV module
- Do not expose the solar photovoltaic module to chemicals
- Do not immerse the solar photovoltaic module in liquids
- Do not install modules when it is raining
- Do not cut or modify parts of rails of the solar photovoltaic module. If you must drill holes in the frame, drill from the base or from the side and avoid damaging the solar cells.
- Completely cover solar photovoltaic module with opaque materials when installing and wiring to halt production of electricity.
- Do not use chemicals on solar photovoltaic module when cleaning
- Do not wear metallic jewelry, which may cause electrical shock when working on solar systems and their accessories
- Do not touch cable electrical contacts
- Install PV modules based on the design specifications

Health and safety measures when installing SPIS

Health and safety are regulations and procedures intended to prevent accident or injury to workers at the workplace. Safety precautions for preventing physical damage to tools, equipment and materials are also very important at the workplace. Some health and safety measures that should be observed by the installer when installing solar PV modules are listed below.

- Avoid working alone when installing PV systems. Always have a co-worker around you.
- Select the right tools before going to the site
- Put on appropriate PPE before starting any installation works
- Select the ladder that best suits the need for access. Adjustable ladder are very helpful.
- Place the ladder on dry, level ground removed from walkways and doorways, and at least 10 feet from power lines and secure it to the ground or rooftop.
- Keep all work areas dry and clear of obstructions.
- For rooftop solar PV mounting, check and certify roof integrity before climbing it.
- Lift each solar panel with at least two people while applying safe lifting techniques.
- Transport solar panels onto and around the work site using mobile carts or appropriate trucks. Do not carry solar panels on your head from the shop to installation site
- To get bulk solar panels onto rooftops, use properly inspected cranes, hoists or ladder-based winch systems. For lifting single solar panel, one worker on the ground can lift to the co-worker on the rooftop provided the height is appropriate. Never climb ladders while carrying solar panels.
- Once unpackaged, cover panels with an opaque sheet to prevent heat buildup.
- Always wear gloves when handling panels.
- Cover the solar array with an opaque sheet to "turn off" the sun's light. This will prevent electricity generation within the panel and any possible electrical shocks whilst installing the panel during the daytime.
- Never disconnect PV module connectors or other associated PV wiring when it is under load.

Pump Installation

It is important to note that different pumps may have unique installation procedures as required by the manufacturer and specified by the pump manual. However, some general procedures for pump installation include:

- **Take the pump unit out of the case and check if all ordered accessories are included.**
- **Examine unit, motor leads and pump cable for possible damage.**
- **Check the pump insulation resistance to earth**

Commissioning and performance verification of SPIS

Once installation is completed, before your client takes ownership of the system, it is important that the system is commissioned. Commissioning is the process of assuring that all the components of the photovoltaic system have been installed and tested and are fully operational according to the requirements of the standards

Commissioning requirements and activities

Commissioning of a solar photovoltaic system comprises the following activities:

Visual inspection

Visual inspection activities must be completed before and after the system is energized. This visual check ensures that:

- Number of PV modules connected in series and in parallel is correct
- All modules are properly wired
- PV array mount is properly fastened
- All cable conduits are properly installed
- All cables are properly terminated and appropriately labelled

Electrical inspection

DC SIDE

On the DC side of the installation, you must verify the following:

- Polarity of all cables (positive and negative)
- Open-circuit voltage of each array string
- Short-circuit current on each array string
- Voltage and readings at the critical connection points (junction boxes, disconnects and at the inverter) in the system
- Correct operating voltages and system current as specified for system design
- Wire insulation and resistance
- Effectiveness of grounding connections

AC SIDE

Once you have verified that the DC side meets all requirements, you need to inspect the AC side. This is done by measuring AC voltages along the circuit. Start at the inverter as this is the origin of the AC circuit in your PV system (ensure that the AC disconnect and MDB breaker are in the "OFF" position). If this voltage measurement is as expected, then:

- Switch "ON" the AC disconnect and measure the output voltage and current from the system .
- Switch "ON" the main breaker on the MDB and measure the output voltage and current from there.

Documentation

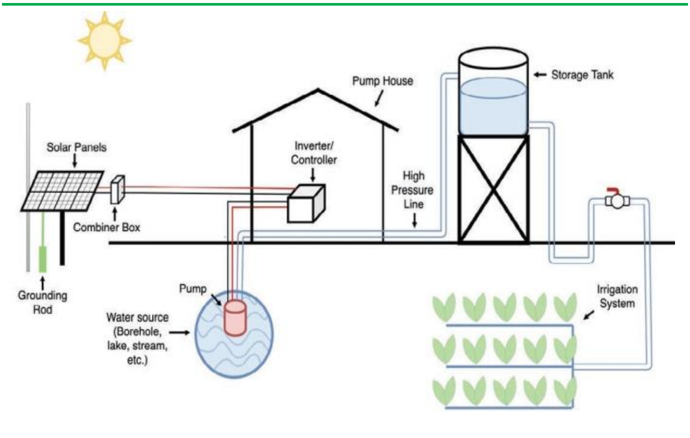
You must document the procedure for installation, commissioning and maintenance for the system owner. This can easily be done by creating a manual with all relevant information. Make sure that all documentation is simple, clearly presented and easy to understand. The manual must include the following information:

- **Date of commissioning**
- **Contact numbers in the event of system failure**
- **Emergency contact numbers**

Basic maintenance schedule for the system owner

STEP 10: Operation & maintenance

Figure 1 shows the major system components that technicians need to look at during system technical operation and maintenance.
These components include the solar array and wiring, controller/inverter, well/pump, conveyance system, storage tank, head and irrigation system.
The operation, maintenance, common problems, diagnosis techniques and repair options of each of the components are explicitly explained below.



Task for technicians

- Technician support will be required by the operator when a failure occurs and the operator is unable to repair it.

- Additional works include:
  - checking potential electrical faults within the SPIS
  - modifying/repairing of the high-pressure line from the well to the storage tank
  - cleaning/repairing storage tank mechanical damage
  - when the pump/motor must be repaired/replaced.

Troubleshooting and Repairs

- Always follow the manufacturer's recommended shutdown and operating procedure.

Key Component Preventive Care Measures Activity Sheet			
Frequency	Preventative Care and Maintenance	Activity	Remarks
As required / Annually	Test SOLAR module output at array to ensure each panel/string is functioning properly	Perform a SOLAR Array test.	If any anomalies are found it may be necessary to replace a module or check wiring. Refer to trouble-shooting
	Check function of the tank flow switch	Repair immediately in case of non-function	Failure can damage pump and well
	Check pump power consumption	Compare to previous month, report increase	Power consumption per m^3 pumped
	Check switch board and installations for corrosion	If corroded ask Technician for rehabilitation	Ensure good aeration in pump house
	Check Valves and Aeration	Cycle valves to ensure functionality clean aeration screens	If valves are found to be tight, they may need to be lubricated. If they are found to be stuck, they may need to be replaced
	Monitor ground water (in the case of a borehole)	If level of ground water has changed a new well capacity test may be required	Recheck design and present demand to assure the well is still adequate for the user demand level

Routine Checks

- Solar panel for condition, dust, exposure to sunlight
- Mainline, sub-main and lateral lines for leaks
- Condition of valves for leakage
- Sprinkler system components
- Drip emitters
- Condition of the spray tube
- Cleaning of filters

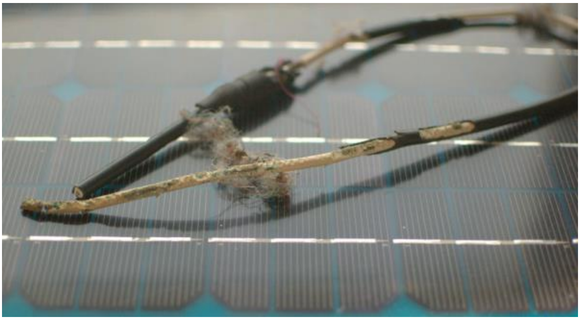
Groundwater Monitoring

- Ground Water Monitoring ensures that the well is not being overutilized.
- Some wells have remote digital monitoring which does not require manual inspection.
- Groundwater monitoring should be done regularly to ensure the health of the well.

Operation & maintenance: panels

- **Clean panels with soft tissues or materials with water only.**

- **Notify technician if you observe panel disconnection or damage.**

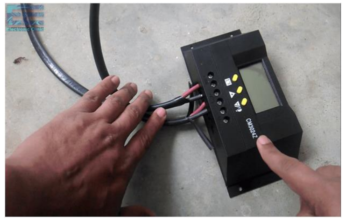


- **Notify the technician when you observed hotspots on the solar panels.**

- **Remove or Trim trees that cast shades on panels.**

Operation & maintenance: panels

Controller



- Inspect controller for loose connections, heat-damaged wires, rodent infestation, burnt area from arcing, and resolve issues found.
  - Switch off the controller, when you identify a fault
- Contact technician if the controller does not start.

Pumps

- Check the pump control switch if the pump is not working.
- Prime the pump if it does not discharge water while operating.
- Do not run pump when the water level is below the pump.
- Contact technician when fuse is burnt.
- All leakages between the pump, pipe lines and tank are rectified.
- In case the pump start and shut frequently notify technician.

Storage Tanks

- Clean tanks regularly if sediments accumulate in them.
- Repair leakages in tanks to avoid loss of water
- Valves should be checked and replaced if they are damaged.
- The tank stand should be replaced or repaired if it is faulty to avoid collapsing
- Replace tank flowing switch when if faulty to avoid overflow of water.

Others

- Leakages on mains and sub mains should be repaired
- Broken pipes should be repaired
- Drip lines should be flushed regularly to avoid blockages of emitters.
- Filters should be washed regularly to avoid malfunction.
- Valves should be checked for condition regularly.
- Replace valves that are stuck shut or leaking.

Sustainability of SPIS

At the end of this module the learner will be able to;

- ❑ Define the concept of sustainability in relation to SPIS
- ❑ Identify the key determinants of sustainability of SPIS and discuss its impact on each of the dimension of sustainability
- ❑ Discuss the potential measures to overcome the challenges which pose a hindrance to SPIS sustainability

Determinants of Environmental Sustainability

- ❑ Water supply sources for SPIS
- ○ Surface Water: River, Pond/Dam
- ○ Groundwater: Tube/borehole, Hand-dug Well
- ○ Harvested Rainwater
- ○ Run-off
- ❑ Water use efficiency (recycling and reuse)
- ❑ Abatement of carbon emissions
- ○ Pollutant levels in the environment
- ○ Climate change effect
- ○ Greenhouse gasses
- ❑ End of the life disposal
- ○ Effective disposal method: Recycling, Reuse, Landfills and Incineration

Factors that influence sustainable water supply for SPIS

- ❑ Environmental and climatic factors
  - ○ Drought
  - ○ Low rainfall
- ❑ Groundwater
  - ○ Water quantity
  - ○ Water table level
  - ○ Hydro-fracture operation
  - ○ Water quality
- ❑ Energy supply situation

Reliable supply of energy for SPIS

- Clean energy (Solar energy with storage)
  - Solar irradiation
  - Metrological data
  - Air mass and indirect radiation
  - Wind movement
  - Dust
- Hybrid energy infrastructure

Determinants of Social Sustainability

- **Awareness**
- **Quality of the system**
- **Repair and maintenance services**
- **Co-benefits**
- **Government policies and incentives**
- **Threats to safety and security**

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 mm/day = 10 m^3/day/Ha = 10 liters/day/m^2

Appendix 2: Form to fill with the information you collected

Step 2: 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): .... m³/h

Step 3: Water need for irrigation

Plot number	A Water needed (mm/ day) (Kc x ETo)	B Water needed (m/ day) (A/1000)	C Length (in m)	D Width (in m)	E Multiply the length & width to obtain the surface area (in m²) (C X D)	F Total water need for the whole farm (m³/day) (B X E)
Plot 1						
Plot 2						
Plot 3						
Plot 4						
Plot 5						
Plot 6						
Plot 7						
Plot 8						
Plot 9						
Plot 10						
Total						

S2.1 Total daily water need for irrigation
= daily water need: .... m³/day =

S2.2 Size of the land to be irrigated: .... m²

In-between check 1

C1 Required pump discharge .... m³/h
(Calculate it by dividing what you obtain at point 2.1 by 6)

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 and start again at Step 2.

Step 4: Water conveyance and application system

S3.1 Which application system did you choose?

- ❑ Drip irrigation (from a kit) (90%)
- ❑ Spray tube / misters (75%)
- ❑ Sprinkler (70%)
- ❑ Hose or pipe (75%)
- ❑ Furrow (50%)
- ❑ 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)....................................m³/h
(Divide the water need you calculated at C1 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 5: 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.

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: Headloss in meter per meter of pipe

Headloss in meter per meter of pipe				
Flow (m³/h)	**Internal Diameter PVC pipe (in mm)**			
	0,75 inch (20 mm ID)	1 inch (25 mm ID)	1,10 inch (28 mm ID)	1,25 inch (32 mm ID)
0.5	0.014	0.005	0.003	0.001
1.0	0.049	0.016	0.010	0.005
1.5	0.103	0.035	0.020	0.011
2.0	0.176	0.059	0.034	0.018
2.5	0.266	0.090	0.052	0.027
3.0	0.373	0.126	0.073	0.038
3.5	0.496	0.167	0.096	0.050
4.0	0.635	0.214	0.124	0.064
4.5	0.789	0.267	0.154	0.080
5.0	0.959	0.324	0.187	0.097
5.5	1.144	0.386	0.223	0.116
6.0	1.344	0.454	0.262	0.137
6.5	1.559	0.526	0.303	0.158
7.0	1.788	0.604	0.348	0.182
7.5	2.031	0.686	0.395	0.206
8.0	2.289	0.773	0.445	0.233
8.5	2.560	0.865	0.498	0.260
9.0	2.846	0.961	0.554	0.289
9.5	3.145	1.062	0.612	0.320
10.0	3.459	1.168	0.673	0.351
10.5	3.785	1.278	0.736	0.385
11.0	4.125	1.393	0.803	0.419
11.5	4.479	1.512	0.871	0.455
12.0	4.846	1.636	0.943	0.492
12.5	5.226	1.765	1.017	0.531
13.0	5.619	1.897	1.093	0.571
13.5	6.026	2.035	1.172	0.612
14.0	6.445	2.176	1.254	0.655
14.5	6.877	2.322	1.338	0.699
15.0	7.323	2.473	1.425	0.744

Appendix 5: Solar panel size

Multiply you water need per day with the head of your system and refer it on the table below.
Here we assume that the yield of the solar panels is 60%, meaning that the solar panels are well maintained and cleaned regularly. We assume that the yield of the pumping unit (pump + motor) is 60%.
And, just like in the rest of this booklet, we assume 6h of peak sunshine hours.

Water need (m^3/day) x head (m)	Power needed from the solar panels (Wp)
0	0
250	315
500	631
750	946
1000	1262
1250	1577
1500	1892
1750	2208
2000	2523
2250	2839