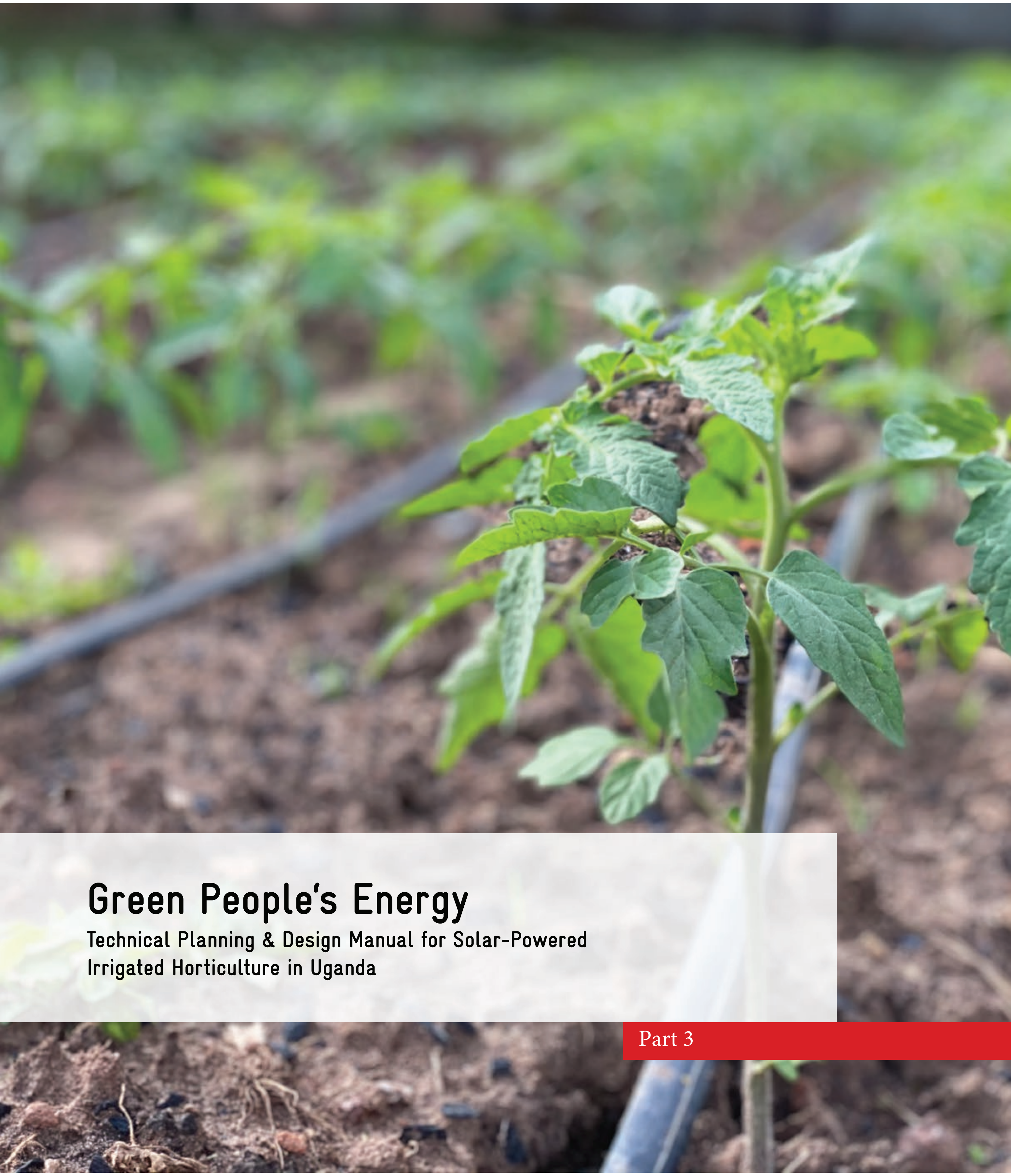

Green People's Energy

Technical Planning & Design Manual for Solar-Powered Irrigated Horticulture in Uganda

Part 3

german cooperation
DEUTSCHE ZUSAMMENARBEIT

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3.3. Detailed System Design

The guidance in this section is not intended to replace the experienced judgment of an electrical and irrigation system engineer. It is intended to assist planners, administrators, and other stakeholders in understanding the critical components of an SPIS and how they work together. This discussion gives sufficient direction so that a preliminary layout for an irrigation system can be prepared and accurate bills of materials and cost estimates developed. This preliminary design and the preparation of the final installation designs should be reviewed by an experienced professional.

❖ Rules of Thumb

Rules of thumb are often valuable in initial assessments or quick evaluations of systems or components. Critical design components such as size of the power source, storage tank, pump, and other items that effect the detailed design should always be measured and calculated as precisely as possible, to complete final design.

❖ Codes

The guidance in this section is not intended to supersede national codes (IEC) and regulations on the design and installation of energy supply and water systems. The designer should be familiar with these codes and follow their directions. Where the suggestions in this section differ from the national guidelines, the requirements of the national code shall govern. This includes energy system, water storage capacity, and water quality testing management.

3.3.1. System Layout

The illustration below shows the basic components of a typical solar-powered gravity flow irrigation water supply system. The system uses power provided by a submersible pump to draw water up from below ground, and to deliver that water to an elevated storage tank sized to meet water use demand. From the tank, gravity powers the flow of water through pipes to the field emitters, where minimum pressure and flow requirements exist.

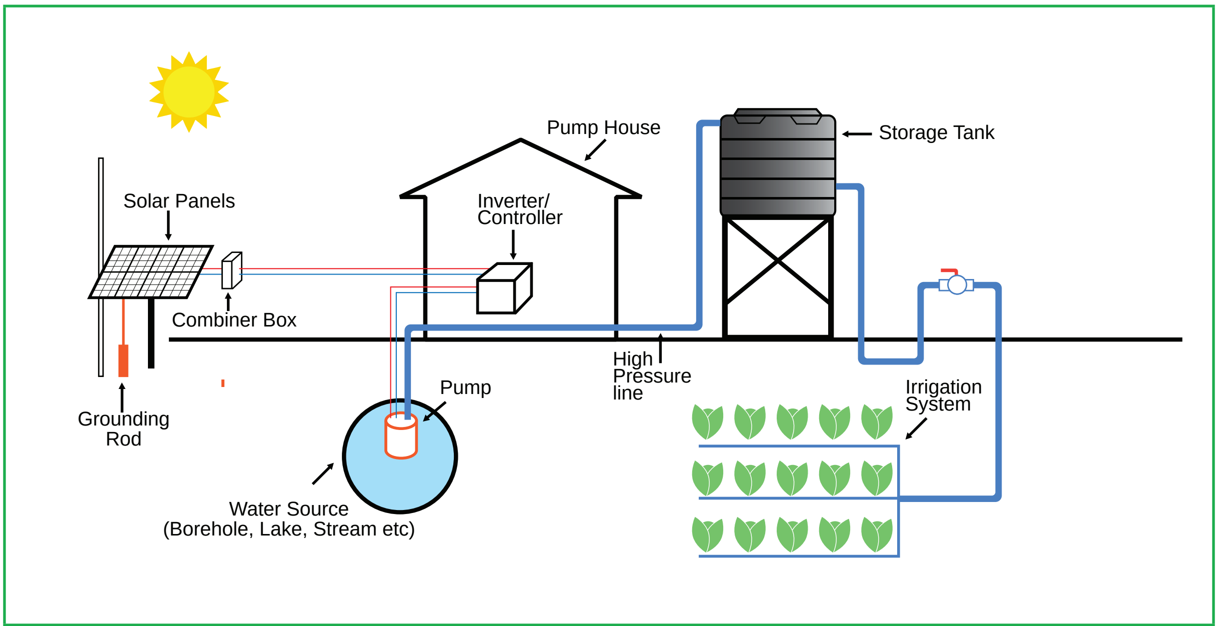


Figure 17: Typical SPIS

❖ Design Process

The following is a step-by-step process for designing the major system components of a solar powered irrigation system:

i. Water Supply Capacity and Water demand
ii. Water Quality
iii. Irrigation System Layout and Storage Height and Sizing
iv. Pump flowrate and Total Dynamic Head
v. Pump Selection
vi. Solar Panel Selection and Solar Array Layout
vii. Final Design package
viii. Bill of Materials

❖ Design Example

As we follow the design process in the detailed sections below, we will be giving example design parameters and some example calculations in boxed text. This is to act as a tool to demonstrate the process being explained in each of the sections.

Table 24: Design Example

Zoe's Solar Powered Irrigation System, Uganda	
Location	Lira, Uganda
Crop Type	Tomatoes
Soil Type	Silty Loam
Area	2000m^2

3.3.2. Water Source Capacity and Water Demand

This data should have been collected during the Technical Survey outlined earlier.

Water Source Capacity= hourly flowrate x solar pumping hours = total daily supply

The solar pumping hours are different for different places. In this manual we shall consider an average of 6 hours. Specific average pumping hours for any Location can be determined through GIS irradiance mapping using any of the links below.

1 Solargis solar resource maps https://solargis.com/maps-and-gis-data/download/

2 POWER Data Access Viewer https://power.larc.nasa.gov/data-access-viewer/

1 European Commission's Photovoltaic Geographical Information System: https://ec.europa.eu/jrc/en/pvgis

We will be designing for total daily supply available.

Zoe's Solar Powered Irrigation System, Uganda	
Water Demand	10,000 L/day
Water Source	Spring Box
Water Capacity	12000L/day

Borehole Information:

Parameter	Example value	Equation/Source
Well Depth	60.0 m	Measured
Static water level (Below grade)	32.3 m	Measured
Dynamic water level	35.0 m	Determined by drawdown test
Drawdown	2.7 m	Dynamic water level less static water level
Maximum Pumping rate	2 m^3/hr	Determined by drawdown test
Total daily well Capacity (SOLAR ONLY)	12 m^3	

3.3.3. System Layout

Conversion of Field Sketch to a Digital System Layout

The field sketch should be converted to a digital format to complete the pressure and flow calculations necessary to determine needed piping sizes and the height of the storage tank to provide the necessary pressure through gravity flow to reach the end of the distribution line.

Software such as EPANET provides a reliable model for the piping network and can be used to double check pipe size and pressure in the design. Detailed instruction on the use of this software is not included in this manual, but is widely available.

Input the values identified into on the field sketch into EPANET, estimate the pipe sizes and flowrate required at the end of the irrigation lines and estimate the height of the tank. EPANET will run these parameters and verify the system as planned or identify errors. EPANET can be freely downloaded from https://www.epa.gov/water-research/epanet.

EPANET example

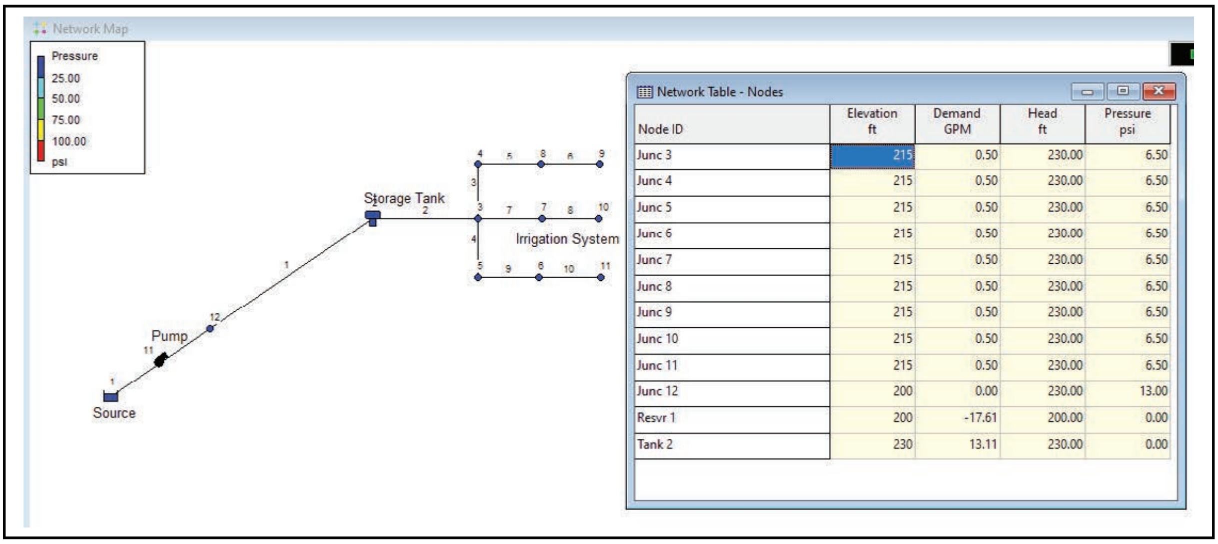


Figure 18: EPANET Example

As a general rule, the distance for a gravity-fed system should not exceed one kilometre (1km) as this extends the height, cost and complication of the storage system. Therefore, the storage tank should be located as close as possible to the irrigation field.

3.3.4. Water Storage

An elevated water storage is required to maintain a pressurized water system. Storage is usually provided by a storage tank located above the irrigated area.

Storage tanks are constructed of various materials. Some of the more common tank materials in Uganda are plastic, welded steel, and reinforced concrete (ferrocement).

❖ Water Storage Sizing

It is recommended to provide a minimum water storage volume equal to the maximum daily demand.

Zoe's Solar Powered Irrigation System, Uganda	
Water Demand	10,000L/day
Water Supply	Spring Box
Water Capacity	12000L/day
Distance from Water Source to Elevated Tank	600m
Elevation change between Water Source to Elevated Tank	25m
Water Tank Height	5m
Water Tank Size	10,000L

❖ Water Storage Tank Height

Determining the height of that system's storage tank is critical to the pump selection as the pump will need a motor strong enough to pump the water up to that elevated location. The tank height facilitates the operation of the irrigation system under gravity flow. The storage tank elevation must provide operating pressure of the emitters and overcome the frictional losses within the pipe. Therefore, the length of the lateral pipes should be limited to the recommended length of flow. The operating pressure and length of flow (for drip lines) is always provided by the manufactures. For example, if the operating pressure of the drip lines is 0.5 – 2 bars as recommended by the manufacturer, based on emitter operating pressure the tank height should be between 5 to 20 m since 1 bar is approximately 10 meters of water. It is often recommended that the operating pressure should not be very low or very high for good emission uniformity. The tank height is best evaluated through EPANET – as previously outlined. Additionally, using the SPIS toolbox, the tank height can be evaluated against the irrigation system pressure requirements. If the pressure required for the irrigation outlet can't be reached by the height of the tank, an additional booster pump on the irrigation site of the system is required.

Rule of the Thumb: For drip tape, the storage tank should be at least 3 m high and the drip line horizontal length should not exceed 50 m. For drip line lengths not exceeding 25m, the tank can be 2 m high.

❖ Water Storage Tank Stand construction

Design in Uganda must consider seismic factors. The tank stand must be designed to withstand the compressive load of the stored water taking into account the dimensions of the tank. Other factors such as wind and fatigue loads must be taken into account. It is recommended that standardized tank stand designs be used and designed by qualified structural engineer. Sizes such as 3-, 5-, 10- and possibly 15-meter stands could be standardized to hold the largest common tank sizes for the area. Tank stands maybe steel, concrete or brick and mortar.

Figure 19: Steel tank stand

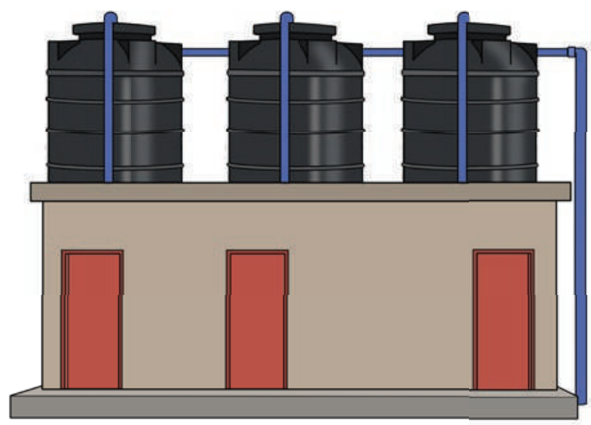


Figure 20:Tank stand that incorporates storage rooms

❖ Storage Tank Level Controls

When supplying a gravity irrigation system, water storage tanks are typically elevated by a steel tower or a reinforced concrete tank pad. Inlet pipes should enter the tank above the maximum water surface level to prevent tank level from affecting pump operation. Outlet pipes exit the tank near the tank bottom. Tanks should be provided with isolation valves on outlet pipes. A separate screened overflow pipe directed to drainage should be provided in case level control mechanisms fail or are not provided. Level controls tell the pump when the tank is full to avoid overflow. Level control is usually accomplished by two reliable methods:

- Electric: A single float switch installed within the tank. When the tank fills to a certain level, a contact is open or closed and a signal is sent to the pump controller to stop the pump. When the tank level falls, another signal is sent to the pump controller to start the pump again.
- Manual: The operator monitors the tank throughout the day. When the tank begins to overflow, he manually turns the pump off at the pump controller.

Pump Flowrate and Total Dynamic Head

The system's pump flowrate is a critical element in the overall system design. For a solar pumping system, the pump flowrate must provide the maximum daily demand in the 6 hours of expected irradiation, while remaining below the safe abstraction rate of the water source. Design guidance for maximum daily demand and abstraction rate of the source are explained in sections 3.2.2 and 3.2.1.1 respectively, whereas detailed pump-specific considerations are identified in this section.

3.3.5. Pump Transmission Line

The transmission line is the piping that runs from the pump to the top of the tank. This line and its fittings affect the pump sizing as they contribute to friction losses which determine the total dynamic head and therefore are preliminarily identified before pump selection. However, the transmission line sizing is determined by the pump outlet, so it may be necessary to recalculate the friction loss should the transmission line size change with the pump selection.

❖ Sizing

The pump transmission line is generally determined by the pump outlet size. A common size for this fitting is 1-1/4 inches or 40mm. The entire length of the pressure line, from the pump to the tank, should be this size or larger to reduce frictional head loss. The pressure line should be HDPE or SOLARC material with a rated operating pressure that exceeds the maximum operating pressure of the pump multiplied by 1.25.

Pressure ratings are determined by the type of pipe selected and are generally specified when selecting the type of pipe for the site as shown in the MWE Water Supply Design Manual.

Note that positive displacement pumps can produce extremely high pressures when pumping into a closed system – systems with positive displacement pumps should be equipped with a pressure relief valve or another means of preventing the pump from generating excessive pressures.

❖ Fittings

A pressure gauge tee and pressure gauge should be installed at the point where the pipe exits the well. The tee and gauge should be protected by being inside the wellhead enclosure.

a) <u>Washout</u>

A washout should be provided at the pump house to divert water from the pump away from the tank allowing the pump to run full speed without sending flow to the tank. This is most important for bigger systems running $5m^3$/hr or more. This section of piping should route flow to a location away from structures and should be equipped with a removable cap or bird screen. This discharge may also be used to sample water from the source. An example detail of a washout assembly is provided below.

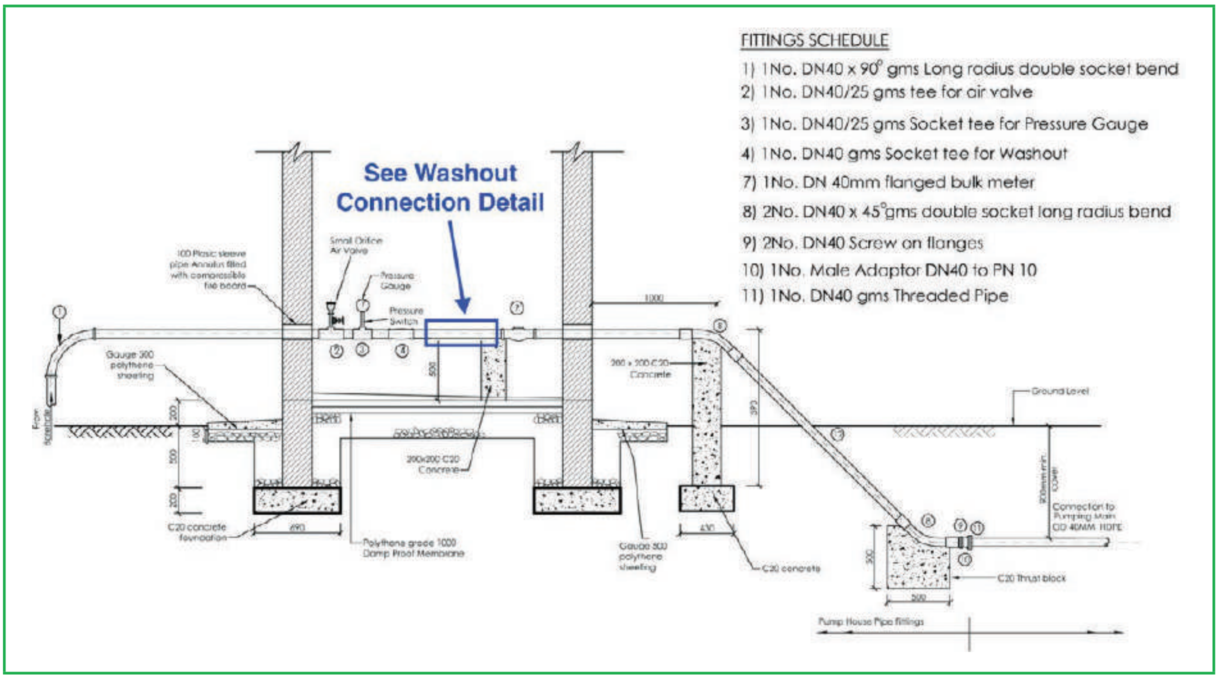


Figure 21: Example Pumphouse Section[19]

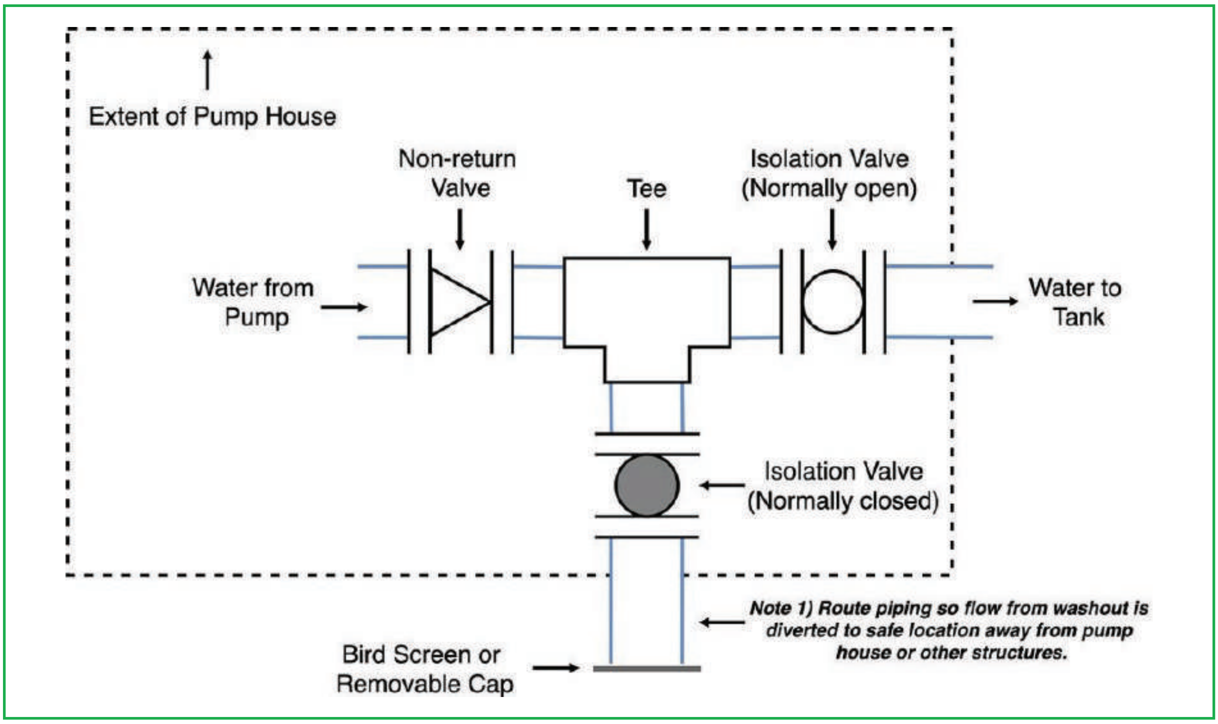


Figure 22: Washout Connection Detail[19]

b) Discharge Non-Return Valve

The purpose of a non-return valve, or check valve, is to prevent reverse flow from pressurized portions of the system during maintenance or regular operation. Submersible pumps are often equipped with a non-return valve as part of the pump assembly, this should be considered when designing system valving. It is often advantageous to install a non-return valve on the pressure line even if the pump assembly includes a non-return valve. The second non-return valve may be installed on the pressure line downstream of the wellhead, upstream of any other system valving. All valving should be covered or protected within the pump house when possible.

19 Source: Engineers Without Borders – USA

c) Discharge Isolation Valve

An isolation valve should be installed at grade on the pressure line, downstream of the wellhead and the discharge non-return valve (if installed). The isolation valve is installed on the system to allow positive shutoff of the pressure line for pump or piping maintenance. In the event of system failure, the isolation valve installed downstream the non-return valve will also allow for service or replacement of the non-return valve without needing to drain the storage tank. The discharge isolation valve should be a butterfly valve, gate valve, or ball valve, depending on the availability of quality materials, available space, and size of the piping.

d) Pressure Relief Valve

A pressure relief valve is recommended for pump discharge piping. Correct installation and setting of the relief valve will prevent failure of system components due to over-pressurisation. The relief valve should be connected to a tee fitting in the discharge line downstream of the discharge valving. A small diameter discharge line should be connected to the relief valve discharge and routed to a drainage location away from the wellhead and protective structure. The pressure relief setting of the valve should be equal to the pressure head rating of the system component most likely to fail due to overpressure. The system component most likely to fail is often at a low elevation, but a combination of absolute pressure rating and elevation must be considered. To evaluate components, use the worst-case pressure condition: pump shutoff head for components upstream of the storage tank, and tank overflow water elevation for components downstream of the storage tank. Worst-case pressure at a given component will equal maximum pressure above datum less component elevation. Static conditions (no flow) will produce maximum pressures so frictional losses may be neglected. A hydraulic grade line diagram will help the process of evaluating system pressures, but a complete EPANET model is easiest.

3.3.6. Total Dynamic Head (TDH) for the pump

It is critical to calculate the total dynamic head of a system design in order to correctly size the pump. The TDH for a pump is the sum of the static head, well drawdown, pressure head, fitting loss and friction loss, each defined, below:

a) Static Head (m): In a borehole application, the static head is the vertical distance between the well's static water surface elevation (this information can be attained from well drawdown tests) to the delivery point elevation at the storage tank.

b) Well Drawdown (m): In a borehole application, this is the vertical distance from the well's static water surface elevation to the dynamic (pumping) water elevation. i.e., the vertical cone of depression of the groundwater when the pump is running at the design condition.

c) Friction head loss (m): The loss of pressure due to the friction caused by the flow of water in a pipe between the pump and the storage tank. Friction loss is affected by the following factors: the inside diameter of the conveyance pipe, the flowrate within that pipe, the length of the pipe, and the pipe roughness (depends on the pipe material). It is determined by consulting standard online friction loss charts or may be calculated with the appropriate method (Darcy-Weisbach, Hazen-Williams, or Manning's). Friction loss is normally expressed in meters of head loss per length of pipe. Note that frictional loss will also occur in the pipe from the pump up to the well head, so it is best to sum vertical head first then calculate and tally frictional losses from each pipe segment separately.

d) Fitting loss (m): Loss of pressure to fittings installed in the pipeline, elbows, valves, screens, entrances, exits, etc. These losses typically run 5-10% of pipe frictional losses. It is normally expressed as equivalent length of pipe from standard charts depending on fitting type and size.

Calculating TDH

Accurate calculation of TDH at design flow is critical for pump selection. To determine the TDH, use the following equation:

TDH = Static Head + Drawdown + Friction Loss + Fitting Loss

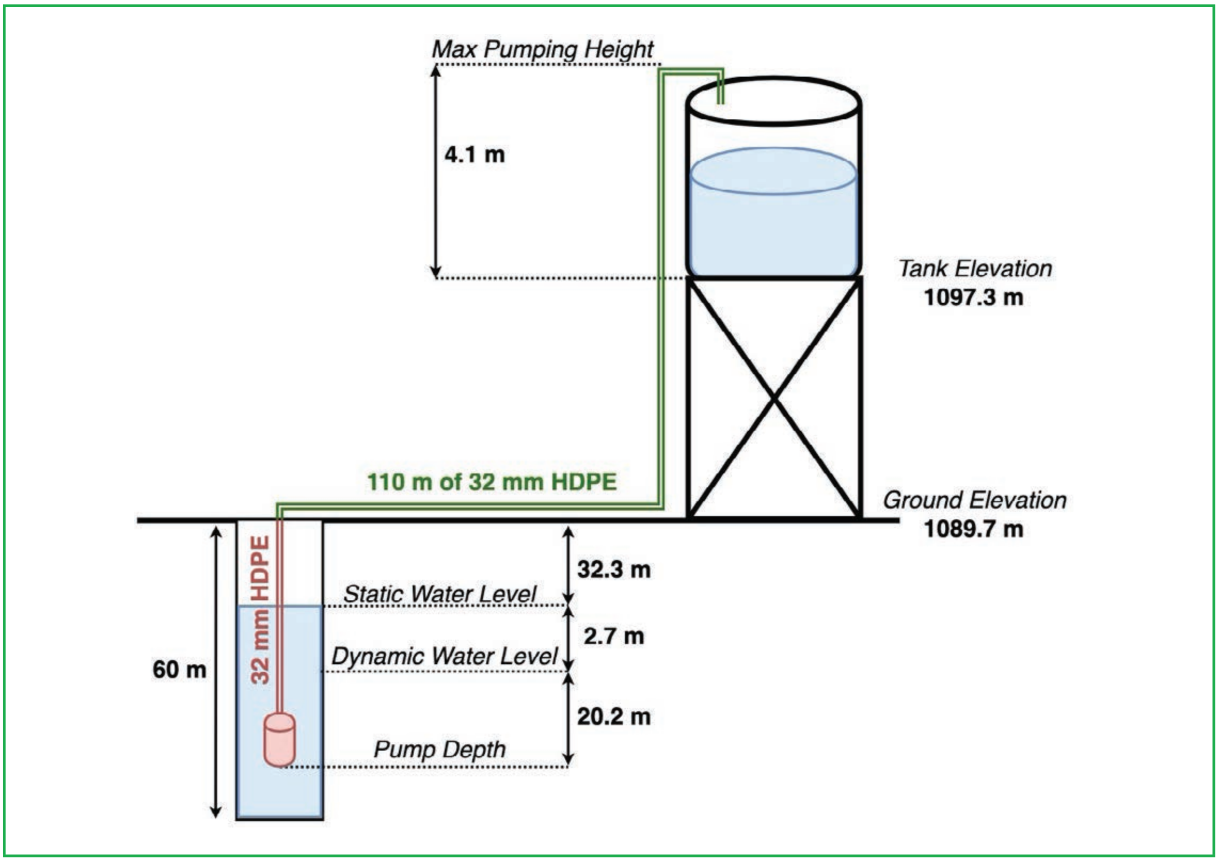


Figure 23: TDH determination Example

The static head is the actual vertical distance the water is lifted. It is vertical distance between the dynamic water level within the well and the delivery point elevation at the storage tank.

The friction loss between the pump and the storage tank must be calculated. First, you must know the flowrate of the water moving through the pipe, the inner diameter of the pipe, and pipe material. The actual flowrate will be determined after pump selection; however, an initial calculation is necessary for determining TDH using the design flowrate. The simplest way to find this design flowrate is as follows:

Design Flowrate = daily demand/solar pumping hours

Generally, a safe 'Rule of Thumb' for the minor losses in a properly designed system would be in the 5-10% of the pipe frictional losses. The total friction loss is the sum of the flow loss within pipes (found in the friction loss charts) and through the fittings (minor losses, 5-10% of pipe friction losses). For detailed design and pump selection these losses shall be calculated for each section of piping based on pipe inner diameter, flowrate, and pipe material.

Total Friction Loss = Pipe Friction Loss + Fittings Minor Losses

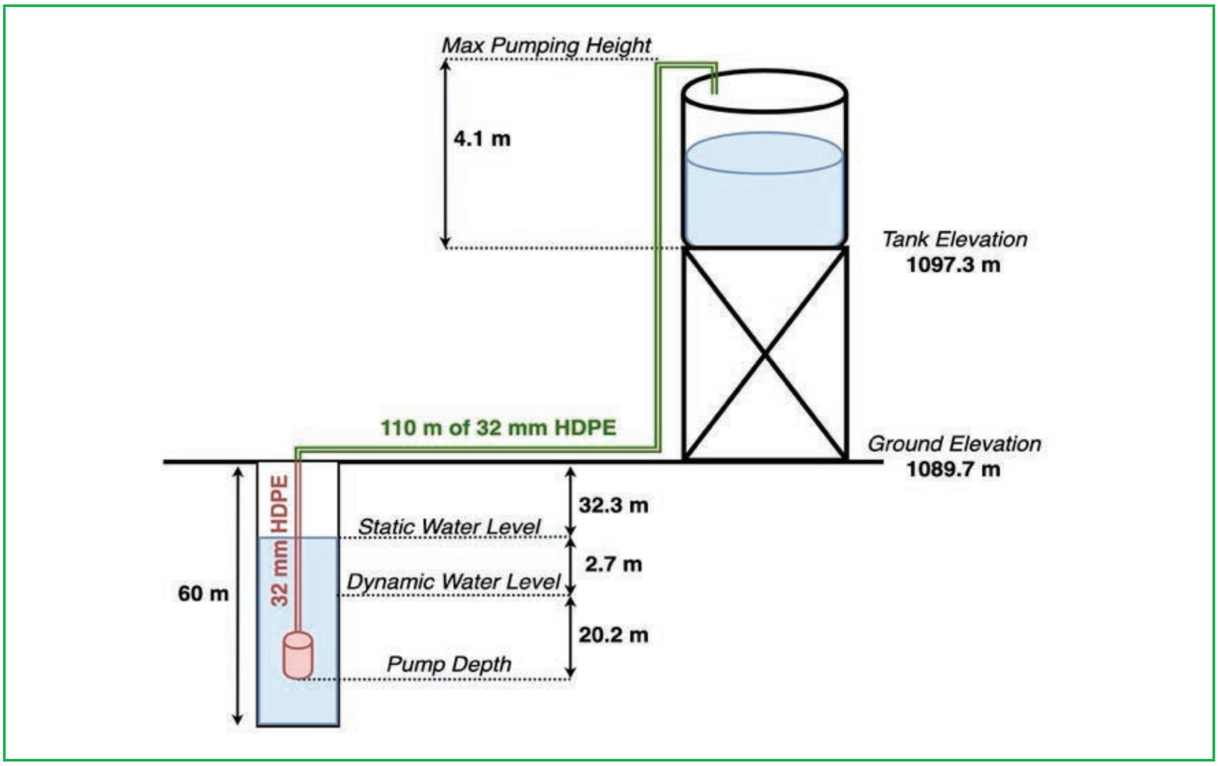
Pipe friction loss is calculated using a friction loss table. Friction loss tables for commonly used piping can be found in the Uganda Water Supply Design Manual Second Addition Appendix 6c.

Fitting losses shall be calculated individually and summed using the equivalent length method. Alternately, the Darcy-Weisbach or Hazen Williams methods may be used but add complexity. Equivalent length tables for commonly used distribution system components are widely available online. Be sure to reference tables are specific to the pipe diameter and type that are used in your system.

Fitting Minor Loss = Equivalent Length * Pressure drop (from a reference table)

Design Example: Atuni Solar Powered Water Supply System, Uganda

Zoe's Solar Powered Irrigation System, Uganda



Static Head = Distance from static water level to maximum pumping height	32.3 m + (1097.3 m – 1089.7 m) + 4.1 m = 44 m
Drawdown	2.7 m
Design flow rate	$12m^3/6$ hours = $2m^3/hr$.
Pipe Friction Loss = Pipe length beyond pump discharge [m] * friction loss coefficient. Where vertical length from pump discharge to well head = 50 m Length from well head to tank = 110 m	(50 m + 110 m) * .07082 mH2O/m = 11.3 meters
Fitting Minor Loss = Equivalent Length * Pressure drop	13.4 m * .07082 mH2O/m = .95 meters
Thus, TDH = 44 m + 2.7 m + 11.3 m + .95 m + 0 m = 58.95, OR approximately 60 meters	

This means the design condition for selecting and specifying our example pump will be:

$2m^3$/hr or $12m^3$/day at 60 meters TDH

Note: In our example we assume all pipe to be 32 mm NPS HDPE. Thus, pressure drop per meter of piping is 0.07082 mH2O/m (from pressure loss table). For systems with different sizes of piping each section must be calculated individually with the appropriate pressure drop from the table.

Note: The complexity of the system and number and type of fittings are simplified for the example. A real system will likely have a more complex calculation, but the earlier "Rule of Thumb" of 10% of frictional losses is shown to be close to the calculated value.

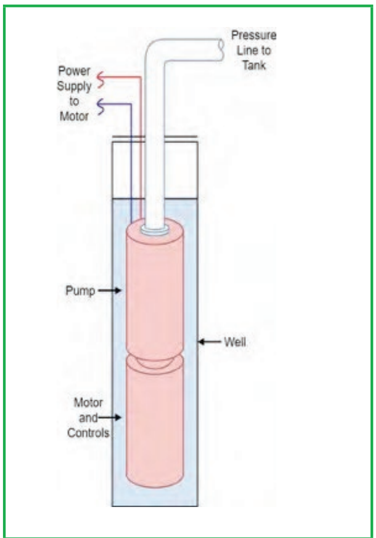
3.3.7. Pump Selection and Associated Components

Up to this point the document has been determining the design requirements for the pumping system. Next, the selection of the pump system will be evaluated for portable systems and semi-permanent systems using manufacturer's software, mobile applications and manual calculations to demonstrate how to determine and recommended a pump system by a supplier. The pump manufacturers used are just examples and are not necessarily recommended above any other suppliers but are used to derive the examples.

❖ General Notes

Surface and Submersible Pumps –

Solar water pumps are typically divided into two categories: submersible pumps and surface pumps.



A submersible pump is installed under water and has a sealed motor. Submersible pumps may be suspended from adjoining piping, mounted to the ground, or supported by a stand and are available for clean water and wastewater service. For borehole applications a submersible pump is suspended above the bottom of the borehole by connected piping with the pump suction extending downwards into the borehole. A submersible borehole pump is designed to be submerged at all times and extended operation outside the working fluid may cause the motor to overheat. For this reason, many submersible pumps are equipped by the manufacturer with a dry run sensor to prevent operation when not submerged.

A surface pump is installed above the water surface and designed to operate in air with piped suction and discharge flanges. Surface pumps may be connected with piping or an intake hose on the suction side. Surface pumps with a pump centreline at a lower elevation than the suction water surface are known as 'lift pumps' while pumps with a centreline elevation below the suction water surface elevation are 'flooded suction' pumps. Net Positive Suction Head (NPSH) is a particularly important design criterion for lift pumps, especially with high flowrates. All pumps described in this manual are low flow, submersible well pumps and NPSH is not considered. However, pump selections should always be checked by a qualified manufacturer's representative.

AC and DC Power

Solar powered water pumps move water from its remote source to the point of use, without requiring access to power lines or high maintenance/cost diesel generation. While power lines/diesel generators produce AC power, solar systems produce DC power that can be used directly or converted to AC power. Use of the solar power supply opens the option of using AC powered pump motors or DC powered pump motors.

The selection of which type of pump motor to use is the first consideration in the design process. In general, DC power pumps are more efficient when used with DC power from solar panels supplying DC. When DC is inverted to AC there are power losses of up to 15% compared to using DC power for the pump motor.

AC powered pump motors vary from a couple hundred watts up to 10's of kilowatts levels for very large pumping applications. DC motors vary from 150W to about 4kW excluding very low flow designs used for irrigation service. The selection of the pump depends on the total head requirement and flow rate of the system and the desired efficiency of the site. Better efficiency improves operating costs but may increase initial equipment costs. Note the choice of a DC powered pump motor does not prevent the system from later being converted to a hybrid system.

Another consideration is the reliability of the pump motors, which depends on the manufacturer. Whether the pump is AC or DC has little if any impact on reliability. Size and reliability of DC pumps has improved greatly over the last few years.

❖ Local Availability –

The availability of spare parts and repair expertise for the pump is critical to its long-term sustainability. The designer should contact several pump shops and determine what brands of pumps are commonly available and what are the most commonly sold sizes of pump. Many of the pumps in these projects will be the same make and model. Selecting a common, locally available brand will improve pump maintenance, as spare parts will be more readily available.

❖ Quality –

The quality of the pump has a direct influence on the life of the irrigation system. High-quality pumps are recommended for their lower total lifecycle cost. There are several high-quality pumps available in Africa that are widely used throughout the world and can be expected to have a reliable parts supply chain. Most pumps will have at least a 1-year warranty; if possible, negotiate 2 years. The pump supplier may insist on installing the pump or inspecting the pump installation to validate the warranty.

❖ Types –

Solar-powered pumps are characterized as either positive displacement pumps (piston, helical rotor, diaphragm, etc.) or centrifugal pumps. Positive displacement pumps use a sealed moving space to push liquid through the pump. Centrifugal pumps use a spinning impeller which accelerates fluid through the pump and converts fluid velocity into pressure. Positive displacement pumps are normally used when design TDH is high and flowrate is low. Conversely, centrifugal pumps are more often used when the design TDH is low and the flowrate required is high, though there is often overlap in pump ranges. Additionally, the amount and size of sediment, organic content, sand, and other solids in the pumped water may be a required consideration for selecting the pump type, per the manufacturer's specifications. The type of pump and materials should be carefully considered and discussed with the manufacturer's representative to protect the pump from abrasion and corrosion, and maximize its performance and useful life.

❖ Other Electrical components –

The wiring from the pump to the pump controller is specified by the supplier in most cases and should be reviewed by the electrician. The pump electrical type should always match the source of electricity. If a hybrid system is being proposed for the site, the alternate energy source must meet the local electrical standards and the design must be compatible with the pump as well. It is essential that grounding and surge protection be applied to the solar DC from the panels and any alternate electrical energy sources to prevent damage of the pump controller. The wiring from the solar panel must follow the appropriate IEC standards. Wire size may need to be increased above the size needed normally for the motor ampacity to reduce voltage drop issues that cause extra stress on the motor.

❖ Float Switch –

The pump should be ordered with automatic on and off controls that will be calibrated for the design parameters of the water system. A float switch in the tank is used to turn the pump on and off. This automated system will relieve the maintenance staff of having to monitor the tank's water surface level to turn on and off the pump. Tank level controls are further outlined in the tank design section of this report.

❖ Sizing –

The size of the pump will depend on the depth, capacity of the water source, and the extent of the irrigation system. For underground water sources, the size of the pump motor will also depend on the diameter of the borehole casing. The designer should also consider the commonly available sizes of pumps in the area. The process below outlines the basics for selecting the pump type and size. Manufacturers provide information (pump curves) to determine the anticipated pumping rate for each pump based on the total anticipated pumping height (Total Dynamic Head). Compare the anticipated pump rate given in these tool kits with the well drawdown test rate and select the appropriate pump. If two alternative pumps will meet the needs of the system, then the designer may want to consider the larger pump, which will reduce the pump run time and increase the life of the pump. However, this has a cost implication.

❖ Pump Selection

Selecting the Appropriate Pump Type for the Site Characteristics and Application Needs

Depending on the site conditions and application needs, the designer will be required to select the most appropriate pump. One will either select a portable system or a semi-permanent system. For portable systems, the farmer or operator is responsible for installing the pump and its accessories every time they need water and also disassemble the system after pumping. The selection of semi-permanent pumping systems is done through manufacturer's software while the selection of portable systems is done through mobile applications as described in the following section. However, both systems can be selected through manual calculations.

3.3.7.1. Pump Sizing for semi-permanent systems

Pump manufacturers provide pump specifications sheets/pump curves or software to aid in pump selection. Some pump sizing software programs are specific to solar pumping systems and will suggest a pump along with a solar array configuration. Other software programs will only suggest a pump for the system and it is up to the user to correctly design the solar array.

Both types of programs often result in multiple pump recommendations, from which you will need to make a manual selection. Thus, a basic familiarity with pump performance curves is necessary.

Pump performance curves provided by the manufacturer are necessary to correctly size a pump. The pump performance curves indicate if a pump can deliver the required flow against the calculated TDH. The curves can also be used to determine the peak power requirement for the pump at a given flowrate and TDH, which will inform the SOLAR selection and electric design of the system. Although software programs and pump curves are helpful in designing the system, all designs must be reviewed by an engineer and discussed with the manufacturer. It is important to note that pump manufacturers can and should always be consulted when sizing a pump. Such coordination minimizes the chance of selecting a pump that is either over- or under-sized, related to flow and efficiency.

Most pump selection software programs ask for the solar pumping system location as well as TDH and the desired water volume. Since they estimate the number of solar pumping hours based on the system location, the expected number of solar pumping hours may differ from the conservative estimate of 6 hrs suggested in this document. To ensure that appropriate assumptions for the number of solar pumping hours and system demand are used in the system design, it is important to have both engineers and the manufacturer review the system design.

The examples below use programs that suggest both a pump and a solar array design. These programs are provided by two manufactures, Grundfos and Lorentz, but the authors do not recommend these suppliers above any other suppliers.

The following data was entered into the programs:

Parameter	Grundfos Example	Lorentz Example
TDH	60 m	60 m
Location	Gulu-Uganda	Uganda
Minimum Daily Flow Rate	12 m^3/day	12 m^3/day

The manufacturers' software programs resulted in several recommendations based on the data above. The Pumps have different solar arrays but identical controllers to produce higher daily water volume. The program matches the pump-controller-solar size to the TDH and daily water volume.

Grundfos example pump selection data

Pump	Sales region	Product number	Solar modules	Solar array power [kWp]	Water [m³/year]	Average water [m³/day]	Water [l/Wp/day]	Water in month for sizing [m³/day]	January	April	July	October	Udc [V]
SQF 2.5-2	Europe/South America/Japan	99299012	3 x GF 270	0.81	5270	14.4	17.8	12.6	15.1	14	12.6	14.9	30-300
SQF 1.2-2	Europe/South America/Japan	99299012	4 x GF 270	1.08	4510	12.3	11.4	12	12.4	12.3	12	12.4	30-300
SQF 2.5-2	Europe/South America/Japan	99299012	4 x GF 270	1.08	4640	12.7	11.8	12.3	12.8	12.6	12.3	12.8	30-300
SQF 1-70	Europe/South America/Japan	99299012	6 x GF 270	1.62	5260	14.4	8.9	13.2	14.8	14.1	13.2	14.6	30-300
SQF 1.2-2	Europe/South America/Japan	99299012	3 x GF 270	0.81	3940	10.8	13.3	10.4	10.9	10.7	10.4	10.9	30-300
SQF 1.2-3	Europe/South America/Japan/Australia	99299012	4 x GF 270	1.08	4210	11.5	10.7	11.1	11.6	11.5	11.1	11.6	30-300
SQF 2.5-2	Europe/South America/Japan	99299012	4 x GF 270	1.08	7360	20.2	18.7	18.7	20.6	19.9	18.7	20.4	30-300
SQF 3A-10	Europe/South America/Japan	99299012	5 x GF 270	1.35	6060	16.6	12.3	14	17.5	16	14	17.1	30-300

Lorentz example pump selection data

For submersible pumps

PS2-4000 C-SJ8-15	7,440 Wp (6x4 LC310-P72)		4 mm^2			30...80 m	80 m^3	11 l/Wp
PS2-4000 C-SJ8-15	7,440 Wp (6x4 LC310-P72)	6x PM-1-5	4 mm^2			30...80 m	80 m^3	11 l/Wp
PSk2-5 C-SJ17-7	9,920 Wp (16x2 LC310-P72)	-	2.5 mm^2			30...70 m	102 m^3	10 l/Wp
PSk2-60 C-SJ150-4-1	48,195 Wp (17x9 WP 315)	-	25 mm^2			40...80 m	430 m^3	8.9 l/Wp
PSk2-70 C-SJ150-5-1	56,700 Wp (20x9 WP 315)	-	25 mm^2			50...100 m	611 m^3	11 l/Wp
PSk2-7 C-SJ17-9	9,920 Wp (16x2 LC310-P72)	-	2.5 mm^2			30...80 m	89 m^3	9.0 l/Wp
PSk2-7 C-SJ12-15	9,920 Wp (16x2 LC310-P72)	-	2.5 mm^2			20...100 m	89 m^3	9.0 l/Wp

For surface pumps

PS2-1800 CS-F4-6	1,860 Wp (3x2 LC310-P72)		2.5 mm^2		30 mm	20...50 m	50 m^3	27 l/Wp
PS2-1800 CS-F4-6	1,860 Wp (3x2 LC310-P72)		2.5 mm^2		30 mm	20...50 m	50 m^3	27 l/Wp
PS2-4000 CS-F16-3	2,170 Wp (7x1 LC310-P72)		2.5 mm^2		40 mm	25...40 m	56 m^3	26 l/Wp
PS2-4000 CS-F32-20-2	2,205 Wp (7x1 WP 315)		2.5 mm^2		50 mm	10...30 m	47 m^3	21 l/Wp
PSk2-7 CS-F20-5	4,960 Wp (16x1 LC310-P72)		4 mm^2		50 mm	20...50 m	163 m^3	33 l/Wp
PSk2-9 CS-F42-20	5,670 Wp (18x1 WP 315)		2.5 mm^2		60 mm	15...45 m	173 m^3	30 l/Wp
PSk2-15 CS-F65-20	9,920 Wp (16x2 LC310-P72)		2.5 mm^2		80 mm	20...45 m	363 m^3	37 l/Wp

With the minimum required daily flow rate, TDH, and estimating the number of solar hours, the programs suggested multiple pump and solar array options. When multiple options are presented by the manufacturer's software, the list of options is evaluated to identify the best overall selection. For the Grundfos example, multiple pumps were suggested but SQF 2.5-2 with a 4 x GF270 solar module configuration was selected because it gives the highest amount of flow per day. It is important to look out for the water production of the pump in the worst-case scenario month, for our case, it is January.

Pump curves

From the pump curve, the designer should confirm that the pump will produce the required flowrate at the determined TDH and solar power array. The curves indicate the total pumping head of the pump on a plot of flowrate against power requirement. The pump curves also can be used to determine the PV-generator power requirements. The designer sites the required flowrate and moves until meets the required head curve. Then drops down to the power axe to determine the required power.

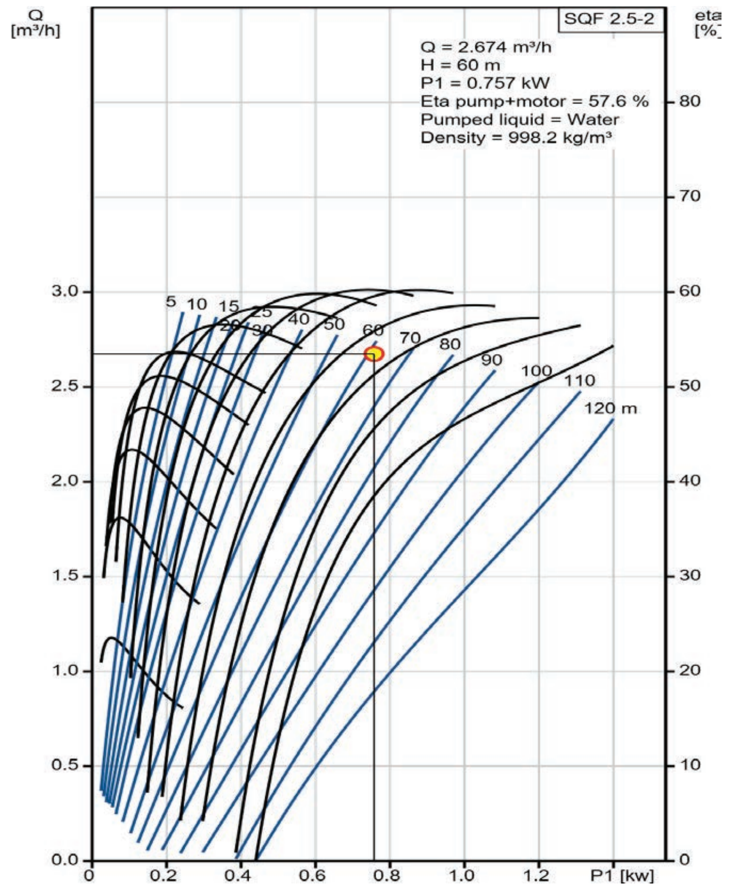


Figure 24: Grundfos pump curve example[20]

From the Lorentz pump curve below, it is observed that the selected pump discharge is 1.8m³/hr which is less than the required discharge of 2 m³/hr and the head is 65m which is higher than 60 m required. This because of the Lorentz sizing system takes into account the location of the place and determines the monthly sun shine hours. The values provided are for the worst-case scenario.

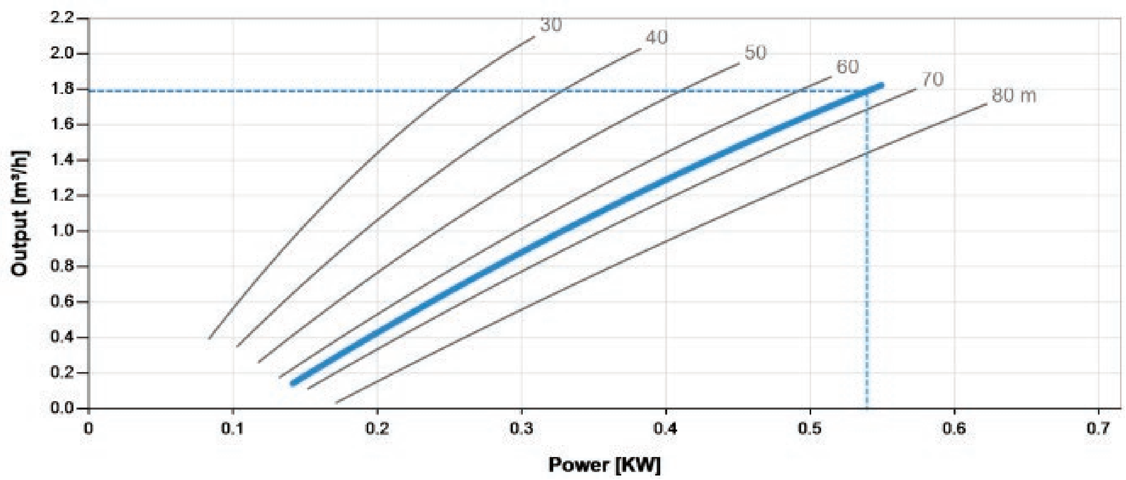


Figure 25: Lorentz pump curve for selected pump[21]

20 Source: Grundfos online pump sizing tool
21 Source: Lorentz Compass, solar pump sizing software

After selection of the pump, the pump specifications and performance sheet can be printed from the sizing tool.

Zoe's Solar Powered Irrigation System, Gulu-Uganda	
Selected Pump	SQF 2.5-2
Pump Motor Requirements	0.757kW
Rated Voltage	30-300 Volts
Current	8.4 Amps

3.3.7.2. Selection of Portable solar powered irrigation pumps.

These pumps are usually supplied by the manufacturers or distributors to the farmers as full kits comprising a pump, controller and solar array. Therefore, the designer only has to select the full kit according to the field conditions. The suppliers of these pumps normally provide the specification sheets from which designers can choose if the specific pump works under the field conditions. It is often difficult to move from one supplier to the other looking for specification sheets. Therefore, there are mobile applications that can help designers to select solar powered irrigation pumps. These include SPIS toolbox, Solar water pump selector etc. The mobile apps have several pumps from different pump manufacturers in their databases from which one can select. The apps use the site-specific conditions such as location, TDH and water demand to select a pump. The pump specifications are also provided.

The following data was entered in the apps

Zoe's Solar Powered Irrigation System, Uganda	
Water Demand	8400L/day
Water Supply	Spring Box
Water Capacity	12000L/day
Distance from Water Source to Elevated Tank	100m
Total farm Area	2000 m^2
Total Dynamic Head	12 m

Example using solar water pump selector app (https://play.google.com/store/apps/details?id=nl.hiemsteed.solarpumping&hl=en&gl=US)

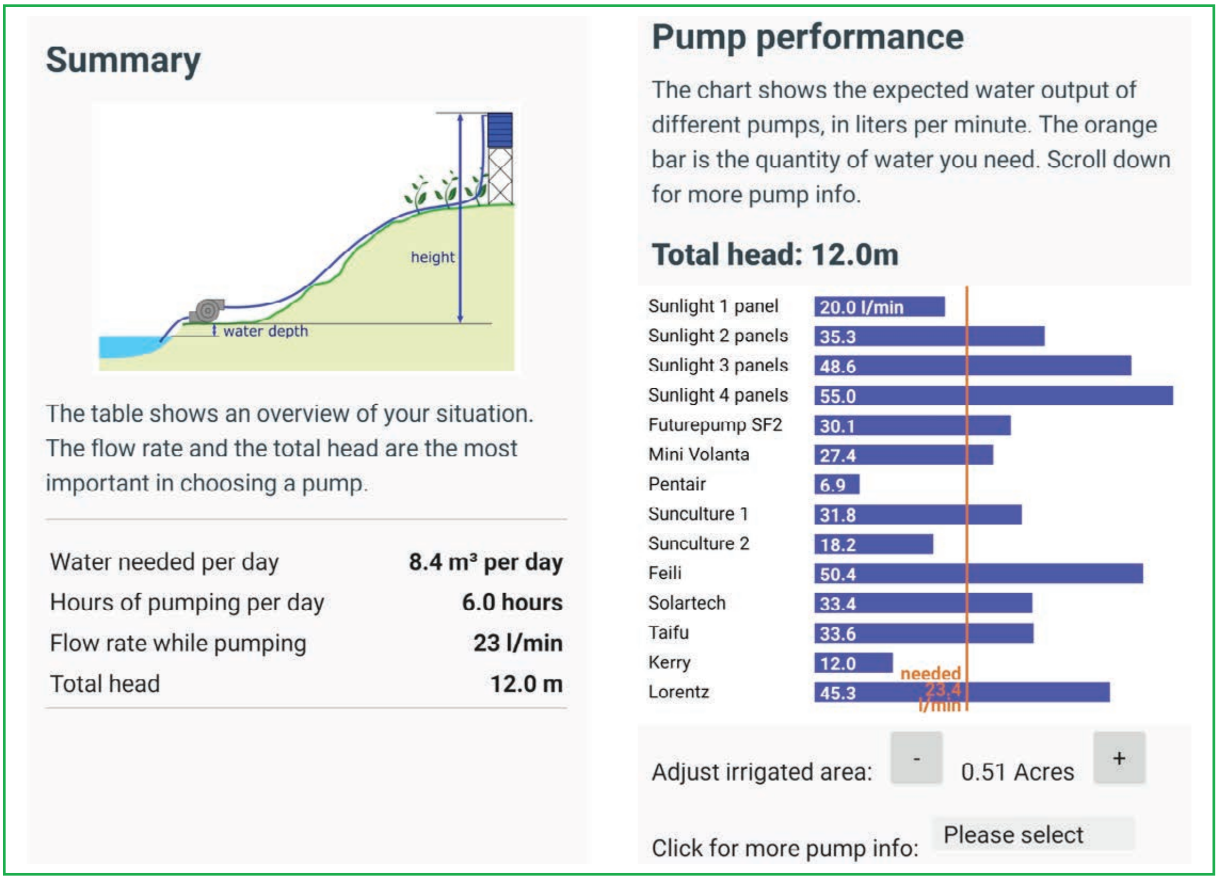


Figure 26: Pump selection example using mobile app

All pumps whose flow rate is beyond the orange line can sufficiently provide the water requirement but because of a surface water source, only two pumps can be considered that is the Future pump SF2 and the Sunlight pump (2-4 panels). In this example, a Future pump SF2 was selected because of being cheaper.

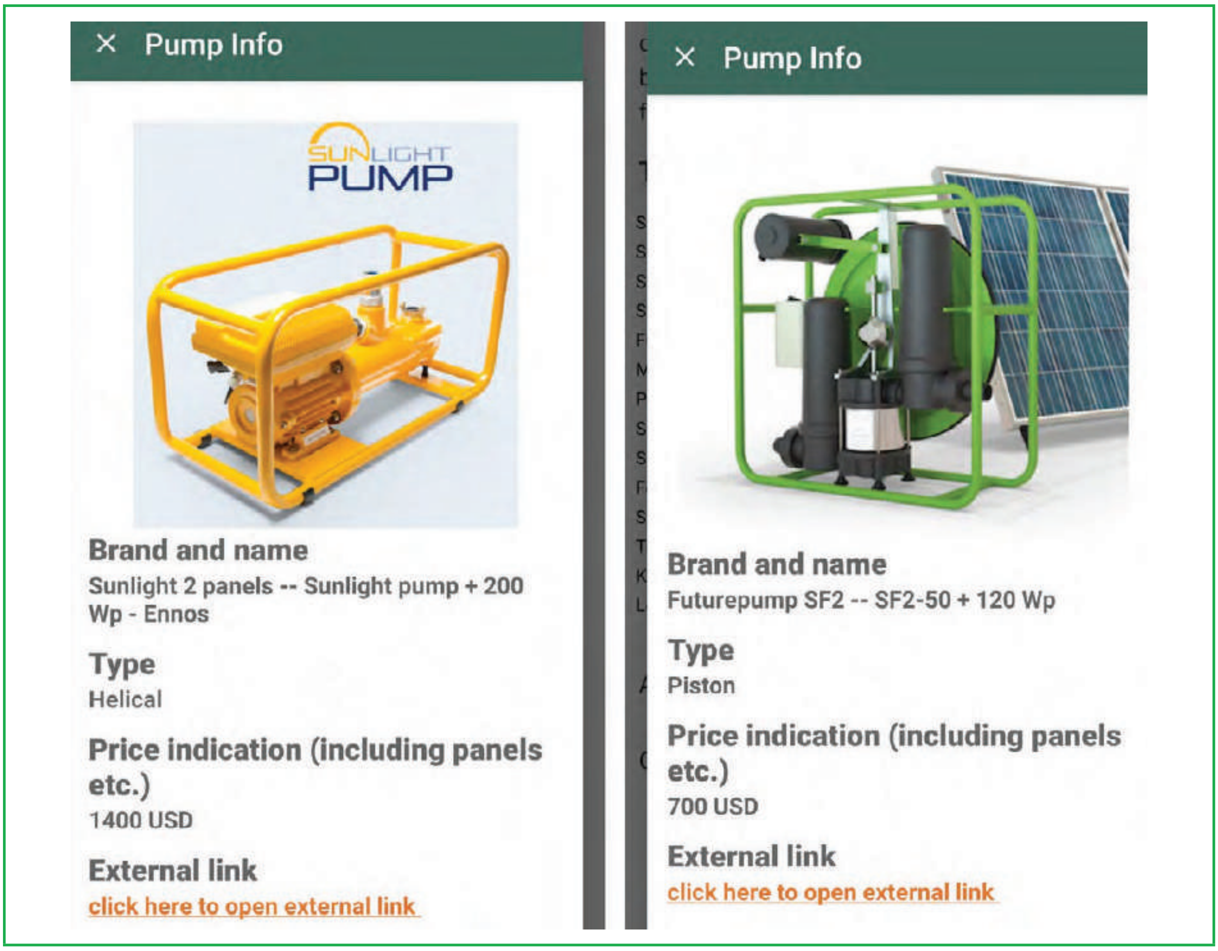


Figure 27: Pump decision example using mobile app

Example for using SPIS toolbox (mobile app)

This does not recommend any specific pump but rather provides information that the designer can match with the manufacturer's manuals to select the pump and solar array size.

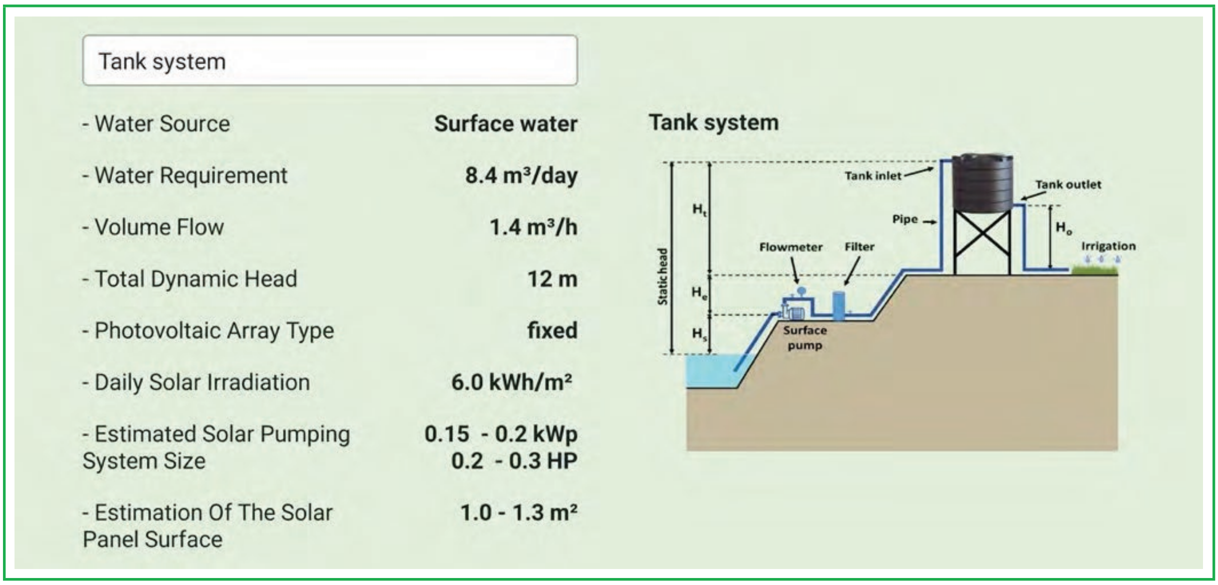


Figure 28: SPIS pump and solar array selection example

3.3.7.3. Manual selection of the pump and solar array

It is most preferable to use the software or mobile application. However, in cases where the designer has no access to software this can be very useful. Using the site conditions, the designer determines the irrigation water demand and the total dynamic head. Using manufacture's pump curves or specifications sheet, select the appropriate pump. Note the pump motor electrical requirements (power, voltage, current, efficiency) as these are key in the determination of the solar array. Alternatively, the power requirement can be calculated the site conditions as:

$$P = \frac{Q\,x\,\rho\,x\,g\,x\,H}{\eta\,x\,3.6\,x\,10^6}$$

Where Q is the flowrate (m^3/hr)
g is the acceleration due to gravity (9.81 m/s^2)
r is water density (1000 kg/m^3)
h is the overall pump efficiency.

The energy requirement is therefore power x the number of operation hours. To determine the size of the solar PV generator required;

$$P_{pv} = \frac{\text{P x operating hours}}{\text{Peak sun hours x performance ratio(losses)}}$$

$$\text{Number of modules} = \frac{P_{pv}}{\text{module rating}}$$

Note: This method may result into either an undersized or oversized of the system leading to performance challenges. Increasing the solar array size increases the operation hours however, this cannot be increased infinitely, an alternative source of energy would be sought.

<u>Pump Controller / Inverter</u>

The pump controller is the link between the solar modules and the pump. It adjusts the output frequency in real time according to the prevailing irradiation levels. Modern controllers incorporate high-efficient power electronics and utilize Maximum Power Point Tracking (MPPT) technology maximize power use from the solar panels. Currently, there are specifically designed controllers that can convert DC to AC power to drive AC pumps. It is important to note the compatibility of the controller to prevent reduced expected lifetime of AC pumps. Therefore, well-matched and tested controller/motor combinations are the preferred option to increase system reliability. Pump manufacturers most times recommend/determine the pump controller. Therefore, the pump controller or inverter will usually be determined by the pump manufacturer when the pump is selected.

MPPT - Larger pump controllers can be supplied with a control that maximizes the power transfer from the solar panels for varying conditions, called Maximum Power Point Tracking (MPPT).

Example pump controller data from Grundfos.

Specifications	Quotation Text	Videos (0)	Documents (5)	CAD drawings	System parts	Sizing result	Service Offerings

Specifications

		Electrical data	
Product name:	CU 200	Power consumption:	5 W
Product No:	96625360	Rated voltage ac:	1 x 90-240 V
EAN number:	5700835135131	Rated voltage dc:	30-300 V
		Enclosure class (IEC 34-5):	IP55
Technical		Back-up fuse:	10 A
Approvals on nameplate:	CE	Maximum load:	100 mA
Installation		**Others**	
Range of ambient temperature:	30 .. 50 °C	Net weight:	2 kg
Relative humidity:	95 %		

Example of controller data from Lorentz

Technical Data	Dimensions	Parts list	Pump Cha

Head	**max. 120 m**
Flow rate	**max. 2.7 m³/h**
Controller	**PS2-1800**
Power	max. 1.8 kW
Input voltage	max. 200 V DC
Motor current	max. 14 A
Efficiency	max. 98 %
Ambient temp.	-40...50 °C
Enclosure class	IP68

Zoe's Solar Powered Irrigation System, Uganda	
Selected Pump	SQF 2.5-2
Pump motor requirement	0.757kW
Switch box/control	IO50, metric
Selected Controller/Inverter	CU 200
Enclosure class	IP54

3.3.8. Solar panel selection and Solar Array Layout

This section goes through the selection of the SOLAR array, the location and foundation requirements and other critical considerations. This section provides a high-level summary of the following:

1. Calculation of the Voltage of the Solar Array (series panels)
2. Calculation of the Wattage of the Solar Array for the Pump (parallel groups)
3. Electrical Equipment protective system
4. Grounding and bonding of the electrical equipment
5. Lightning and Surge Protection
6. Location of the Solar Array
7. Foundation Requirements

❖ Solar Array, Voltage and Wattage

Once the pump size has been determined, power supply for the pump needs to be designed. You must determine if the borehole has a sustainable flow rate to allow solar pumping to meet the daily demand or if a hybrid system will be required to lengthen the daily pumping period. If the system is to be solely powered by solar, the pump selection can be made from available solar pump by matching needed flow rate and total dynamic head requirements. The pump curves will show the required pump power for the needed operating point.

Solar pump manufacturers provide design information about the needed voltage operating range of the pump / pump controller. The selection will need to provide enough solar panels so that the voltage range and current needs of the pump can be satisfied, even under less than optimum conditions. Cloudy days, dirty panels, and high levels of smoke, haze or dust can reduce forecasted solar resource power levels. In addition, as solar panels age, their power output decreases. Power output also decreases in warmer conditions than the standard conditions under which solar panels are rated, since both voltage and current will vary from the published ratings.

Since solar panels have lower voltage when the cells are warmer than the internationally set testing conditions, each manufacturer provides the percentage of voltage reduction for elevated temperatures. Likewise, current flow also changes slightly at elevated temperatures. It is important to make sure under very hot conditions that adequate current flow will be available and that the voltage of the panels remains within the proper operating range for the pump and controller. Most system provider software will account for the difference of expected temperature range and the panel standard conditions, but it is wise to understand the effects of temperature on the system.

Available solar irradiance, which changes throughout the day and seasonally through the year, also greatly impacts the performance of solar panels. Again, records of this data should be utilized by the manufacturer's software used to make selections. It is important to understand the effect and be sure that the selection process accounts for variable solar irradiance.

Standard Test Conditions - The solar panel ratings published by the manufacturer are measured under standard test conditions (STC) with solar irradiance of 1000 watts/m^2, cell temperature of 25°C, and air mass of AM1.5. These conditions are not common for operating solar panels installed in the field, due to variations in ambient air temperature, heating of the cells due to solar irradiation, and cooling of the cells due to wind. Thus, the expected output at the installation site must be considered in the design of the system. Most design software provided by manufacturers accounts for deviations between the reported performance at STC and the actual performance the installation location, and we suggest that you use this software to inform the design of your Solar array. However, the following section will explain how to perform some of the necessary design calculations by hand to give you a better understanding of SOLAR design.

The expected deviation from an STC rating due to changes in temperature is described by the temperature coefficient for that rating. Temperature coefficients are provided by the manufacturer and reported as a percent change from the STC rating per degree of temperature increase. For example, according to the Grundfos data above, the temperature coefficient for Pmax is -0.45. This means that an increase in solar cell temperature of one degree Celsius will cause the maximum power to decrease 0.45% from STC Pmax rating. These deviations from STC must be considered to design a solar array that will meet the current and voltage requirements of the solar pump.

Use the following equation to calculate solar panel performance given the expected temperature in the field:

$$Expected\ Output = ((\boldsymbol{T_f} - 25\,℃) * \boldsymbol{coef_x}) * \boldsymbol{STC_x} + \boldsymbol{STC_x}$$

$\boldsymbol{T_f}$ = $Temperature\ in\ the\ field$ [℃]

$\boldsymbol{coef_x}$ = $Coefficient\ of\ temperature\ for\ parameter\ x$ [%/℃]

$\boldsymbol{STC_x}$ = $STC\ value\ for\ parameter\ x$

If the manufacturer's software or selection process has not accounted for ambient temperature, it is important to adjust the open circuit Voltage (Voc) of the chosen panel to the lowest ambient operating temperature determined for the installation site. This will produce the highest Voc value and will need to be compared to the pump controller maximum voltage to make sure it is below the rating.

Zoe's Solar Powered Irrigation System, Uganda

V_{OC} Adjustment

Specifications

Electrical Data

Peak power	Pmax	[Wp]	150
Tolerance		[%]	+5/0
Max. power current	Imp	[A]	7.98
Max. power voltage	Vmp	[V]	18.8
Short circuit current	Isc	[A]	8.5
Open circuit voltage	Voc	[V]	22.7
Temperature co-efficient for Pmax		[%/°C]	-0.42
Temperature co-efficient for Voc		[%/°C]	-0.34
Temperature co-efficient for Isc		[%/°C]	0.06
Max. system voltage		[VDC]	1,000
Module efficiency		[%]	14.94
Practical module efficiency		[%]	17.12

All technical data at standard test condition:
AM = 1.5, E = 1,000W/m², cell temperature: 25 °C

If the yearly data showed that the lowest ambient temperature was 5°C, and using the information for the Grundfos solar panel in the above example, the adjustment for the maximum Voc would be as follows:

$\boldsymbol{T_f} = 5\,^{\circ}\mathbf{C}$

$\boldsymbol{coef_{Voc}} = -0.33\ \%/^{\circ}\mathbf{C}$

$\boldsymbol{STC_{Voc}} = 22.7\ V$

Substituting these values into the expected output equation, results in the following calculation:

$U\ (5\,^{\circ}\mathbf{C} - 25\,^{\circ}\mathbf{C}) * -0.33\ \%/^{\circ}\mathbf{C}W * 22.7\ \mathrm{V} + 22.7\ V = 24.2\mathbf{V}$

Solar Array Configuration

With the pump motor requirements and the controller/inverter input maximums, the solar array can be selected and configured. It is highly recommended to increase the required power input by a minimum of 1.2-1.6 times the required Wattage of the pump motor. It is for this reason that the selected controller/inverter usually has much higher maximum inputs. Size the solar array for the maximum inputs and the desired times factor of the pump motor requirements, as well as the minimum pump motor requirements.

Zoe's Solar Powered Irrigation System, Uganda	
Selected Pump	SQF 2.5-2
Pump power requirement	0.757 kW
Number of modules and configuration	4 in series
Solar panel peak power	270-Watt peak

Solar array rated power	1.08 kW
Solar array Voltage	126.4
Tilt angle	3 degrees

❖ Panels in series and Parallel

The configuration of panels will either increase the output voltage or current.

- Higher voltage increases the pump flow rate
- Higher current increases the pumping head.
- However, it can never exceed the maximum output of the pump therefore the voltage and current must be in the acceptable/recommended range by the pump manufacturer.

Note: When panels are connected in series, a small shading on one panel significantly affects the whole system output. Therefore, parallel connections with strings are highly recommended. Be sure that the output current and voltage are above the pump requirement but less than the controller rating.

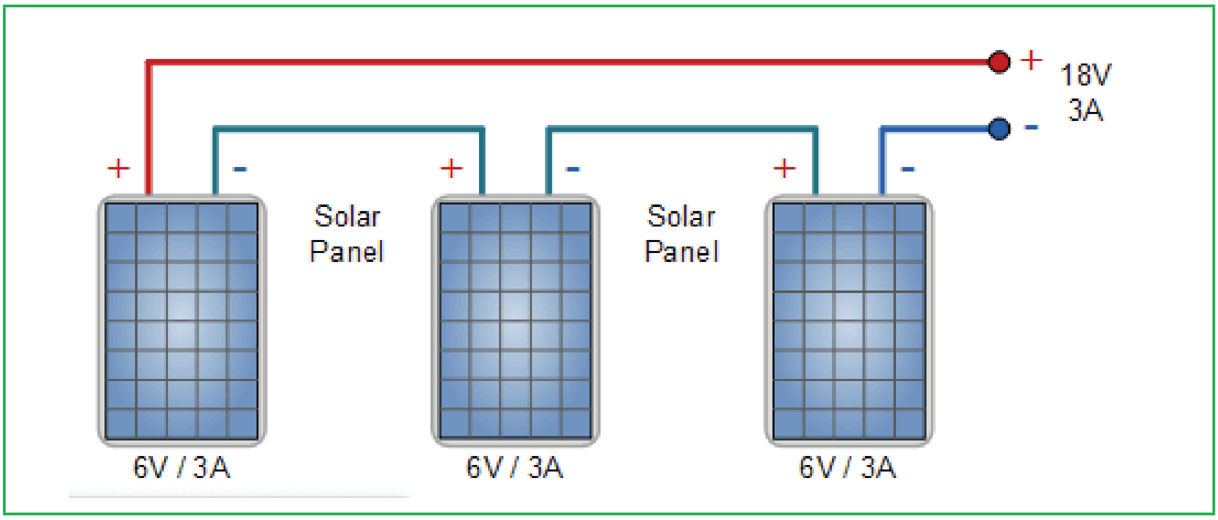


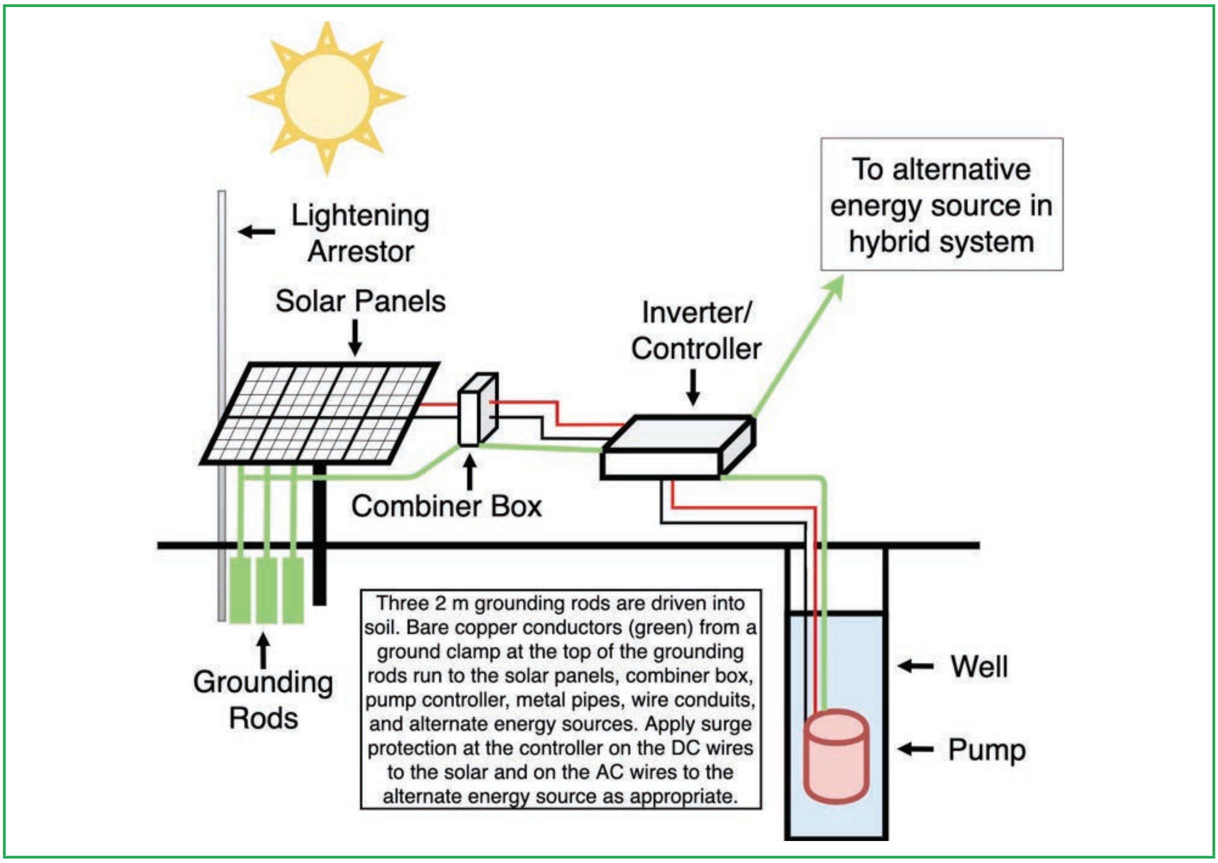
Figure 29: Series connection

3.3.9. Wire Connections from the Solar Panels to the Pump Controller

When multiple panels are required, which is typical, they can be connected in series or in parallel. Both series and parallel configurations can provide similar power. Series connections result in a higher voltage/lower current output. Parallel connection results in a lower voltage/higher current output and will require larger gauge wires to be used.

The wire connections for a typical Solar system are shown in the Figure 30. The solar panel to the combiner box to the controller with the essential addition of the grounding and surge protection system.

Figure 30: Parallel connection



Zoe's Solar Powered Irrigation System, Uganda	
Selected Pump	SQF 2.5-2
Pump Motor Requirements	0.757 kW
Voltage	30-300 Volts
Maximum Current	8.4 A
Selected Controller/Inverter	IO50/CU-200
Desired input: x 1.4 (applies to Watts only)	1.08 kW
Solar array	4 x 270 Wp
Solar array Voltage	126.4 Volts
Panel peak power	270 Watts
Max. power point voltage	31.6 Volts
Module short circuit current	9.11 Amps
Arrangement Options	
4 panels, all in series,	Watts 1080 - good
	Volts 126.4 – below inverter maximum
	Amps 9.11 – meets pump motor need

3.3.10. Grounding the Electrical System

The following earthing guidelines should be used unless local codes require a different arrangement, in which case local codes should be followed, in consultation with the manufacture's guidelines.

Earthing the solar panels and mounts is different than any earthing of power conductors of the solar output power. The panel frames and metal support mounts must be earthed for protection from lightning strikes. This can consist of the metal frames being in direct contact with the concrete footings. It can be supplemented by deliberate bonding of the SOLAR panel frames to the painted metal support mounts by removing paint at bolted connections or with paint break (star or lock) washers. If the frames are galvanized metal, no additional bonding to the panels should be needed. It is wise to bond the panel frames together with lugs bolted to the metal solar panel frames by at least a 16 mm2 cross sectional area copper bonding wire then connected to a driven earthing rod comprising a solar earthing conductor system.

❖ Lightning Protection

While lightning surge protection is vital in these systems, the voltage range of any transient surge suppressor (protector) on the DC or AC power system MUST be cross checked with the required voltage operating range of each of those circuits. Surge suppression must be provided on the DC circuits as close to the panels as possible and connected to the SOLAR earthing conductor as a grounding/earthing reference.

Follow the pump controller recommendations for any AC or DC surge protection between the pump controller and the pump motor.

❖ Location

The solar panels should be mounted in a secure location such as a roof or in a locked fenced enclosure. Solar panels should be positioned at the correct tilt angle to receive maximum solar power during the average day and to wash correctly during rain.

Positioning of the panels in Uganda is relatively simple. Since the system is very near the equator, the best angle practically zero or flat. A maximum tilt of 15 degrees should be provided to allow rain water to wash the modules. For areas north of the equator raise the top of the panel by 10 to 15 degrees to face south. For areas south of the equator tilt the panels to face North.

Solar panel shading is a critical part of placing the panels. Shading one panel will reduce power from all panels because of the electrical properties of the connections. Selection of site must eliminate shading.

❖ Foundation/Mounting Considerations

Shading of the panels can also occur as a result of oversized panel mounting that covers part of the panel. A picture of this is shown below. In the picture, the angle iron covers part of the panel and increases dust collection in the lower elevation portion of the panel reducing panel efficiency by up to 10%. Ensure, when panel mounting is being selected/installed that the full panel is exposed.

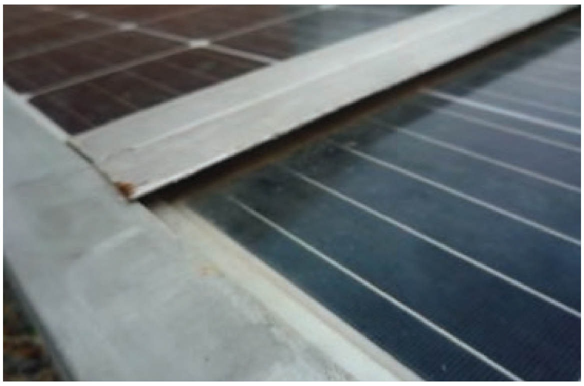


Figure 32: Poorly mounted panels demonstrating shading[22]

Figure 33: Properly mounted panels, fully exposed to sun[22]

Standard foundation designs for the solar mounting systems can typically be supplied by the panel/panel mounting manufacturer. If locally fabricated mounts are used, standardized foundations need to be provided by a structural engineer.

Panels mounted on a roof are not outlined in detail in this document. Where roof mounting is desired, a licensed structural engineer should check the design and approve the structure, roof, and mounting detail for new or existing structures.

3.3.11. Well Head Protection/Pump House

Well Head Protection – For smaller systems a simple well head enclosure will be sufficient to protect the well and pump. The well head should be covered with a brick or concrete structure so that rocks and dirt will not fall into the well. The lid should be lockable to prevent damage to the piping and pressure gauge and to avoid theft.

Figure 34: Well head protection house[22]

❖ Pump house

Installation of a pump house is also an option providing housing around the pump discharge piping and electrical controls is recommended to provide protection for controls and electrical equipment. Pumphouse sizing and structure would normally be a standardized design.

22 Figure 32/33/34 – Source: Engineers Without Borders

Figure 35: Pump house[23]

3.3.12. Transmission

Transmission Line

The transmission line is sized according to the pump outlet. The line is fully pressurized to ensure that the water reaches the tank from the pump. The operating pressures, flow and materials are selected at the beginning of the design process working with the EPANET modelling.

Zoe's Solar Powered Irrigation System, Uganda	
Pump Outlet size	40mm
Transmission Line Size	40mm
Transmission Line Material	HDPE
Transmission Line Flow	2.7 m^3/h
Transmission Line Operating Pressure	15 bars

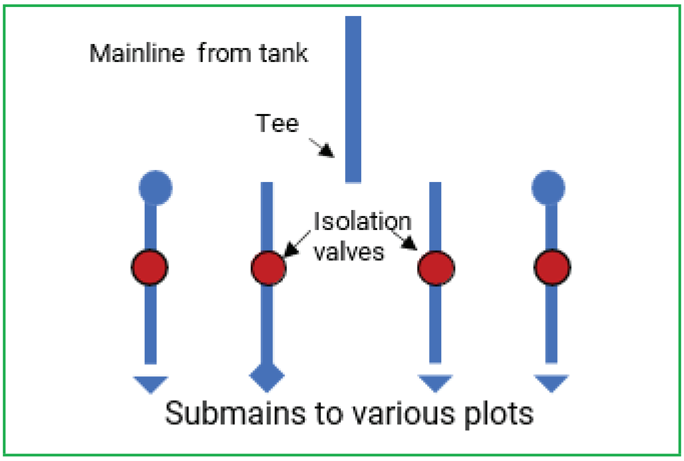
Tank Mainline (Down Line)

The tank mainline, also referred to as a down line, is the piping that runs from the outlet of the tank to the valve box. The valve box is the point where the various submain lines to different irrigation plots separate. The pressure line (from the pump to the tank) enters at the top of the tank and the mainline exits the tank near the bottom and runs to the valve box connecting the submain lines.

Valve Box

The valve box is where the water from the mainline is divided into the various submain lines that run to the irrigation plots. The valve box should be in a protected location at the base of the tank stand. If the valve box is buried, it should be enclosed in a lockable concrete or brick enclosure similar to the wellhead enclosure and easily accessible should repairs be necessary. Where above ground, the valve box should be placed out of reach of children. In some cases, there may be no valve box but rather connections into the mainline.

23 Source: Engineers Without Borders



The submain lines are the pipes that run from the valve box/mainline to the plots that are supplied by the irrigation system. In this case, the submains will run to the irrigation system.

Tools/Resources for Irrigation System Design
- SPIS Toolbox (app)
- IRRICAD
- AUTOCAD
- Irrigate Plus
- IrriPro

And many others

3.4. Irrigation System Design

3.4.1. Detailed layout of the irrigation system

An irrigation system essentially comprises a main line, submain, head unit (control valve, filtration and fertigation unit), laterals and emitters. These components are connected together through fittings. To prepare an appropriate layout of the system, the size, shape and slope of the field are required. Distances along the perimeter of field can be measured with a measuring tape or estimated by pacing. For small irrigation plots, the slope of the field surface may be determined through visual inspection based on experience with a naked eye and taken into consideration while designing the irrigation system. If the field is too undulating and slope is difficult to be judged by naked eye, then ground levels should be taken with surveying instrument such as dumpy levels and contours drawn on the map to make proper design of the irrigation system. The position of the water tank should be marked on the layout before deciding on the final irrigation layout. The field survey sketch layout has to be transformed into a final design layout. Below are some guidelines for making an accurate and practical final layout:

- If the field slope is less than 3%, laterals can be placed equally on both sides of the submain along the slope.
- If the slope of the field is more than 3 % laterals should be laid along the contours (across the slope) as far as possible.
- If it is not possible to use laterals along the contours on sloping surface due to plant spacing etc., the length of laterals on downside of the sub main should be more than laterals on the upside. For higher slopes laterals only on downside should be used.