SOLAR WATER PUMPING SYSTEMS
SYSTEM DESIGN, SELECTION AND INSTALLATION GUIDELINES

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These guidelines have been developed for The Pacific Power Association(PPA) and the
Sustainable Energy Industry Association of the Pacific Islands (SEIAPI).
They represent latest industry BEST PRACTICE for the Design, Selection and Installation of Solar Water
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Table of Contents

List of Figures

List of Tables

List of Abbreviations

A summary of the main acronyms and terms used in this document is listed below:

AC	Alternating current
AWG	American wire gauge
CCC	Current carrying capacity
DC	Direct current
DN	Diametre Nominal (nominal diametre)
FPS	Feet per second
GPM	Gallon per minute
IEC	International Electrotechnical Commission
IP	Ingress protection
ISO	International Organization for Standardization
kWh	Kilowatt hour
kPa	Kilopascal
L	Litres
MAOP	Maximum allowable operating pressure
MPPT	Maximum power point tracker
MRS	Minimum required strength
NEC	National Electrical Code (US)
PSI	Pounds per square inch
PE	Polyethylene
PSH	Peak sun hour
PV	Photovoltaic
PVC	Polyvinyl chloride
SDR	Standard dimension ratio
US	United States (of America)
UV	Ultraviolet (radiation)
W_p	Peak Watt, also known as Watt-peak

1. Introduction

This guideline provides the minimum knowledge required when designing, selecting and installing a solar water pumping system.

When designing a solar pumping system, the designer must match the individual components together. A solar water pumping system consists of three major components: the solar array, pump controller and electric water pump (motor and pump) as shown in Figure 1.

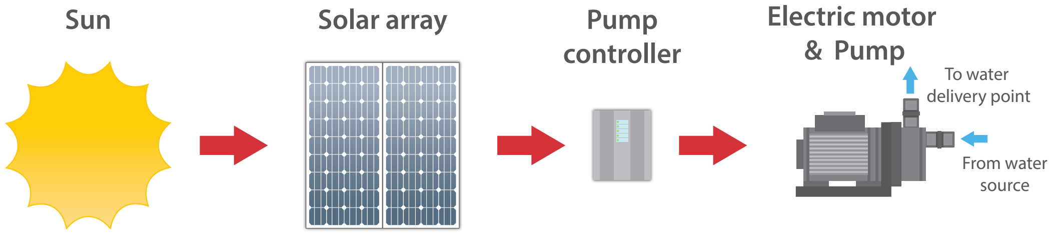

Figure 1: Typical Solar Water Pumping Systems

Note: Motor and pump are typically directly connected by one shaft and viewed as one unit, however occasionally belts or gears may be used to interconnect the two shafts. In this guideline we will use the words 'water pump' to describe the complete motor/pump assembly.

Unlike other design guidelines, this guideline does not cover how these three components are sized and matched, this has already been undertaken by the solar water pump manufacturers/suppliers. Design and selection of the correct solar water pumping system mainly requires knowledge of the actual site including:

- Solar Irradiation;
- How much water is required to be pumped each day; and
- The total dynamic head.

The total dynamic head is calculated based on the vertical height (static head) that the water must be pumped and the effective head caused by having to pump the design volume of water per unit time (gallons/minute or litres/minute) through the actual length and diameter of the pipe (frictional head) that is used to transport the water from the source to the final destination, often a water tank.

A solar water pump manufacture/supplier will have tables or computer software which specify the flow from the solar water pumping system for various heads and solar irradiation. The "solar water pump designer" shall be capable of:

- Determining the solar irradiation for the site:
- Determining the volume of water required on a specified time basis, typically daily;
- Measuring the static head;
- Measuring the length of pipe required;
- Selecting the appropriate type of pipe and its diameter;
- Calculating the total frictional losses (friction head) for the type, size and length of pipe used;
- Calculate the total dynamic head for the site; and
- Using the manufacturers data sheets or software to select the most appropriate solar water pumping system.

Notes:

1. Litres is used within the book however the number of US gallons will be shown in brackets. There are 3.785 litres in a US gallon and 4.54 litres in an imperial gallon.
2. IEC standards use a.c. and d.c. for alternating and direct current respectively while the NEC uses ac and dc. This guideline uses ac and dc.

2. System Types and Configurations

There are many possible applications for solar water pumping, especially when considering that the pump can be combined with energy storage or other types of generation to make it more versatile. However, this guideline is related to solar only systems. These would typically be used for supplying water for a village, an individual residence or a resort. Other potential applications could be for agricultural irrigation or water for animals. In general battery storage is not used, storage in the form of water tanks, often elevated to provide pressure for delivery, takes the place of batteries in most of these systems.

A solar water pump theoretically consists of three key components: a pump control system that may be just an on-off switch or may be a more complex electronic unit, a motor and the pump; however, in practice they are considered as one unit and generally called the "water pump" or in this guideline the "solar water pump".

The different system configuration can be defined by:
- How the electric pump is powered (dc or ac);
- The mounting of the water pump (submerged, floating or on the surface);
- The type of the water pump (roto-dynamic or positive displacement)

2.1 How the Electric Pump is Powered?

The solar water pump could be either a dc powered pump (Figure 2) or an ac power pump (Figure 3).

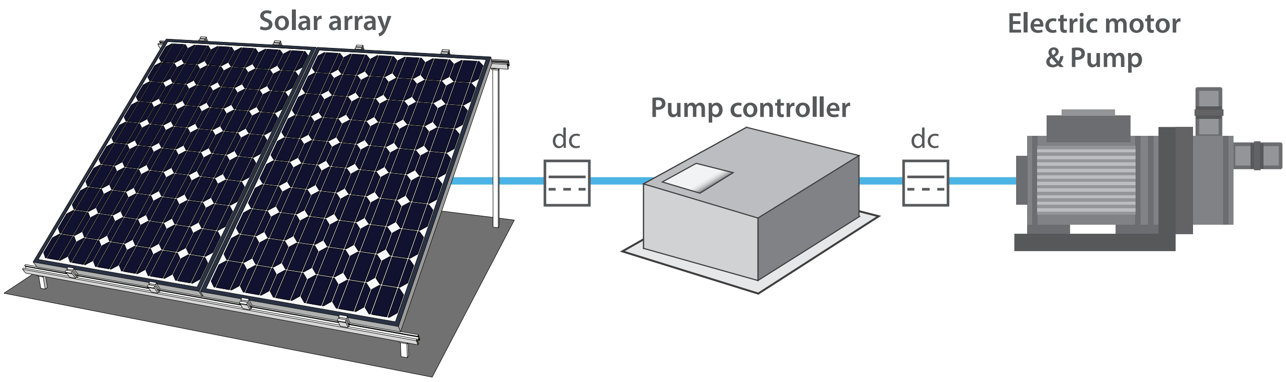

Figure 2: dc powered pump

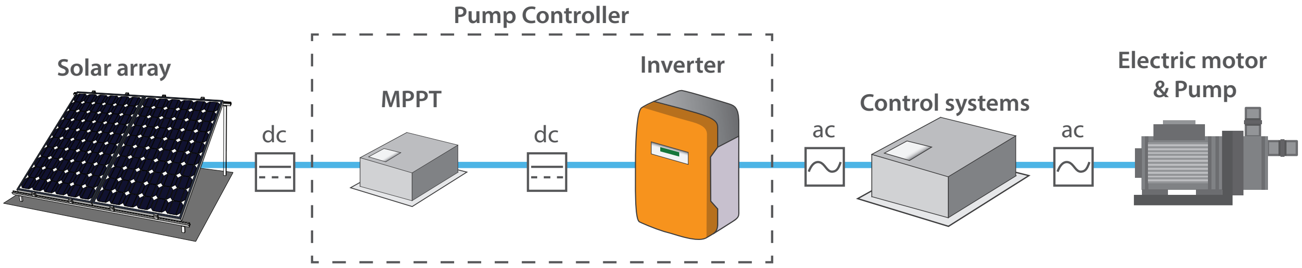

Figure 3: ac powered pump

The "pump controller" in the dc powered pump system would typically include a maximum power point tracker (MPPT) to ensure that the solar array is delivering power at its peak power point.

The "pump controller" in the ac powered pump system would include an MPPT as well as a dc to ac inverter in order to operate the ac electric motor which is part of the water pump. In larger systems these should be three-phase inverters to operate three-phase motors.

2.2 Type of Water Pump Systems

Three types of solar water pumping systems are available including:

- Borehole/well (submersible) pumps;
- Surface pumps; and
- Floating pumps.

It is assumed that the first two will be the most common in the Pacific and this guideline will detail how to determine the dynamic head for these types of systems.

2.2.1 Borehole/ Well Pump (Submersible Pump)

The most common water source in the Pacific is a borehole or well, fitted with a submersible pump. Figure 4 shows a typical borehole pump system.

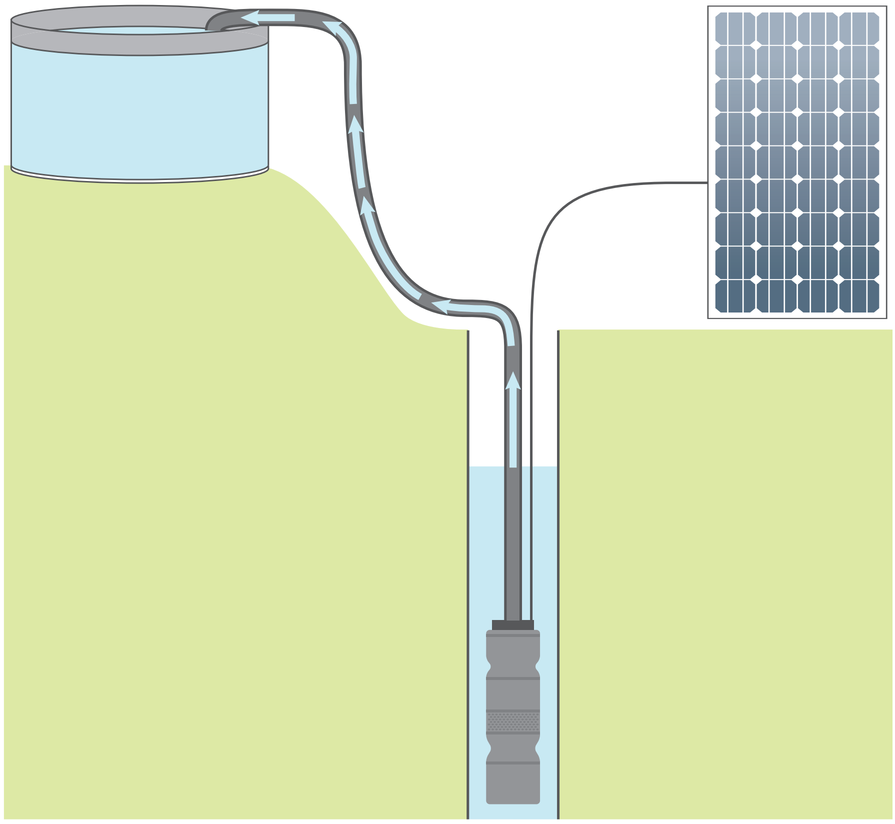

Figure 4: Borehole pump system

In these systems the solar water pump is located within the borehole or well. These pumps are generally available for 100 mm (4 inch) and 150 mm (6 inch) boreholes. The solar array is typically located near the top of the borehole/well and the water is generally pumped to a storage tank. The pump controller is typically located at the solar array. The pump and pump controller are interconnected using waterproof cables.

2.2.2 Surface Pump

These systems are typically used in shallow wells or boreholes and also lakes, rivers and any open water source that is near or on the surface. The solar water pump is located above the water level and a suction pipe is used for drawing the water from the water source as is shown in Figure 5. In the Pacific they could be installed beside rivers and streams, though flooding may be a serious problem. It is not anticipated that there will be many sites associated with dams built specifically for the pumping system though that may be the case for some larger irrigation water supplies.

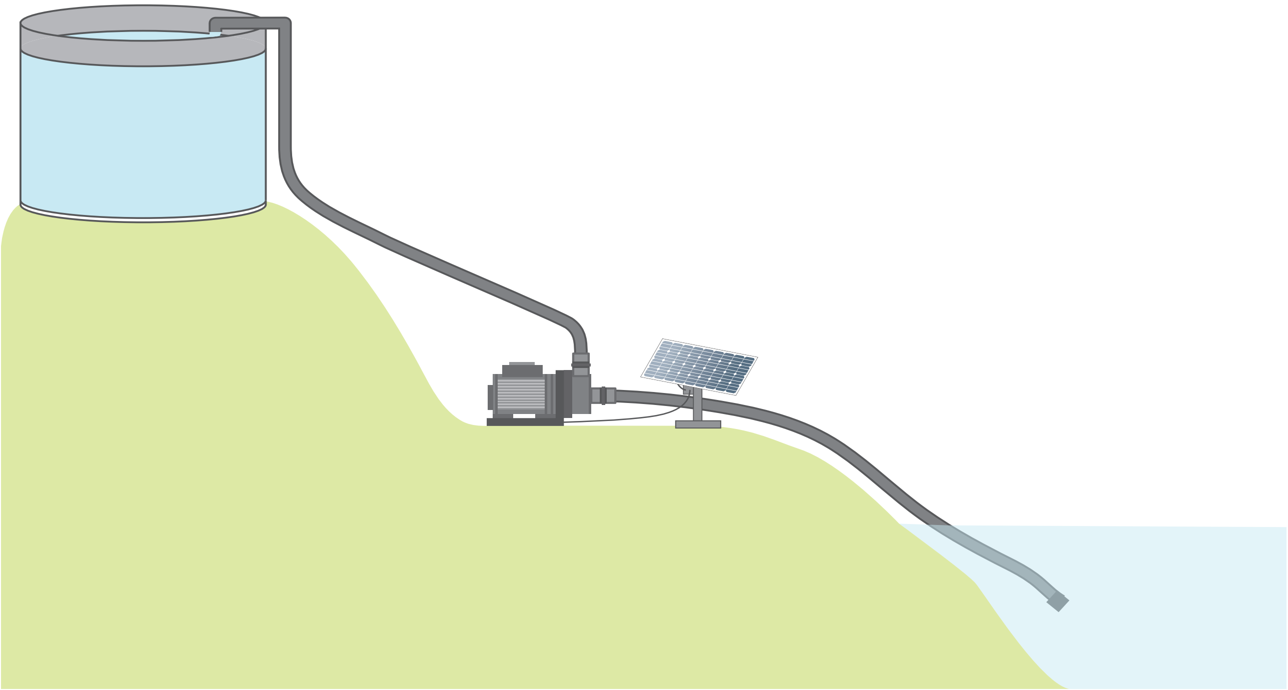

Figure 5: Surface pump system

2.2.3 Floating Pump

If the water source is a large dam or large open well, then a floating pump may be installed. In these systems the water pump component is mounted within a floating device such that the pump inlet is located within the water source. These systems remove any requirement for a suction pipe and the problems that can be associated with them, though a floating pump does usually require a flexible outlet pipe due to changes in the level of the water over time.

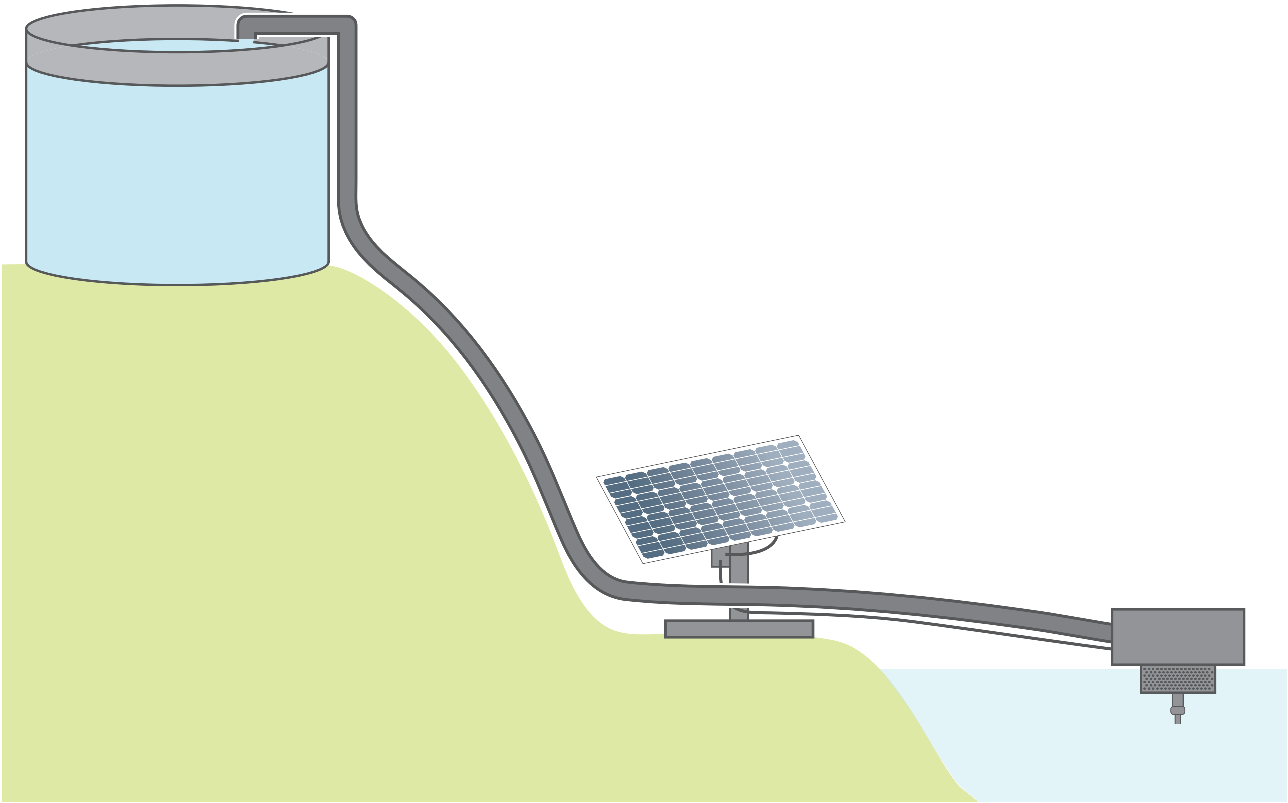

Figure 6: Floating pump system

The solar array is located on land near the pump and the water is typically pumped to a storage tank (or water troughs) located well away from the actual water source.

The pump controller is typically located near the solar array with the pump and pump controller interconnected using waterproof cables.

2.3 Types of Pumps

There are two main types of pumps

1. Roto-dynamic pumps (the most common being centrifugal pumps), and
2. Positive displacement pumps (e.g. diaphragm pumps)

Both types of pumps can form part of the water pumping systems described in section 2.2.

2.3.1 Roto-Dynamic

These types of pumps transfer the energy of the pump to the water by a rotating component of the pump (i.e. an impeller, propeller or rotor).

Figure 7 shows how roto-dynamic pumps can be classified further.

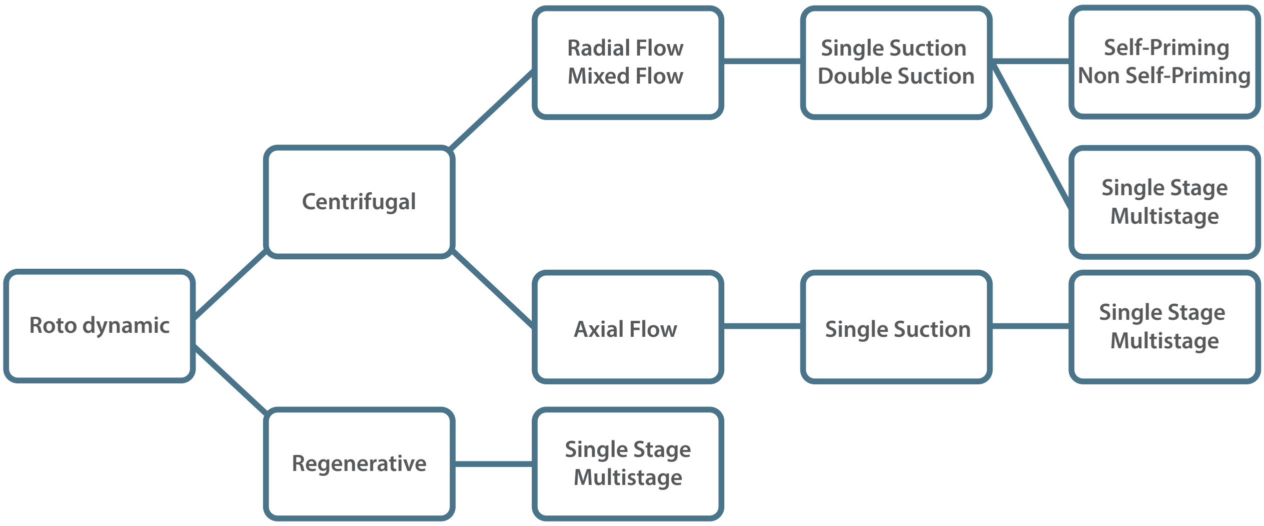

Figure 7: Classification of roto-dynamic pumps

Detailing the operation of each of these types of pumps is outside the scope of this guideline. A detailed training course would focus on explaining the various types of pumps and their relative advantages and disadvantages.

2.3.2 Positive Displacement

Positive displacement pumps work by drawing a known amount of water into a chamber, and then pushing it out again through the mechanical action of the pumping elements. Pressure actuated valves ensure that the water flows only in the right direction.

Figure 8 shows how positive displacement pumps can be further classified.

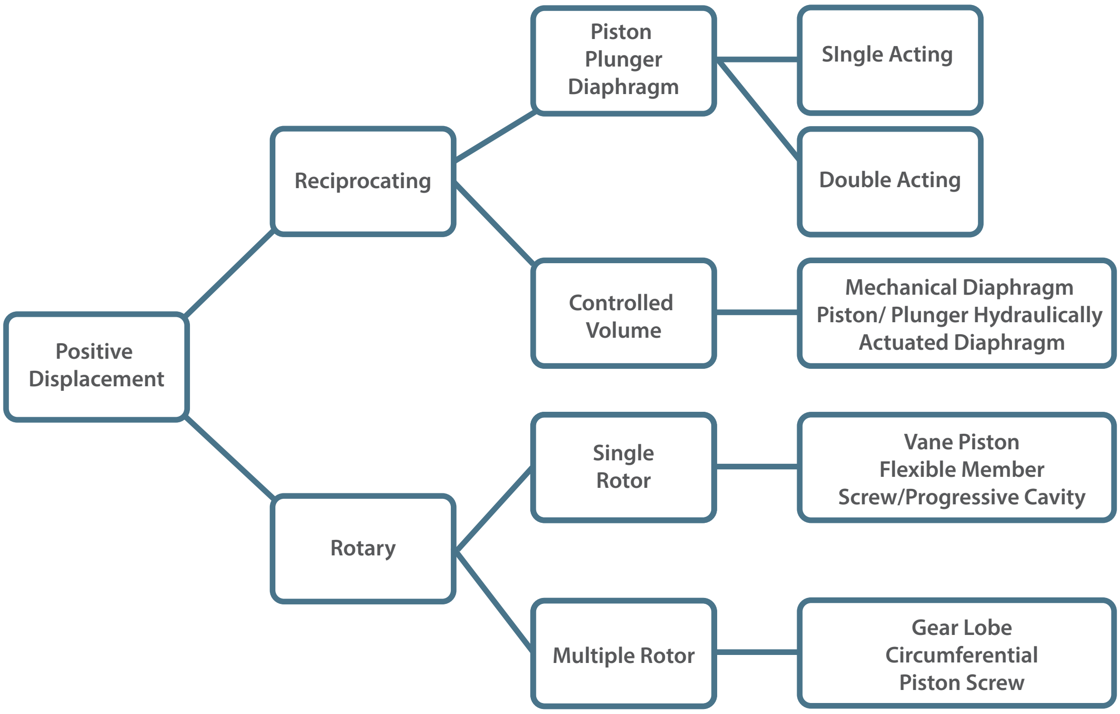

Figure 8: Classifications of positive displacement pumps

3. Designing and Selecting a Solar Water Pumping System-Summary

The steps in designing and selecting solar water pumping system are summarised as follows:

1. During a site visit:
    a. Determine the water source and, based on the characteristics of the water source and the water's end usage, select the appropriate solar water pumping system to be installed.
    b. Determine the daily or weekly water requirement and verify that the water resource availability over the long term can meet the requirements.
    c. Determine where the solar array will be located.
    d. Determine where the water pump will be located.
    e. Determine the length of cables required between the solar array, pump controller and water pump.
    f. Determine where and how the water will be stored.
    g. Measure the static head for the site.
    h. Measure the total distance from the water source to the final location of the water.
    i. Determine and measure any land irregularities (hills, ditches, etc.) that the piping system must traverse.
2. Determine the solar irradiation for the selected site on an annual and a monthly basis.
3. Select the size and type of the water pipe to be used to transfer the water from the source to its storage tank or its final destination if there is no storage tank.
4. Make an estimate of the expected dynamic head and select a possible solar water pumping system using either manufacturers' tables or an appropriate computer program, accounting for available solar irradiation. This will then provide information on the maximum flow rate.
5. Use the estimated maximum flow rate and calculate the frictional losses (flow friction head) and determine the dynamic head.
6. Choose a type of pump consistent with the quality of the water being pumped and the overall characteristics of the site (especially the particulate content of the water such as mud or coral sand),
7. With the final calculated dynamic head finalise the selection of the solar water pumping system from either manufacturer's tables or a computer program.

4. Site Visit

The designer shall obtain all the information as specified in this section either during the site visit or during follow up visits if required.

4.1 The Type of Solar Water Pumping System to be Installed.

The type of solar water pumping system: borehole/well (submerged), floating or surface will depend on the water source. If the source is a borehole (proposed or existing) or deep well, then a submersible pump that fits the borehole or well should be selected. If the water source is a river, then a surface pump should usually be selected. If the water resource is a shallow well, pond or lake, then either a surface or floating pump may be selected.

During the site visit the designer selects the pumping system that is most suitable for the site.

If the system will be for a borehole then the designer must obtain information on the diameter and depth of the borehole. Diameters of boreholes are typically 100 mm (4 inch) diameter or 150 mm (6 inch) diameter but they can be greater.

4.2 Determine the Daily or Weekly Water Requirement.

The amount of water required each day or week will depend on the actual application. If the water is being used within a village, household or a resort then data should be available on the amount of water required per person in the village, household or resort. This information could be obtained from the relevant government departments or could already be known by the client. The designer might need to have an ongoing consultation with the client and government departments to determine what is the actual daily volume of water required.

As an example, the World Health Organisation (WHO) states that a person requires, as a minimum, 20 litres (5.3 US gallons) per day. If the site includes showers, washing machines etc. then the water usage would increase accordingly.

If the water is required for agricultural use, then the client should know their water requirements or again it may be available from relevant government departments.

Worked Example 1

Assume the required water requirements for a village is estimated at 45 litres (11.9 US gallons) per person. There are 200 people in the village. The required daily volume of water required is: 45 x 200 = 9000 litres or 9 m^3 (2378 US gallons)

This data is used by the designer to select a solar water pumping system that will provide this volume of water per day. However, though this might be the required water volume, the designer must verify that the source can provide that volume of water consistently when using a solar pump that only operates during the day. This will be mostly dependent on the water resource though in some cases the solar resource may be a factor. (See section 4.2.1)

Sometimes the actual water requirements may vary by the month. If this is the case, then the maximum daily or weekly water requirements will need to be obtained and or determined in consultation with the client and water needs calculated on a month by month basis and then, using the solar resource for each month, determine the solar pumping system that can reliably provide the needed water all months of the year.

The daily water requirements can then be recorded as shown in Table 1

Table 1: Daily flow rate that is required each month

Month	Required average daily flow rate each Month in litres per day	Month	Required average daily flow rate each Month in litres per day
January	________ L/Day	July	________ L/Day
February	________ L/Day	August	________ L/Day
March	________ L/Day	September	________ L/Day
April	________ L/Day	October	________ L/Day
May	________ L/Day	November	________ L/Day
June	________ L/Day	December	________ L/Day

4.2.1 Verifying Water Resource: Borehole or Well Pump

When a borehole/well is created, the person preparing the borehole/well should undertake tests to determine the maximum flow possible from the borehole or well. The designer must obtain this information from either the client or the person/company who developed the water source. If this information is not obtained further tests must be done to obtain the maximum flow possible. This information is generally provided in litres per minute or cubic metres per hour (or gallons per minute).

When selecting the solar water pumping system, the designer shall ensure that the system does not have a maximum flow rate greater than the borehole can provide.
The volume of water pumped by a solar water pumping system varies throughout the day because the

available solar power (irradiance) varies throughout the day. This results in the maximum flow rate possible from the borehole pump only being achieved when the solar power (irradiance) is at its highest value during the day and also means that there will be no water pumped after sunset and before sunrise. There may be times, because of this maximum flow rate possible from the borehole and the fact that the solar water pumping system can only provide a specified total volume of water over a day, that a system cannot be selected to meet the total daily water volume required. If this occurs the designer may need to include batteries to allow the water to be pumped more slowly and more evenly over more hours of the day. If the borehole is close to having the capacity to deliver the needed water during the day, another alternative could be selecting an oversized solar water pumping system that intentionally has a maximum flow rate greater than that being provided by the borehole. During the periods of lower solar power (irradiance) the system will be pumping less than the maximum flow rate of the borehole but still more than the possible flow from a smaller pump. For the periods when the available solar power results in a pumped flow rate greater than that possible from the borehole, the designer can include in the system installation a set of water sensors which turn the water pump off when the water falls below the level of the intake of the pump. It will restart when the source refills. The designer shall design the sensors such that there is not an excessively rapid cycling of the pump. Also arranging the solar modules so half face east and half face west will make the water delivery more even over the day by lowering the noon-time pumping rate but increasing the morning and afternoon rates.

4.2.2 Verifying Water Resource: Surface Pump.

If the water resource is a flowing stream, then the designers should try to determine if any government department has data on the flow rates for the stream. This will help to determine if there is a sufficient flow the year around for the required volume of water to be removed daily. As with the borehole/well pump, arranging half the modules to face east and half to face west will result in a more even rate of pumping over the day. If the pumping rate is still too high, then battery storage may be necessary to extend the time the pump will operate.

Ideally the designer should only design and install a system when it is known that the stream can provide that volume of water on a daily basis. The client should be informed that if the stream level lowers due to the pumping then the amount of pumping will have to be reduced.

If the water resource is a lake or pond (or even a dam), then the designer should obtain information on the total volume of water in the source. The designer should then estimate how many days or weeks storage there is in the source and inform the client. The designer should also find information on how the lake, pond or dam is filled and whether this will affect the amount of water that can be pumped daily.

4.3 Determine Where the Solar Array Will be Located.

The solar array should be located as close as is practical to the solar water pump, however it should be located where it is not shaded through the hours of 8am to 4pm. Section 5 provides more information on determining the available solar irradiation. If the system is shaded sometimes during the day, then the calculated available irradiation shall allow for the effect of the shading. Note that shading will vary, sometimes dramatically, due to the movement of the sun toward the north and south over a year’s time and from east to west over the day. The worst case shading condition should be the one used for the calculation.

For solar water pump systems, the solar array is typically provided with ground mounted stationary frames or frames that track the sun in two or three dimensions. It is recommended that because of cyclones and maintenance problems, that only stationary ground mounted arrays should be selected for systems in the Pacific Islands.

If the system being installed is a surface system and the water resource is a stream, then the solar array should be located above the known maximum flood levels of the river or protected against damage due to flooding.

4.4 Determine Where the Pump Will be Located.

The type of water pump is based on the water resource which helps determine the preferred location of the water pump.

4.4.1 Location of Borehole or Well Pump

When the borehole was installed the person drilling the borehole or digging the well should have determined the total depth of the borehole/well, the static water level and drawdown level (refer Figure 10). When water is being pumped the water level in the borehole or well will drop from the static level to the drawdown level. It will then stay at this level for a specified flow rate (litres per second or gallons per minute) The designer shall obtain this information either during the site visit or by contacting the borehole driller or well digger after the site visit.

The designer shall then determine the depth of the borehole or well pump and the bottom. The pump intake should be a minimum of 1 metre (39 inches) above the bottom of the borehole or well and the top of the pump shall be below the drawdown level by at least 1 metre (39 inches).

4.4.2 Location of Surface Pump

Surface pumps have a specified maximum suction head. This is typically no greater than 8 metres (26.3 feet) but often only from 6.5 metres (21.3 feet) to 7.5 metres (24.6 feet). This suction head includes the static head plus the frictional head of the selected suction pipe (refer section 7.4). The designer shall locate the pump so that the actual suction head is lower than the maximums specified by the manufacturer.

If possible, the surface pump shall be located above the known flooding level of the river and intake structures built to resist damage due to flood conditions. If not, the client should be informed and told what to do in the event of a flood.

4.5 Determining Length of Cables Required.

Cables are required to connect the solar array to the pump controller, and the pump controller to the pump motor.

Typically, the pump controller will be located on or near the solar array frame. Therefore, the distance between the array and the pump controller is often known by the manufacturer/supplier, however this distance should be clarified while at the site.

The critical distance is that between the pump controller and the pump. This must be determined during the site visit so the correct size cables are selected to avoid voltage drop issues and that the correct length of cable is either supplied with the complete system or obtained prior to system installation.

For surface mounted pumps the length of cable shall be dependent on the location of the solar array/pump controller and solar water pump. Determine how the cable will be installed between the pump controller and the pump to avoid the risk of mechanical or local fauna (e.g. rat) damage.

For borehole/well pumps the length of cable will be dependent on the location of the solar array/pump controller and the borehole/well and plus the depth that the pump will be located below the ground level.

4.6 Determine Where and How the Water Will be Stored.

In consultation with the client, the designer shall determine where the pumped water will be stored. This is required in order to determine the static head and the length of the water pipe used to transfer the water from the source to the point of storage. For this guideline and for simplicity it assumed that the water will be stored in a storage tank. It is acknowledged that if the system is to be used for irrigation a storage tank might not exist. In the case of stock watering systems, the drinking troughs may be considered all or part of the storage.

The advantage of a storage tank is that it can be used to store excess water on the days when the solar energy (irradiance) is greater than the value used in selecting the solar water pumping system. This excess water can then be available on the days (and nights) that the solar irradiance is less than the value used in selecting the solar water pumping system. Basically, the storage tank is an energy storage system much like a battery.

The reliability of the water supply will increase with the size of the storage tank. For installations requiring high reliability of supply, at least 5 days of storage should be provided in order to have water available even during a week of cloudy weather.

4.7 Measure the Static Head For the Site.

The static head is the vertical distance between the point where the pump obtains the water and the point where the pump discharges the water.

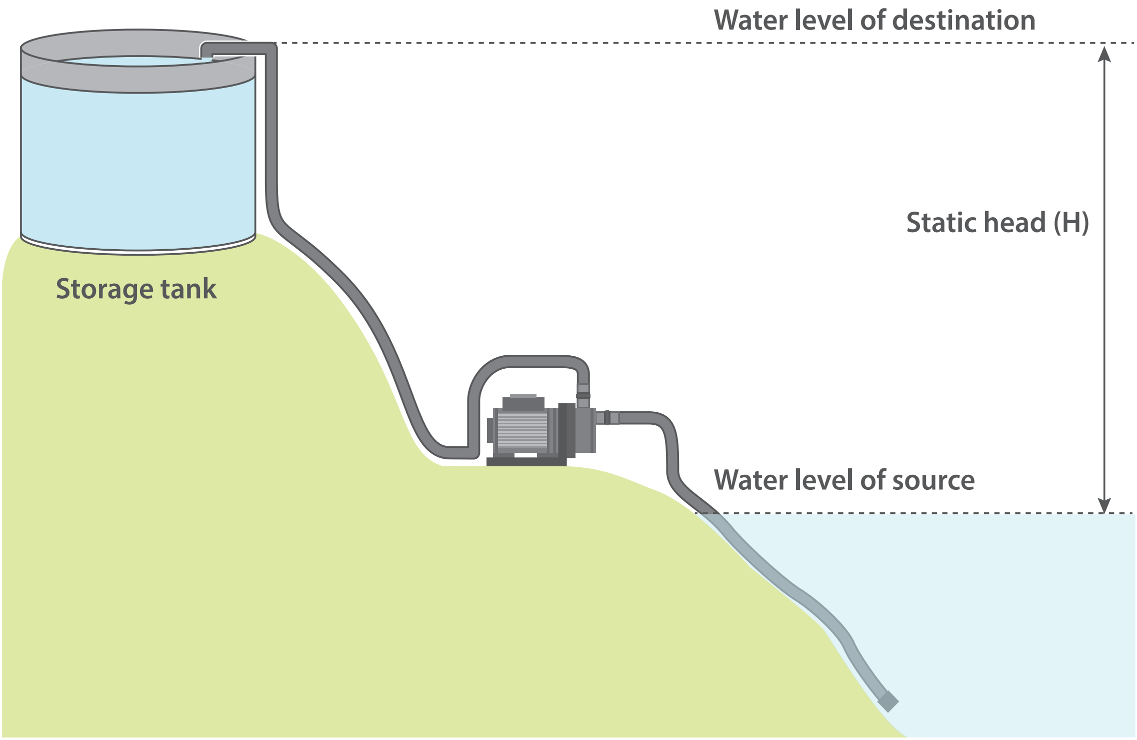

Figure 9: Total static head of a solar water pumping system

During the site visit the designer shall determine the static head. How this is determined will vary whether the water source is a borehole/well using a submersible pump or a river or lake and using a surface pump. Note that the upper limit of the head measurement is the height of the maximum level of the outlet pipe and the lower limit of the head measurement is the drawdown level of the water (the level of the water at mid-day when the pump is operating at its maximum flow rate). The pump must be capable of exceeding this static head if any water is to be delivered from the outlet pipe into the storage tank.

4.7.1 Calculating Static Head- Borehole/ Well Pump

Figure 10 shows the static head for a submersible borehole pump. It is the vertical distance between the drawdown level and the highest point in the output pipe.

This can be specified as:
Static head = Drawdown level + Static water level + Lift from surface

Note that Lift from surface level describes the distance from the pump location on the surface to the maximum elevation of the delivery pipe.

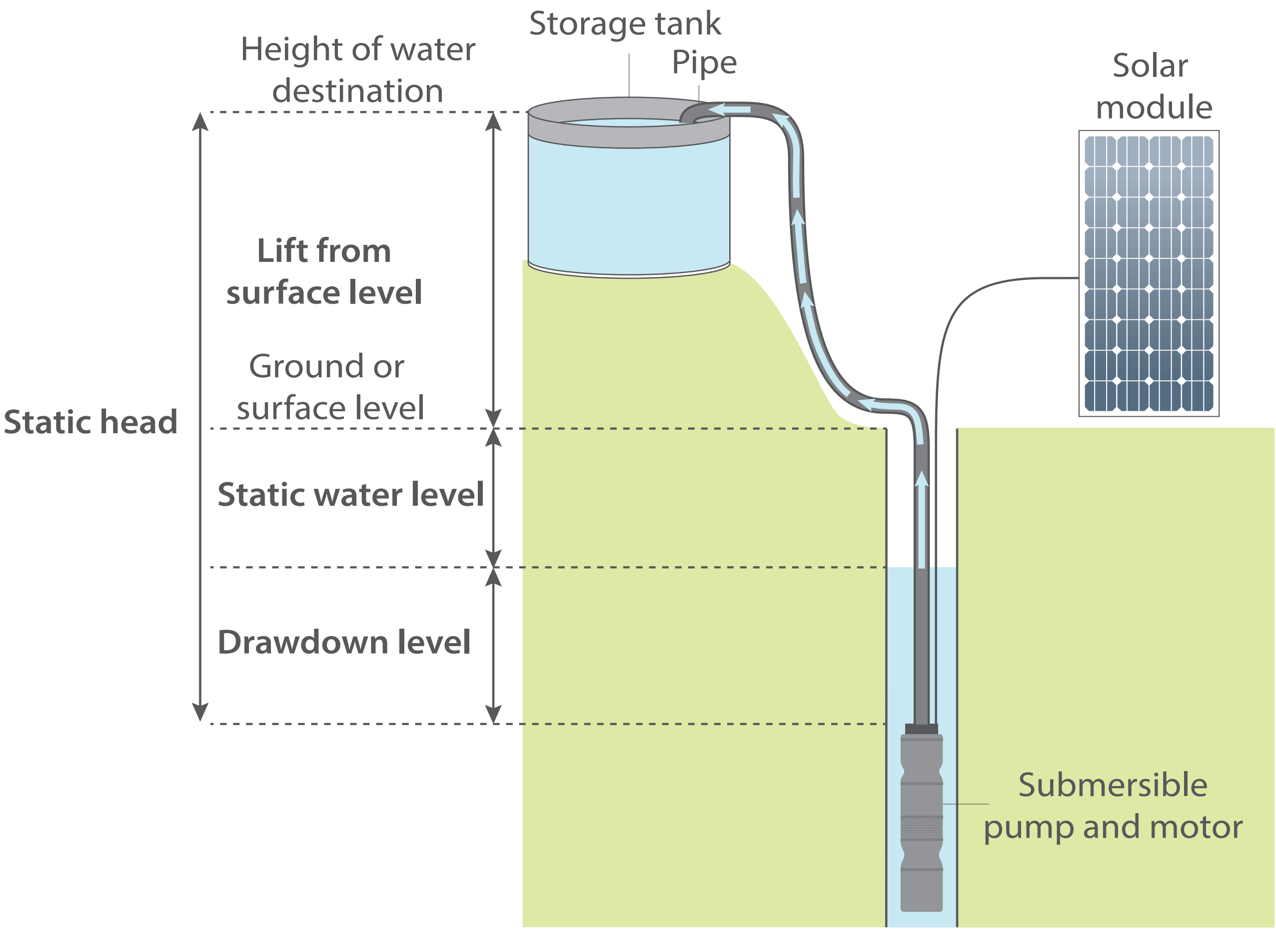

Figure 10: Static Head for submersible water pump.

4.7.2 Calculating Static Head- Surface Pump

Figure 11 shows the static head for a surface level pump. It includes the total vertical distance between the water level of the river (or dam) and the top level of the piping into the storage tank.
This can be specified as:

Static head = Suction lift + Lift from surface level

Lift from surface level describes the distance from the pump location on the surface to the maximum elevation of the delivery pipe.

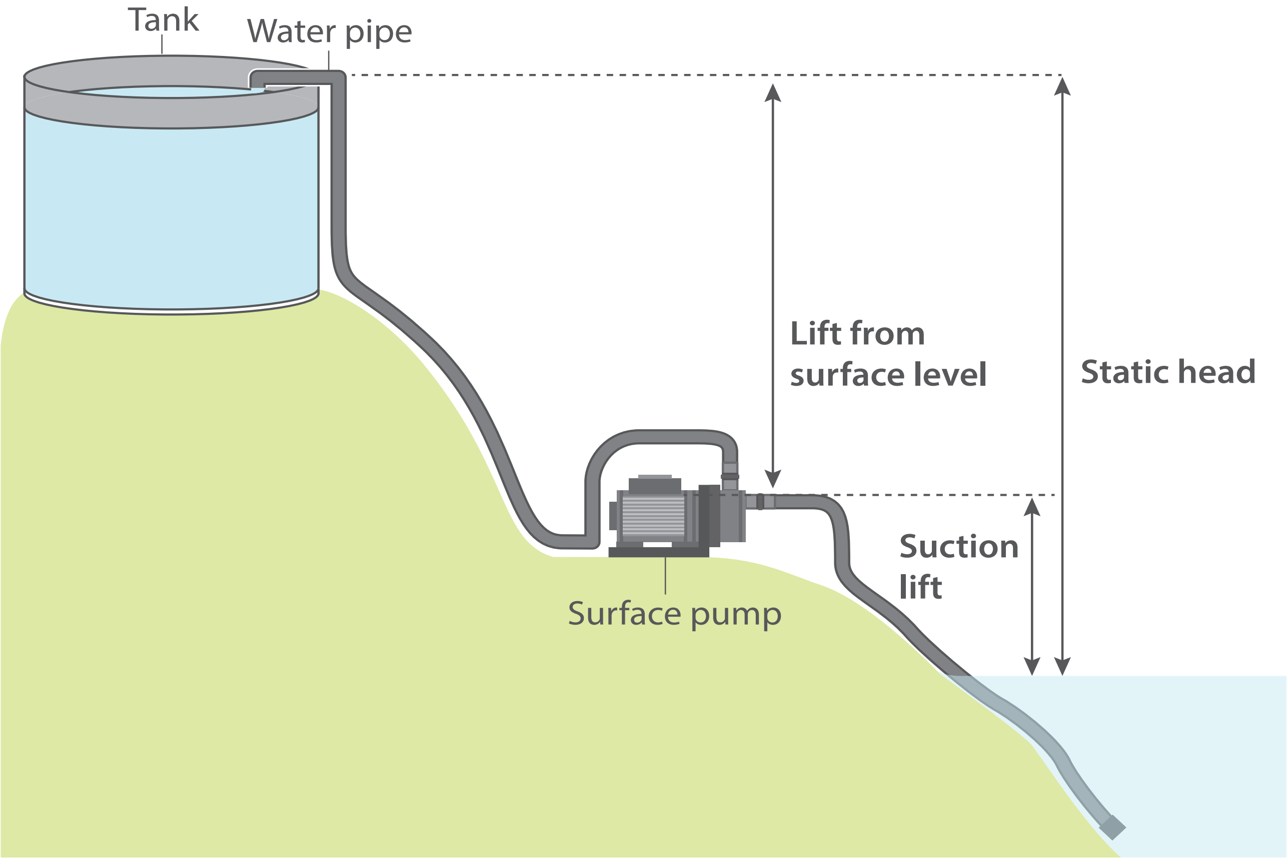

Figure 11: Static Head for Surface Level Pump

4.8 Measure the Distance Between Water Source and the Location Where Water Is Pumped.

The designer shall determine the total distance between the water resource and the location where the pumped water is stored. This distance is required for determining the length of water pipe required to move the water from the source to the storage tank. It is also used to determine the diameter of the water pipe required and frictional losses (frictional head) and ultimately the water pump and solar array rating. Note that the suction lift distance is limited by the type of pump being used and must be measured separately.

4.8.1 Borehole/ Well Pump

For the borehole/well pump the depth of the water pump in the borehole/well determines the length of pipe between the pump and the surface. The designer shall measure the distance between the top of the borehole/well to the storage tank.

Hence the total length of water pipe required is:
Distance from top of submersible pump to top of borehole/well + distance between borehole/well and the outlet at the storage tank.

4.8.2 Surface Pump

For the surface pump there will be two water pipes:

- The suction water pipe; and
- The discharge water pipe.

The lengths of both of these pipes need to be determined individually.

The designers shall measure the physical distance between the water surface at the inlet level and the location of the surface pump. This distance is to determine the length of the suction pipe and hence for calculating the frictional losses (refer section 7) of this pipe. As stated in section 4.4.2, the designer shall install so that the total suction head is less than the maximum specified by the manufacturer.

The suction head = suction lift + the frictional head.

The designer shall measure the total length of the discharge pipe from the surface pump to the outlet at the storage tank.

The two pipes, suction and discharge, will be used in determining the total dynamic head for the site.

5. Solar Irradiation

Solar data obtained from ground mounted instruments near the site that have collected at least three and preferably more than five years of solar data should be the first choice for estimating the solar energy input at the site. Such data may be available from various local sources; typically, the national meteorological or agricultural departments. In the case of some islands, (e.g. Nauru and Papua New Guinea) the United States Department of Energy Atmospheric Radiation Measurement (ARM) program has collected high quality multi-year, ground level solar data that can be obtained from the home office of the agency collecting the data.

In 2017 the World Bank launched a new tool, for the Pacific Islands as part of their solar atlas. Data can be downloaded from Global Solar Atlas - http://globalsolaratlas.info/.

One other source for solar irradiation (energy) data is the NASA website: https://power.larc.nasa.gov/. Please note that the NASA data has, in some instances, had higher irradiation figures than that recorded by ground collection data in some countries. But if there is no other data available it is data that can be used. One advantage of this data is that it is shown as monthly averages and the timing of high and low solar inputs can be easily seen.

Solar irradiation (energy) is typically provided as kWh/m^2, however, it can also be stated as daily Peak Sun Hours (PSH). This is the equivalent number of hours with a solar irradiance (power) of $1kW/m^2$. Solar water pump manufacturers typically specify their tables for a specified solar irradiation stated in kWh/m^2.

If no ground level solar data is available, Appendix 1 provides a long-term average of satellite measured monthly PSH data for the following sites:

- Alofi, Niue (Latitude 19°04'S, Longitude 169°55'W)
- Apia, Samoa (Latitude 13°50'S, Longitude 171°46'W)
- Hagåtña, Guam (Latitude 13°28'N, Longitude 144°45'E)
- Honiara, Solomon Islands (Latitude 09°27'S, Longitude 159°57'E)
- Koror, Palau (Latitude 7°20'N, Longitude 134°28'E)
- Lae, Papua New Guinea (Latitude 6°44'S, Longitude 147°00'E)
- Majuro, Marshall Islands (Latitude 7°12'N, Longitude 171°06'E)
- Nauru (Latitude 0°32'S, Longitude 166°56'E)
- Nouméa, New Caledonia (Latitude 22°16'S, Longitude 166°27'E)
- Nuku'alofa, Tonga (Latitude 21°08'S, Longitude 175°12'W)
- Pago Pago, American Samoa (Latitude 14°16'S, Longitude: 170°42'W)
- Palikir, Pohnpei FSM (Latitude 6°54'N, Longitude 158°13'E)
- Port Moresby, Papua New Guinea (Latitude 9°29'S, Longitude 147°9'E)
- Port Vila, Vanuatu (Latitude 17°44'S, Longitude 168°19'E)
- Rarotonga, Cook Islands (Latitude 21°12'S, Longitude 159°47'W)
- Suva, Fiji (Latitude 18°08'S, Longitude 178°25'E)
- Tarawa, Kiribati (Latitude 1°28'N, Longitude 173°2'E)
- Vaiaku, Tuvalu (Latitude 8°31'S, Longitude 179°13'E)

5.1 Array Orientation and Tilt

For maximum solar input at latitudes higher than 10 degrees, the fixed ground mounted array frame usually should be orientated towards the equator. This means that in the southern hemisphere the modules usually should point north while in the northern hemisphere they usually should point south. For latitudes less than 10 degrees the orientation is not an issue. Also, the tilt should never be less than 10 degrees because that much tilt is needed to allow rain water run off fast enough to help clean the modules. The available solar irradiation (energy) varies somewhat with the tilt of the array frame as can be seen in Table 2. As is noted separately in this Guideline, in some cases having half the modules tilted toward the east and half toward the west may result in more water being pumped over a 24-hour period. For maximum output, solar modules that track the position of the sun will increase the pump output but their high installation cost and their complexity that results in high maintenance requirements have not allowed them to be used successfully in the islands.

Table 2: Solar Irradiation (Energy) for Suva: latitude 18 Degrees

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.29	6.2	5.54	4.67	4.05	3.72	3.89	4.44	5.08	6.04	6.32	6.38	5.21
18° Tilt[2]	6.27	5.88	5.55	4.99	4.61	4.38	4.51	4.88	5.21	5.83	6.1	6.41	5.38
33° Tilt[2]	5.95	5.4	5.33	5.03	4.84	4.7	4.8	5	5.1	5.43	5.71	6.13	5.28

If the water use requirement is constant throughout the year and there is no significant seasonal difference in cloudiness, then the solar array will typically be tilted at latitude plus 15 degrees but the best orientation will depend on many factors including the patterns of water use, the presence or absence of battery storage, the effects of seasonal cloudiness, and the characteristics of the pumping system being installed.

If the water resource requirement varies throughout the year, the designer will need to select a tilt angle and array size such that the solar water pumping system can provide the water required for all months. (Refer to section 8 for a worked example).

5.2 Shading of Solar Array

The array should be located in an unshaded location. If shade is unavoidable then the designer shall use appropriate tools (e.g. Solar Pathfinder) to determine the loss in irradiation due to the shading and shall choose a location with minimum shade over the year.

The designer shall use a calculated or computed irradiation value when selecting the solar water pumping system (refer to section 8).

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[1] *Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day)*

[2] *Monthly Averaged Radiation Irradiance for Equator Facing Tilted surface tilted at an angle equal to the latitude of the location and at an angle equal to the latitude of the location plus 15 degrees (kWh/m²/day)*

These data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program. (https://power.larc.nasa.gov/)

6. Selecting the Water Pipe

Water pipe can be supplied as metal pipes, PVC pipes (hard plastic pipes) or polyethylene pipes (commonly known as poly pipe). Because if its flexibility poly pipe is often used with solar water pumping systems as the suction pipe for a surface pump and for the pipe within a borehole for the borehole pump.

For the discharge pipe (from the top of a borehole/well and the discharge pipe from a surface pump) the designer should select the most appropriate pipe suitable for the location that the pipe will be installed. In many cases it would be poly pipe for the intake pipe and possibly for the discharge pipe as well. However, if there is a risk that the pipe could be mechanically damaged then a pipe with stronger walls will be required. Metal pipe could be selected, however the disadvantage of galvanised iron pipe (most common type of metal pipe) in the Pacific is that it will ultimately rust and hence should be avoided. Galvanised iron pipes also have a slightly rough interior surface and usually have higher friction losses than do plastic pipes. PVC pipes with extra wall thickness for water pumping applications do exist and could be selected. If the plastic pipes are going to be exposed to the sun, they should be UV resistant or must be painted with a UV blocking paint suitable for the pipe material.

6.1 Rating of Pipes

The thickness of the water pipe wall mainly determines the water pressure that the pipe can withstand. The pressure that will affect the pipe comes from the water pump itself — that is it generates a water pressure sufficient to move the water from one location to another at the needed rate. This pressure can be determined from the dynamic head that the water pump must overcome. Water pipe specifications include the pressure rating for the pipes. The designer shall ensure that they select a pipe suitable for the maximum pressure (head) possible for the system. Table 3 shows the pressure unit conversions.

Table 3: Pressure Unit Conversions

Pressure Nominal (PN)	Kilopascals (kPa)	Metres of Water Head	Feet of Water Head	Bars	Pounds Per Square Inch (PSI)
4	400	41	134	4	58
6.3	630	65	211	6.3	90
8	800	82	268	8	116
10	1000	102	335	10	145
12.5	1250	123	419	12.5	181
16	1600	163	536	16	229
20	2000	204	669	20	290

For metric pipes, Polyethylene (PE) pipes are designated by their outside diameter or DN (for Diametre Nominal). For water and other general pressurised applications, the maximum allowable operating pressure (MAOP) with a minimum service coefficient is designated by the pressure rating or PN. The standard dimension ratio (SDR) of a PE pipe describes the geometry of the pipe and is the ratio of the outside diameter and the minimum wall thickness. Pipes with a higher SDR have a thinner wall than pipes with a low SDR. The SDR can be related to the MAOP using the material Minimum Required Strength (MRS) and the service coefficient appropriate for the application.

PE pipes are either classified as PE80 or PE100. The designations PE80 and PE100 are based on the long-term strength of the respective materials, known as the minimum required strength (MRS) in accordance with ISO 12162. The designations are provided in Table 4.

Table 4: PE Classifications

Material Designation	Minimum Required Strength (MRS) Mpa
PE 100	10.0
PE 80	8.0

Table 5 shows the comparison of SDR and Pressure Ratings denoted by PN (‘Pressure Nominal’) which are used to specify a particular water pipe.

Table 5: SDR and PN Comparison

SDR	41	33	26	21	17	13.6	11	9	7.4
PE 80	PN 3.2	PN 4	-	PN 6.3	PN 8	PN 10	PN 12.5	PN 16	PN 20
PE 100	PN 4	-	PN 6.3	PN 8	PN 10	PN 12.5	PN 16	PN 20	PN 25

Metric water pipes are sold based on their outside dimensions and their SDR ratings.

The outside diameters range from 16mm to 1200mm. Examples are 16mm, 20mm, 25mm, 32mm, 40mm, 50mm, 63mm, 75mm, 90mm, 110mm and on up to 1200mm.

The SDR ratings are specified as: 41, 33, 26, 21, 17, 13.6, 11, 9, and 7.4

Imperial (British and US) standard pipes are specified as the inside diameter in inches: ½ inch, ¾ inch, 1 inch, 1 ¼ inch, 1 ½ inch. 2 inch, 2 ½ inch, 3 inch and so on. This is the same independent of the material. The pressure ratings of pipes will depend on the actual material e.g. flexible pipe, galvanised iron, bare iron pipes etc.

6.2 Friction in Pipes

To force water to flow through a pipe there must be certain pressure at the inlet to the pipe. For there to be a flow of water, the inlet pressure must overcome both the static head and the friction losses encountered as the water flows through the pipe. When there is flow through the pipe. Thus, for the same inlet pressure, the pressure at the discharge end of the pipe will be reduced relative to no-flow conditions because of the drop in pressure due to friction losses in the pipe.

The larger the pipe the lower the percentage of the water volume flowing actually comes in contact with the inner surface of the pipe, so for a specified flow rate the friction losses will be less in a larger pipe than in a smaller pipe. Also, the rougher the inner surface of the pipe, the higher the friction losses. Galvanized iron pipe has a rougher inner surface than most plastic or copper pipes and therefore tends to have somewhat higher friction losses.

Pipe manufacturers provide tables or graphs depicting the friction loss in their pipes at various flow rates. These are generally expressed as friction head per length of pipe for a specified flow. The distance value can be per metre of pipe or, as is often expressed, per hundred metres of pipe.

Hence, by knowing the flow rate in a pipe the diameter of the pipe and the length of the pipe, the friction losses (and therefore the dynamic head) can be determined using the manufacturer's tables or graphs.

The Australian Pump Manufacturers Association, Ltd. (https://pumps.asn.au) produces a Pipe Friction Handbook that is a useful resource that provides friction losses for a variety of pipe types for various flow rates.

Figure 12 (provided in Appendix 2 in higher resolution) provides an example of a friction loss curve for various metric size poly pipes. It shows the flow in litres per second and the friction loss in metres per 100 metres of pipe. A corresponding graph for imperial pipe would show the flow as gallons per minute and the loss in pounds per square inch (PSI) per 100 feet.

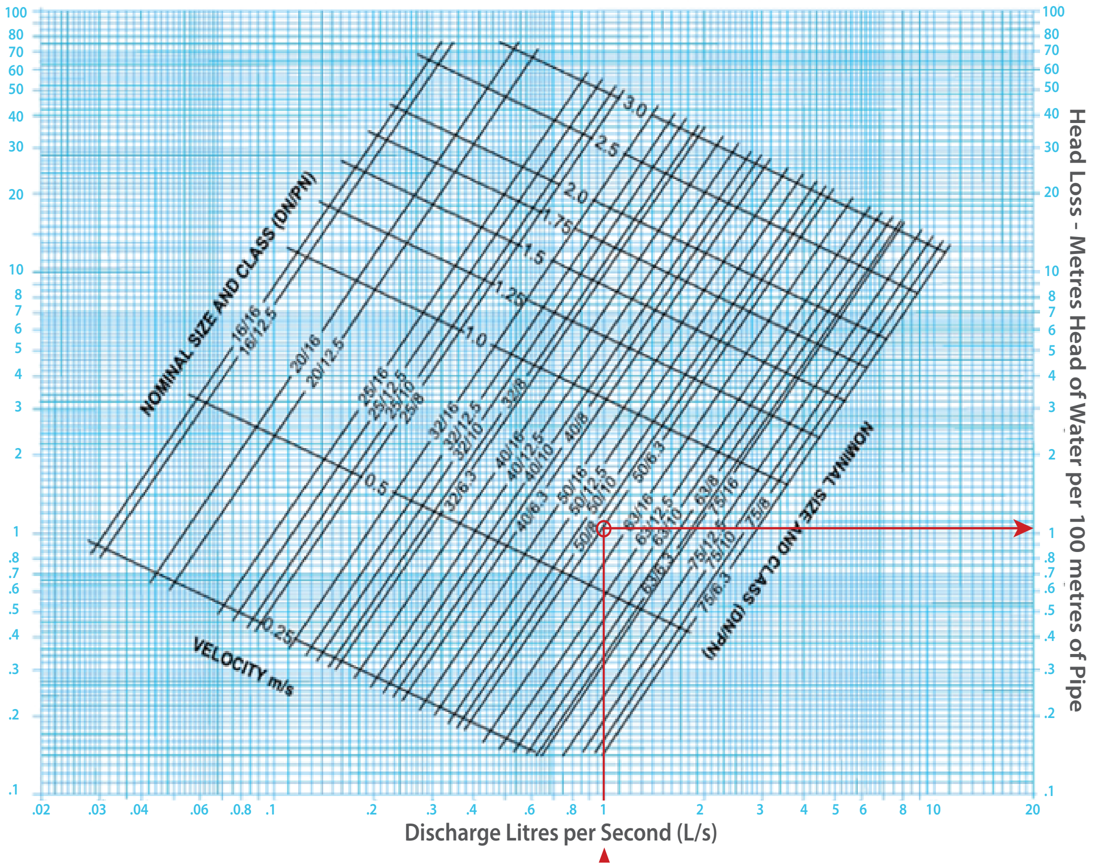


Figure 12: Chart showing friction lass for various types of Poly Pipes (metric)
(Source: Vinidex Pty Limited)

Worked Example 2 (Metric)

If the flow is 1 litre per second (3.6m^3 per hour) what is the friction loss per 100 metres of 50mm/PN6.3 poly pipe. Refer to red line in Figure 12. It is approximately 1.05 metres per 100 metres of pipe.

Table 6 provides an example of a table showing friction losses. This table is based on imperial sized poly pipe. It shows the friction loss in PSI per 100 feet of pipe. A corresponding table for metric pipe would show friction loss in metres per 100 metres of pipe based on flow rates in litres per second.

Table 6: PSI Loss per 100 feet for Poly Pipe (tube)

Size	1/2”		¾”		1”		1 ¼”		1 ½”		2”		2 ½”	
ID	0.622		0.824		1.049		1.380		1.610		2.067		2.169	
Flow GPM	Velocity FPS	PSI Loss	Velocity FPS	PSI Loss	Velocity FPS	PSI Loss	Velocity FPS	PSI Loss	Velocity FPS	PSI Loss	Velocity FPS	PSI Loss	Velocity FPS	PSI Loss
1	1.05	0.49	0.6	0.12	0.37	0.04	0.21	0.01	0.155	0.00	0.095	0.00		
2	2.10	1.76	1.2	0.45	0.74	0.14	0.42	0.04	0.31	0.02	0.19	0.01		
3	3.16	3.73	1.8	0.95	1.11	0.29	0.63	0.08	0.47	0.04	0.29	0.01	0.20	0.00
4	4.21	6.35	2.4	1.62	1.48	0.50	0.84	0.13	0.62	0.06	0.38	0.02	0.26	0.01
5	5.27	9.60	3	2.44	1.85	0.76	1.05	0.20	0.78	0.09	0.48	0.03	0.33	0.01
6	6.32	13.46	3.6	3.43	2.22	1.06	1.26	0.28	0.93	0.13	0.57	0.04	0.40	0.02
7	7.38	17.91	4.2	4.56	2.59	1.41	1.47	0.37	1.09	0.18	0.67	0.05	0.46	0.02
8	8.43	22.93	4.8	5.84	2.96	1.80	1.68	0.47	1.24	0.22	0.76	0.07	0.53	0.03
9	9.49	28.52	5.4	7.26	3.33	2.24	1.89	0.59	1.40	0.28	0.86	0.08	0.60	0.03
10	10.54	34.67	6	8.82	3.7	2.73	2.1	0.72	1.55	0.34	0.95	0.10	0.66	0.04
11	11.60	41.36	6.6	10.53	4.07	3.25	2.31	0.86	1.71	0.40	1.05	0.12	0.73	0.05
12	12.65	48.60	7.2	12.37	4.44	3.82	2.52	1.01	1.86	0.48	1.14	0.14	0.80	0.06
14	14.76	64.65	8.4	16.46	5.18	5.08	2.94	1.34	2.17	0.63	1.33	0.19	0.93	0.08
16	16.87	82.79	9.6	21.07	5.92	6.51	3.36	1.71	2.48	0.81	1.52	0.24	1.07	0.10
18	18.98	102.97	10.8	26.21	6.66	8.10	3.78	2.13	2.79	1.01	1.71	0.30	1.20	0.13

(Source: Hunter Industries)

If metal pipes are being used, in particular galvanised pipes, due to the roughness of their surface they tend to have higher PSI losses than poly pipe for similar flow rates.

Worked Example 3 (US/Imperial)

The flow is 15.85 gallons per minute (3.6 m^3 per hour) what is the friction loss per 100 feet of 2inch poly pipe. From Table 6, 16 gallons per minute is 0.24 PSI per 100 feet. Using Table 3, PSI = 2.31 feet head. So 0.241 PSI per 100 feet = 0.56 feet per 100 feet

Whenever the flow of the water changes speed or direction there will be a resultant friction loss. Therefore, bends, changes in pipe diameter and the presence of valves will all have an effect on the friction losses in a piping system. This is detailed in section 7.

6.3 Flow Rates

In solar water pumping systems without batteries, the flow rate will vary during the day due to the variations in available solar energy. The solar pump manufacturer should provide information on the maximum flow rate for a particular solar water pumping system that is based on the pump selected for the complete system operating at a specified input power. The actual flow rate will also vary depending on the actual total dynamic head of the system. So, at first it is very difficult to estimate what the actual maximum flow rate in the water pipe will be for a specific pump. The solar pump manufacturer will often provide the maximum possible flow rate for the water pump that is supplied with the system.

Figure 13 shows the actual flow rates of three of the pumps used in a Mono Pump surface water pumping system.


SRX CP25
Up to 50 Mts
Up to 28 L/min

SRX CP800
Up to 35 Mts
Up to 68 L/min

SRX CP1600
Up to 25 Mts
Up to 130 L/min

Figure 13: Maximum Flow Rates of three pumps used in Mono Surface Solar water Pumping Systems (Source: Mono Pumps)

The designer must use this maximum flow rate when undertaking the initial estimate of the friction losses in the selected water pipe.

The final actual maximum flow rate in litres per second (or gallons per minute) for the system will often be less than the maximum for the pump because of the effect of the actual dynamic head on the system.
To help explain this, Tables 7a and 7b show the data sheets provided by Mono Pumps for selecting a solar water pumping system using their surface pump. The three colours match the three different pumps shown in Figure 13. It can be seen that as head increases for a specific pump and array size (in Watts) remains constant, the maximum volume of water in m^3 (multiply by 3785 to obtain number of gallons per day) being supplied over the day is reduced; this would be reflected by a reduced maximum flow rate.

Table 7a: Daily Flow in m^3 for surface Mono Solar Water Pumping Systems

6.5kW/hr average performance tracking						
	System Size (watts)					
Head (m)	200	400	600	800	1200	1600
5	33	53	102	104	110	112
10	24	46	81	93	105	108
15	17	39	47	79	98	104
20	14	31	42	62	90	99
25	11	25	36	49	80	93
30	9	20	31	34		
35	7	16	26	30		
40	6	12	15			
45		10	13			
50		8	11			

Table 7b: Daily Flow in gallons for surface Mono Solar Water Pumping Systems

6.5kW/hr average performance tracking						
	System Size (watts)					
Head (ft)	200	400	600	800	1200	1600
16.4	8718	14001	26946	27474	29059	29587
32.8	6340	12152	21398	24568	27738	28531
49.2	4491	10303	12416	20870	25889	27474
65.6	3698	8189	11095	16379	23775	26153
82.0	2906	6604	9510	12944	21134	24568
98.4	2378	5283	8189	8982		
114.8	1849	4227	6868	7925		
131.2	1585	3170	3963			
147.6		2642	3434			
164.0		2113	2906			

(Source: Mono pump)

Notes:

1. The three colours in the table match the three pumps shown in Figure 13.
2. The daily flow is based on a tracking solar system and for an irradiation of 6.5kWh/m^2 per day.

A tracking array system produces approximately 30% more than a stationary system so the flow in Tables 7a and 7b can be multiplied by 0.77 (100/130) to obtain the approximate output of a stationary system. The actual difference between tracking and non-tracking solar will be less when there are many clouds as is often the case in the Pacific Islands. Therefore assuming 0.77 in creating the design is conservative and should not result in an actual water delivery that is less than the calculated value.

Worked Example 4

The solar water pumping system uses a stationary solar array. What would be the approximate daily flow of a $200W_p$ solar system at 20 metres (65.6 Ft) head?

From Table 7a, the flow with a tracking system = $14m^3$
From Table 7b, the flow with a tracking system = 3.698 US gallon

The flow with a stationary system is expected to produce = 0.77 x 14 m^3 = $10.78m^3$
(2,847 US gallons) on the same day.

For the purpose of this guideline it is assumed that the water output for sites where the irradiation is less than $6.5kWh/m^2$ per day, then the daily water flow would be a proportion of the flows shown in Table 7.

Worked Example 5

What would be the daily flow of the 200W system at 20 metres (65.6 Ft) head if the irradiation was 5 kWh/m^2 and the array was on a tracking frame?

The flow with a tracking system = $14m^3$ (3,698 US gallons)

The flow with irradiation of $5kWh/m^2$ is expected to produce = 5/6.5 x 14 m^3 = $10.77m^3$
(2,485 US gallons)

Though this guideline shows how a designer can use the data provided by the manufacturers to select the final system, most of the solar water pump manufacturers/suppliers provide free online software for selecting the correct system components. (Refer to section 8.4)

6.4 Selecting the Size of Water Pipe

The length, diameter and material (which affects the roughness of internal surfaces) of the water pipes all affect the dynamic head of the pumping system. The length of the water pipe is fixed by the on-site conditions in relation to the location of the water resource and the water delivery location (often a water tank). A larger diameter and/or pipe with a smoother internal surface will reduce the frictional head so installing a larger diameter and smoother internal surface pipe will possibly reduce the size of the pump required. However, a larger diameter and/or smoother internal surface pipe will generally also increase the system costs.

The selection process for the most appropriate water pipe will involve balancing the additional costs incurred against the increased system efficiency. However, with a solar water pumping system the solar array and its mounting is usually the costliest component so the objective is to select the smallest solar water pumping system that can provide the daily required water.

Because the friction losses increase the overall effective head (total dynamic head) that the solar water pumping system must meet, the designer shall select a size of water pipe to minimise the effect of friction losses in the system. Unlike voltage drop in electrical systems there is no maximum percentage frictional head loss specified. It is the designer's role to reduce the amount of frictional loss to minimise the total dynamic head of the complete system while maintain a reasonable cost. This is done by using a larger diameter pipe, a pipe with a smoother inside surface, using bends in the pipe that are not abrupt and minimizing the number of valves or using low head loss type valves.

The process for selecting the size of water pipe is an iterative process. The overall dynamic head is estimated based on the static head and a predicted total frictional head loss so that the designer can then select a solar water pumping system that provides the required water volume with the solar irradiation available at the site. It is recommended that the solar water pumping system be simple and includes no more than a foot (non-return) valve and one or two gate valves. Typically, the result will be adding 3 to 5 metres to the static head to obtain an estimate of the total dynamic head.

The flow in litres per second (or gallons per minute) is then determined from the specifications of the selected solar water pumping system. This would normally be the maximum flow rate stated for the water pump used in the system.

The designer then obtains the data on the specific pump used in the selected solar water pumping system. The specific data would be the size of the inlet and outlet that the water pipe would be connected to. Figure 14 a, b and c shows key dimensions of the three water pumps shown in Figure 13 and used in the solar water pumping systems used in Table 7.

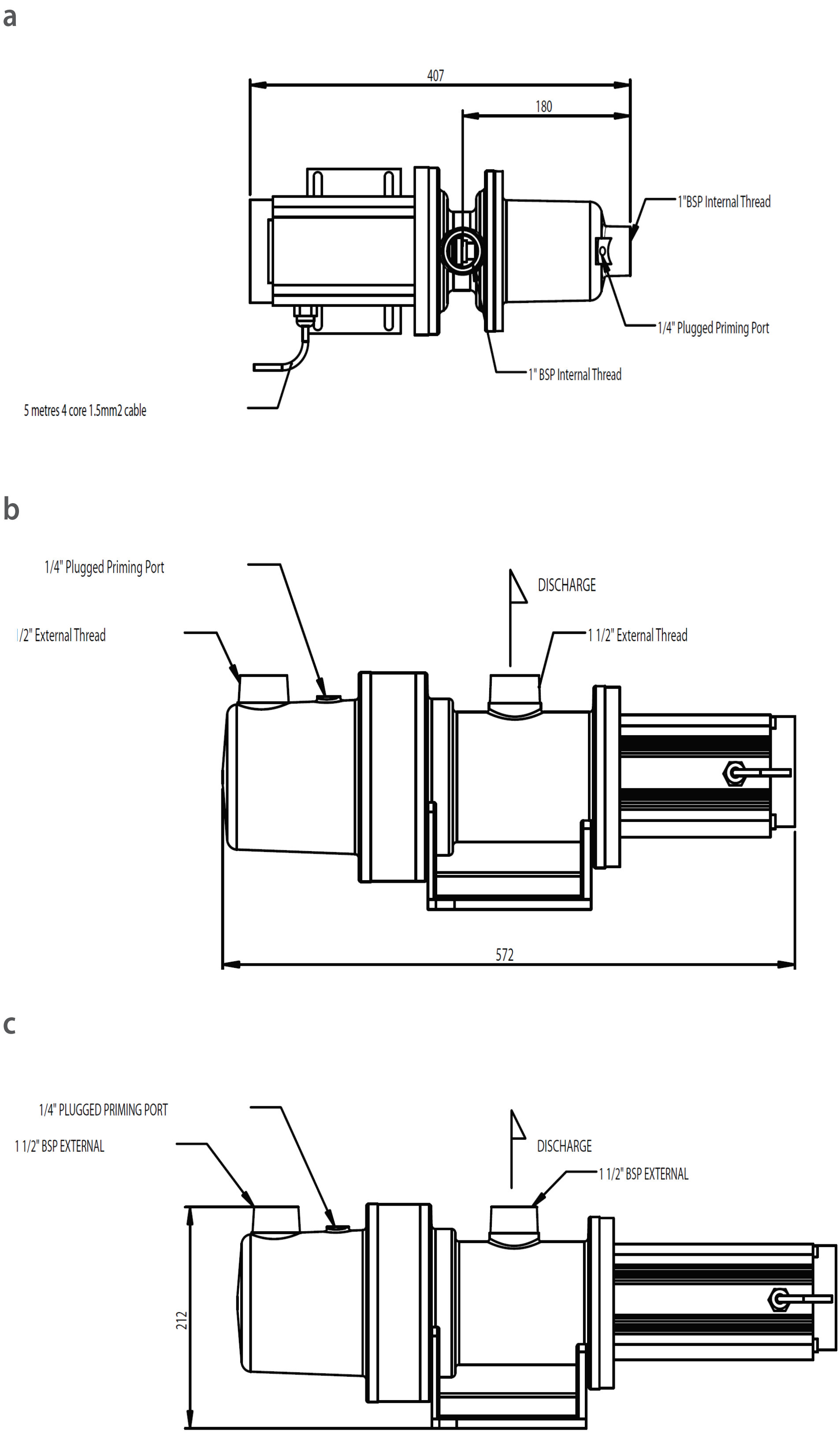


Figure 14: (a) Dimensions of CP25 Pump (b) Dimensions of CP800 Pump (c) Dimensions of CP1600 Pump (Source: Mono Pumps)

The designer should initially use pipe that is the same size as the inlets and outlets. The designer then undertakes the frictional loss calculations for that size of water pipes using the known maximum water flow for that solar water pumping system. If the frictional losses are high, in particularly greater than the 3 to 5 metres (10 to 16 feet) assumed, the designer should select a larger diameter water pipe and start again. As a result of this process the designer selects the most appropriate sized water pipe for the system.

As stated in section 6.3, because the final actual flow rate will usually be less than that used in the calculations for the friction losses, the overall result will be a lower total dynamic head and potentially a greater volume of water provided by the selected solar water pumping system than initially calculated.

7. Total Dynamic Head

The total Dynamic head includes:

- Static Head: this is the vertical distance as determined in section 4.7;
- Frictional Head- the water that is transferred by the pump from the water source to the storage tank must travel in pipes. These pipes restrict the flow of water due to friction and therefore increase the actual head that the pump must meet. Section 6.2 only considered the frictional head in a straight pipe. There are also frictional head components due to bends, reductions in pipe diameter at connection points and valves. The designer must determine all these frictional heads.
- Pressure Head: this is the head represented by the actual pressure (if any) required at the outlet of the pipe. In solar only water pumping systems this pressure head is generally ignored because a solar water pumping system with its variable energy resource is unable to provide a constant flow and constant pressure all through the day. This is not a problem when the system fills a tank or provides ditch type irrigation but In town water supplies or sprinkler irrigation systems the water must reach these outlets with sufficient pressure for the home owner in a village to provide water for showers, to provide water to a second or higher level of the house or to operate the sprinklers in the case of a piped irrigation system. For this guideline it is assumed that the water is stored in a tank and no pressure head is required to be provided by the pump.
- Velocity Head: The head in metres at the discharge nozzle of the pump. This is required for the water to be discharged from the water pipe into the storage tank. It is a function of the velocity of the water and gravity. Typically, it is less than 1 metre. So, when there are high static heads it is only a small part of total head but in low head installations it can be significant.

In summary the total dynamic head = static head + friction head of complete water piping system + velocity head at the discharge point.

Section 4.7 described how to determine static head while section 6.2 through to 6.4 describes how to calculate friction loss (frictional head) in a straight water pipe only.

7.1 Calculating Total Frictional Head of Water Piping System

As stated in section 6.2 the frictional head of the pipe is based on the length of the straight pipe, the maximum flow of the water in the pipe and the size of the pipe. Curves (Figure 12) or tables (Table 6) can be used to determine the frictional head of the pipe based on known maximum flow provided by the solar water pump manufacturer (section 6.3) and the size and characteristics of the water pipe selected (section 6.4).

Bends, reductions in pipe sizes, meters, valves, etc. all increase the frictional losses of the overall water piping system.

The friction loss in pipe fittings is determined by the following formula:

$$= K \times v^2/2g$$

Where:
K is the resistance coefficient
v is the velocity of the water in metres per second (m/s) or feet per second (FPS)
g is gravity (9.81m/s) or (32.185 f/s)

K is dependent on the type of fitting and the size and the size of the pipe that the fitting is connected to.

The K values for different types of fittings are provided by manufacturers and are also included in the Pipe Friction Handbook referred to previously.

If a solar water pumping system is installed with poly pipe, then the main valves that will exist in the system generally will include a foot valve (or non-return valve) and gate valves.

Tables 8 and 9 provides typical K values for gate valves and foot valves that are common in solar water pumping systems.

Table 8: K Values for Some Fittings (metric)

Size (mm)	16	20	25	32	40	50	63/80	100	125	150
Foot Valve	11.34	10.50	9.66	9.24	8.82	7.98	7.56	7.14	6.72	6.30
Gate Valve	0.22	0.20	0.18	0.18	0.17	0.15	0.14	0.14	0.13	0.12

(Source: Australian Pump Friction Handbook)

Table 9: K Values for Some Fittings (US/imperial)

Size (mm)	½	¾	1	1 ¼	1 ½	1 ¾	2	2 ½ to 3	4	6
Foot Valve	11.3	10.50	9.7	9.3	8.80	Not supplied	8.00	7.6	7.1	6.30
Gate Valve	0.22	0.20	0.18	0.18	0.15	0.15	0.14	0.14	0.12	0.11

(Source: Metropumps)

The velocity of the water is provided in the friction loss tables and charts.

Worked Example 6 (Metric)

If the flow is 1 litre per second ($3.6m^3$ per hour) what is the friction loss for a foot valve located in a 50 mm poly pipe. Refer to the red line in Figure 12. It is approximately 1/3 between the velocity of 0.5 and 1.0 metres per second—so V, the velocity would be about 0.667 m/s.
From Table 8 the K value is 7.98

Hence the friction loss is:
$= K \times v^2/2g$
$= 7.98 \times 0.667^2/ (2 \times 9.8)$
= 0.18 metres

Worked Example 7 (US/Imperial)

The flow is 15.86 gallons per minute (952 gallons per hour) what is the friction loss for a foot valve located in a 2inch poly pipe. Refer to Table 6, the velocity would be about 1.52 feet/s.
From Table 9 the K is 8

Hence the friction loss is:
$= K \times v^2/2g$
$= 8 \times 1.52^2 / (2 \times 32.185)$
= 0.29 feet

When determining the friction loss of the solar water pumping pipe system the designer shall include the friction loss of the pipe and those of the various pipe fittings.

Worked Example 8 (Metric)

The village used in Worked Example 1 is located beside a river. The surface pump will be located 4 metres above river level. The suction pipe will be 12 metres in length. The water will be stored in a water tank that is located 100 metres away from the river and 10 metres vertically above the location of the surface pump. There will be a foot valve in the suction pipe and a gate valve in the discharge pipe. The daily irradiation is 6.5 kWh/m^2 and the solar array will be mounted on a fixed array frame. The village requires a minimum of 9 m^3 of water per day. What pipe would you select and what would be the total frictional head loss of the water piping system?

The total frictional head loss of the water piping system will consist of:
Frictional head loss of suction pipe plus frictional head loss of discharge pipe plus frictional head of a foot valve plus frictional head loss of a gate valve.

The total static head = 4 + 10 = 14 metres. After allowing 3 to 5 metres for estimated frictional head loss — this would assume a total dynamic head is 17 to 19 metres.

Referring to Table 7a, the 200W solar system can provide 14 m^3 with a head of 20 metres using a tracking solar system. Using a stationary array frame this will produce 0.77 x 14m^3 = 10.78m^3. This system should meet the requirement of providing a minimum of 9 m^3 of water per day. From Figure 13 it can be seen that the pump to be used is the CP25 with a maximum flow rate of 28 L/min or 0.47 L/sec.

Referring to Figure 14a the inlet and outlets are 1 inch. Therefore, start with 25mm diameter water pipes for the inlet and outlet

Figure 15 below is an excerpt from Figure 12. Referring to the figure, it can be seen that at 0.47 L/sec with 25mm/8PN poly pipe the frictional head loss is about 9 metres per 100 metres of pipe; this is too much particularly considering the discharge pipe is 100 metres in length.

Selecting a 40mm/6.3PN poly pipe the friction loss decreases to approximately 0.8 metres per 100 metres of pipe, so this will be selected.

So the 40mm/6.3PN poly pipe will be selected for the water piping system.

The total length of pipe is 12 metres (suction) plus 100 metres (discharge)= 112 metres.

Therefore, the friction head loss due to water pipe = 112 m x 0.8m/100 m= 0.986M.

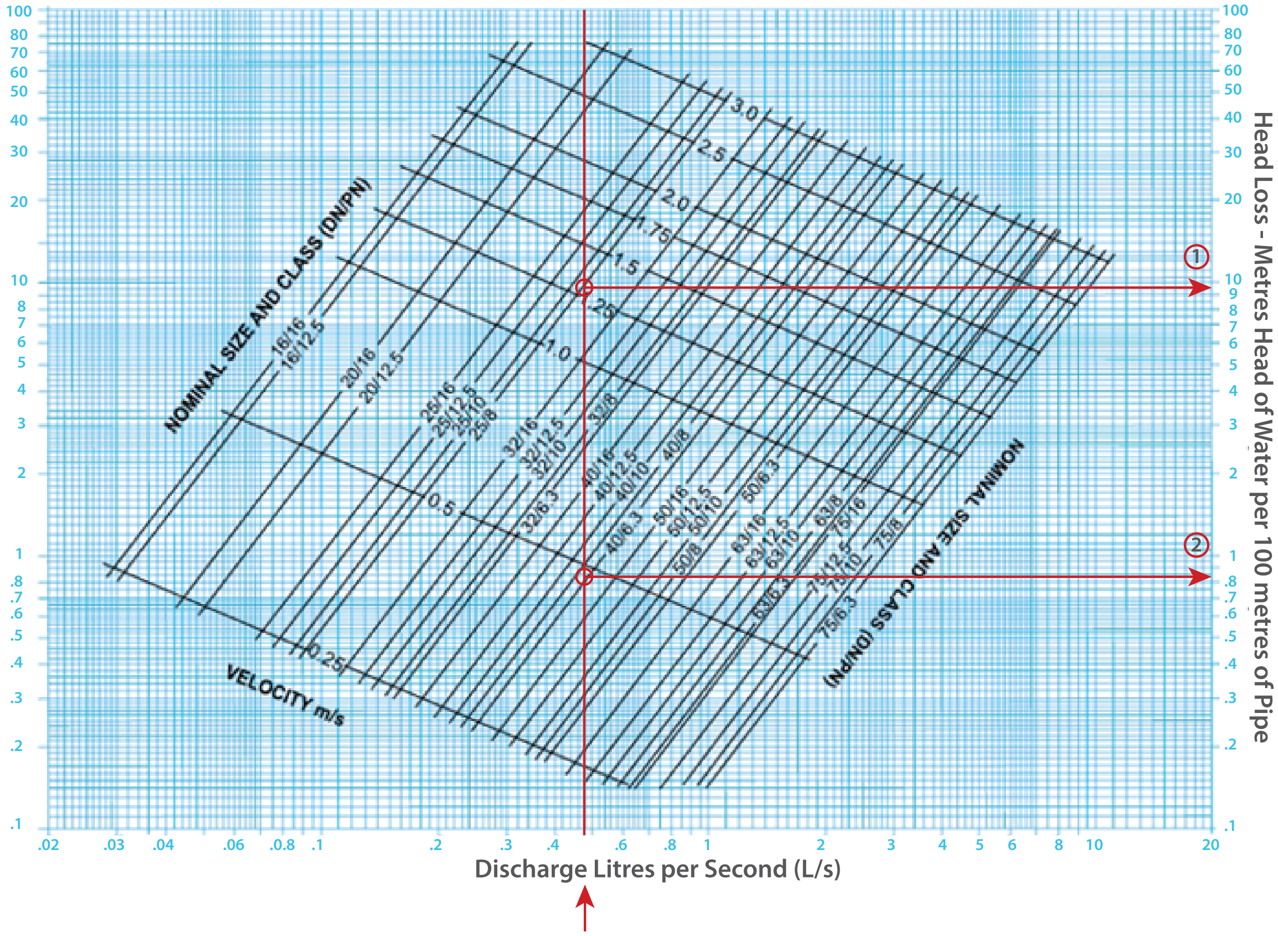


Figure 15: Friction Head Loss for Metric Poly Pipe for Worked Example (Source: Vinidex Pty Limited)

From Figure 15 the velocity for the 40mm/6.3PN pipe @0.47litres per second is approximately 0.49m/sec.

The K for the foot valve (Table 8) in a 40mm pipe is 8.82 while the k for the gate valve in a 40mm pipe is 0.17

The frictional head loss of the foot valve:
$= K \times v^2/2g$
$= 8.82 \times 0.49^2/ (2 \times 9.8)$
= 0.108 metres

The frictional head loss of the gate valve
$= K \times v^2/2g$
$= 0.17 \times 0.49^2/ (2 \times 9.8)$
= 0.002 metres

The total frictional head of the water piping system
=Frictional head of the total length of water pipe plus the frictional head of a foot valve plus the frictional head of a gate valve:
= 0.986 + 0.108 + 0.002
= 1.096 M

Worked Example 9 (US/Imperial)

The village used in Worked Example 1 is located beside a river. The surface pump will be located 13 feet above river level. The suction pipe will be 39 feet in length. The water will be stored in a water tank that is located 330 feet away from the river and 33 feet vertically above the location of the surface pump. There will be a foot valve in the suction pipe and a gate valve in the discharge pipe. The daily irradiation is 6.5kWh/m^2 and the solar array will be mounted on a fixed array frame. The village requires a minimum of 2378 gallons^3 of water per day. What pipe would you select and what would be the total frictional head loss of the water piping system?

The total frictional head loss of the water piping system will consist of:
Frictional head loss of suction pipe plus the frictional head loss of the discharge pipe plus the frictional head of a foot valve plus the frictional head loss of a gate valve

The total static head = 13 + 33= 46 feet allowing 10 to 16 feet for an estimated frictional head loss, assume the total dynamic head to be 56 to 62 feet.

Referring to Table 7b the 200W solar system can provide 3698 gallons with a head of 65.6 feet using a tracking system. Using a stationary array frame, it will produce at least 0.77 x 3698 gallons = 2847 gallons (see Worked Example 4). This system should therefore meet the requirement of providing a minimum of 2378 gallons of water per day. From Figure 13 it can be seen that the appropriate pump is the CP25 with its maximum flow rate of 7.4 gallons per minute.

Referring to Figure 14a, the inlet and outlets are 1 inch. Therefore, for the design start with 1 inch diameter water pipes for the inlet and outlet pipes.

In Table 6 it can be seen that at 7 gallons per minute with 1inch poly pipe (tubing) the frictional head loss is about 1.41 PSI per 100 feet of pipe and 1.80 PSI at 8 gallons per minute. At 7.4 gallons per minute it would be approximately 1.56 PSI which is 3.6 feet of frictional head per 100 feet of pipe, this is too much particularly considering that the discharge pipe is 330 feet in length.

Selecting a 1 ½ inch poly pipe the friction loss decreases to approximately 0.196 PSI which is an acceptable 0.453 feet of frictional head per 100 feet of pipe (see Worked Example 3 for how to convert PSI to feet), so this will be selected.

So, 1 ½ inch poly pipe (tubing) will be selected for the water piping system.

The total length of pipe is 39 feet (suction) plus 330 feet (discharge) = 369 feet.

So the friction head loss due to the water pipe = 369 ft x 0.453 ft/100 ft= 1.67 feet.

From Table 6 the velocity for the 1 ½ inch poly pipe @7.4 gallons per minute is approximately 1.175 feet per second.

The K for the foot valve (Table 7) in a 1 ½ inch pipe is 8.80 while the k for the gate valve in in 1 ½ inch pipe is 0.15

The frictional head loss of the foot valve.:
= K × $v^2/2g$
= 8.80 × 1.175^2/ (2 × 32.185)
= 0.189 feet

The frictional head loss of the gate valve
= K × $v^2/2g$
= 0.15 × 1.175^2/ (2 × 32.185)
= 0.003 feet

The total frictional head of the water piping system = Frictional head of the total water pipe plus the frictional head of the foot valve plus the frictional head of the gate valve:
=1.67 + 0.189 + 0.003
= 1.862 feet

When determining the total friction loss for the piping system for a borehole/well pump there will just be the discharge pipe and associated pipe fittings. If poly pipe (flexible plastic tubing) has been used, then there might be a foot valve (also called non-return valve) on the outlet of the submersible pump and a gate valve located at the exit of the borehole. The calculations will then be similar to what has been shown in the worked examples for the surface pump.

7.2 Velocity Head

The velocity head is determined by the following formula:

$$\text{Velocity head} = v^2/2g$$

where:
v is the velocity of the water in metres per second (m/s) or feet per second (FPS)
g is gravity (9.81m/s) or (32.185 feet/s).

The velocity of the water is provided in the friction loss tables and charts.

Worked Example 10 (Metric)

For the water pipe system determined in Worked Example 8, what is the velocity head?

The velocity was 0.49 metres per second.

The velocity head
= $v^2/2g$
= 0.49^2/ (2 × 9.8)
= 0.012 metres

Worked Example 11 (US/Imperial)

For the water pipe system determined in Worked Example 9, what is the velocity head?

The velocity was 1.175 feet per second.

The velocity head
= $v^2/2g$
= $1.175^2/(2 \times 32.185)$
= 0.021 feet

7.3 Calculating Total Dynamic Head

The total dynamic head = static head + friction head of the complete water piping system + velocity head.

Worked Example 12 (Metric)

For the solar water pumping system used in Worked Example 8, what is the total dynamic head?

From Example 8 the static head = 4 + 10 = 14 metres

The total frictional head loss based on maximum flow of the pump was calculated as 1.096 M

The velocity head was determined in example 10 as 0.012 metres

The total dynamic head = static head + friction head of the complete water piping system
+ velocity head.

= 14 + 1.096 + 0.012 = 15.108 metres

Worked Example 13 (US/Imperial)

For the solar water pumping system used in Worked Example 9, what is the total dynamic head?

From Example 9 the static head = 13 + 33 = 46 feet

The total frictional head loss based on maximum flow of the pump was calculated = 1.862 feet

The velocity head was determined in example 11 as = 0.021 feet

The total dynamic head = static head + friction head of the complete water piping system
+ velocity head.

= 46 + 1.862 + 0.021 = 47.883 feet

This guideline has shown how to calculate the total dynamic head but the designer has to have access to pipe friction data along with the K values for various water pipe fittings. There are many websites, typically those provided by water pump suppliers and manufacturer's or pipe manufacturers, where this data is available. Many of these websites also include their own calculators for determining the total dynamic head of a water pumping system.

Some websites that provide tools for calculating dynamic head or pipe friction losses include:

- http://www.pumpworld.com/total-dynamic-head-calculator.htm.
- http://www.ajdesigner.com/phppump/pump_equations_total_head.php
- http://www.csgnetwork.com/csgdynamichead.html
- https://www.nationalpump.com.au/calculators/friction-loss-calculator/
- https://www.tuhorse.com.au/total-dynamic-head-tdh-calculator/

Some include fittings while others do not. It is recommended that the designer determine where they will be sourcing pipes and fittings and check the websites of those companies to see if there are tools suitable for the pipe systems selected by the designer.

7.4 Suction Head

For a system where the water pump is a surface, the pump is effectively "sucking" the water from the water resource – e.g. river, pond or lake, then the total dynamic head of the water piping system should be analysed in two parts: total dynamic head on the suction side and the total dynamic head on the discharge side.

The formulas for determining the total dynamic head is as follows:

$H = h_d + h_s + f_d + f_s + v^2/2g$

Where:

H = Total Dynamic Head in metres (or feet) delivered by the pump when pumping the desired flow.
h_d = static discharge head in metres (or feet)
h_s = static suction head or lift in metres (or feet)
f_d = friction head in discharge pipe in metres (or feet) (must also include pipe fitting friction)
f_s = friction head in suction pipe in metres (or feet) (must also include pipe fitting friction)
$v^2/2g$ = the velocity head in metres (or feet) at the discharge of the pump

When a pump is operating in suction lift, that is the water level is below the pump, the pump actually creates a vacuum in its inlet such that the pressure is lower than the atmospheric pressure on the water surface and therefore the atmospheric pressure pushes the water into the pump.

There is a maximum head possible between the inlet of the pump and the water above which the pump will not be able to draw water due to the atmosphere not having enough pressure to push the water all the way up the inlet pipe). Since this is dependent on atmospheric pressure the maximum height that a pump can lift at sea level under standard conditions of atmospheric pressure is 9.81 metres (or 32.185 feet). But this varies according to the temperature of the water and also atmospheric pressure which is reduced as the altitude of the pump increases.

The pump manufacturer will specify the maximum head between the pump's inlet and the water resource.

As an example, the three pumps shown in Figure 13 have the following maximum suction heads/lifts:

- CP25: 6 metres (19.7 feet)
- CP800: 6 metres (19.7 feet)
- CP1600: 3 metres. (9.8 feet)

The total dynamic suction head must be less than the maximum head/lift specified by the manufacturer.

The total dynamic suction head = static suction head in metres (or feet) + friction head in the suction pipe in metres (or feet). Note that this must also include the pipe fitting friction value.

For most suction lift systems, the only pipe fitting will be a foot valve (non-return valve). If the pump is self-priming this may not be installed but it is still good practice to prevent the water flowing backwards down the discharge pipe since It means a slower start for the water flow because the inlet and outlet pipes must first fill with water before any will be delivered to the outlet.

Worked Example 14 (Metric)

For the solar water pumping system used in Worked Examples 8, 10 and 12 what is the total dynamic suction head and is it less than the maximum of the pump that is part of the system?

The static suction head = 4 metres

The total length of pipe is 12 metres, so friction head loss due to water pipe =
12 m x 0.8m/100 m= 0.096 metres.

The frictional head loss of the foot valve = 0.108 metres.

The total dynamic suction head = 4 + 0.96 + 0.108
= 5.06 metres

This is less than the maximum allowance of 6 metres

Worked Example 15 (US/Imperial)

For the solar water pumping system used in Worked Examples 9, 11 and 13 what is the total dynamic suction head and is it less than that allowed by the pump that is part of the system?

The static suction head = 13 feet

The total length of pipe is 39 feet, so friction head loss due to water pipe = 39 ft x 0.453 ft/100 ft = 0.177 feet

The frictional head loss of the foot valve = 0.189 feet

The total dynamic suction head = 13 + 0.177 + 0.189
= 13.366 feet

This is less than the 19.7 feet that is the maximum allowed

8. Selecting the Solar Water Pumping System

Solar water pump suppliers/manufacturers match the solar array to the pump. Some manufacturers will produce tables or graphs showing the estimated total daily water flow based on specified daily irradiation and total dynamic head for different size systems given the solar array capacity in peak watts (W_p). Many of the manufacturers have developed software for selecting the most appropriate solar water pumping system for a specified head, flow requirements and location. (Refer to section 8.4)

Tables 7a and 7b showed the daily flow for the mono surface pump systems where the array was tracking the sun and the daily irradiation was assumed to be 6.5kWh/m^2 per day. The systems ranged from 200W_p to 1600W_p.

Figures 16 provide the curves for different models of Grundfos solar borehole pumping systems ranging from 100W_p to 1400W_p. These curves are based on daily irradiation of 6kWh/m² and a stationary array mounting.

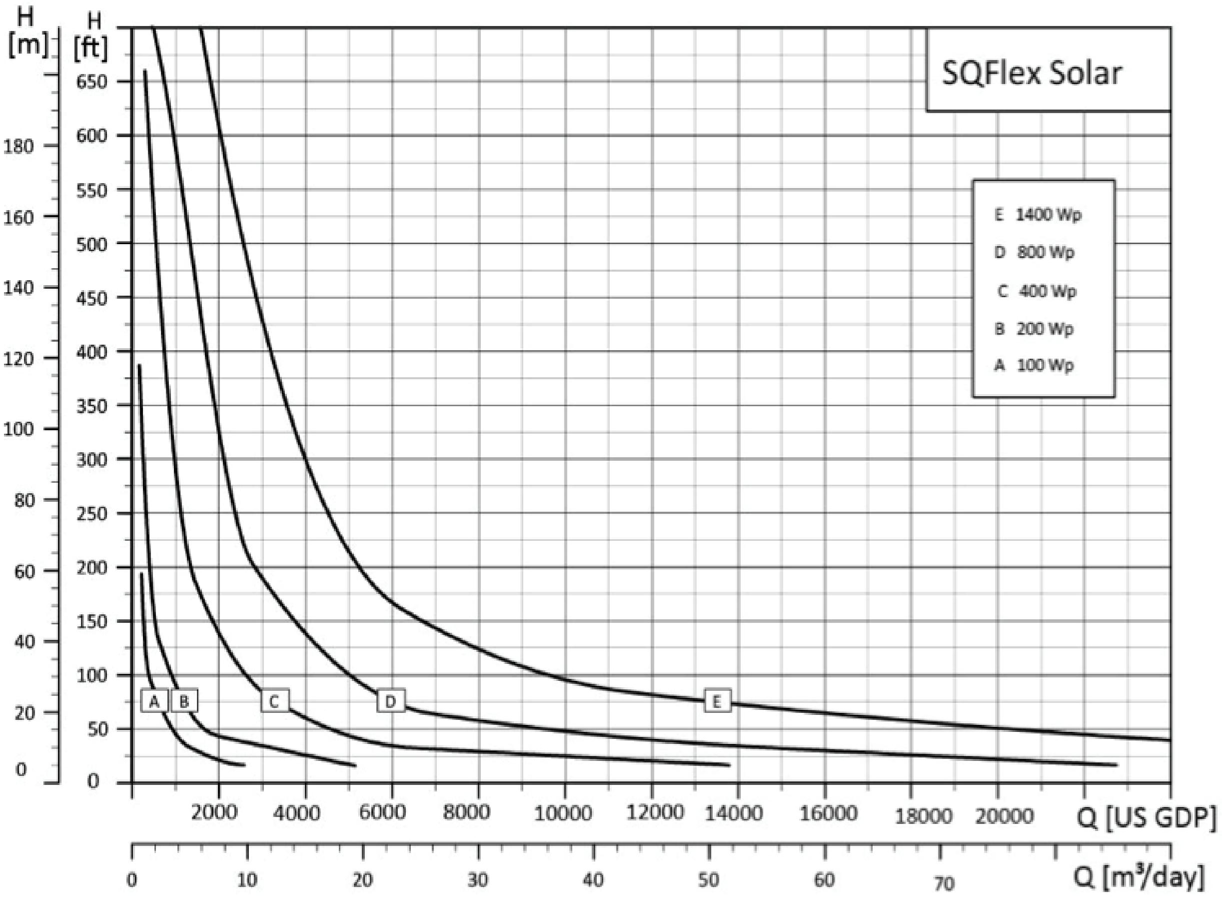


Figure 16: Curves for Grundfos SQFlex Borehole Pumps (Source: Grundfos Pumps)

Once they have determined the daily flow requirements and the total dynamic head, the designer can use these tables and curves to select the most appropriate pumping system.

Worked Example 16 (Metric)

The designer has determined that the site requires 10m^3 of water per day and the total dynamic head has been calculated as 40 metres. The site has irradiation of 6kWh/m² on a fixed array frame. Which Grundfos SQFLEX solar water pumping system will be suitable?

Using Figure 16 the intersection of the 10m^3 (horizontal axis) and 40m (vertical axis) lines lie between the 400W$_p$ (System C) and 800W$_p$ (System D) systems, hence 800W$_p$ is the minimum system size that will meet the requirements.

Worked Example 17 (US/Imperial)

The design has determined that the site requires 3000 gallons per day. The total dynamic head has been calculated as 150 feet. The site has irradiation of 6kWh/m^2 on a fixed array frame. Which Grundfos SQFLEX solar water pumping system will be suitable?

Using Figure 16 the intersection of the 3000 gallons (horizontal axis) and 150 ft (vertical axis) lines lie between the 400W$_p$ (System C) and 800W$_p$ (System D) systems, hence 800W$_p$ is the minimum system size that will meet the requirements.

8.1 Solar Irradiation Varies From That Specified On Manufacturer's Product Information?

The daily flow volume will vary from that specified in the manufacturers data depending on the irradiation at the site. The variation will be directly proportional to the available irradiation compared with that provided by manufacturer’s data.

Worked Example 18 (Metric)

The designer has determined that the site requires 10 m^3 per day, the total dynamic head has been calculated as 40 metres. The site has irradiation of 5kWh/m^2 on a fixed array. Which Grundfos SQFLEX solar water pumping system will be suitable?

The metric horizontal axis shown in Figure 16 currently are in multiples of 10m^3, with minor axis of 2m^3. Based on site having irradiation values of 5kWh/m² instead of the 6kWh/m^2 these major axis values now represent 5/6 × 10 = 8.33m^3 multiples. The existing 10m^3 would represent a flow of 8.33m^3 while the next line with no number but currently 12m^3 (at 6kWh/m^2) would now be representing a flow of 9.99 m^3. The 10 m^3 flow would be at the point of 10/8.33= 1.2 lines on the horizontal axis. Therefore, 10m^3 would now be represented by 12m^3 on the horizontal axis.

Using Figure 16 the intersection of 10m^3 (approximately the 12m^3 on the horizontal axis) and 40m lines lie between a 400W$_p$ and 800W$_p$ system, hence the 800W$_p$ is the minimum system size that will meet the requirements.

Worked Example 19 (US/Imperial)

The designer has determined that the site requires 3000 gallons per day, the total dynamic head has been calculated as 150 feet. The site has irradiation of 4.5kWh/m^2. Which Grundfos SQFLEX solar water pumping system will be suitable?

The vertical lines shown in Figure 16 currently are in multiples of 1000 gallons. Based on site having irradiation values of 4.5kWh/m^2 instead of the 6kWh/m^2 these vertical lines now represent 4.5/6 x 1000 = 750 gallons. The 3000 gallons flow would be at the point of 3000/750= 4th lines on the horizontal axis. Therefore, 3000 gallons would now be represented by the 4th vertical lines. The existing 3000gallon line (at 6kWh/m^2) would represent a flow of 2250 gallons while the next line currently 4000 gallons (at 6kWh/m^2) would now be representing a flow of 3000 gallons.

Using Figure 16 the intersection of the 3000 gallons point (at 4.5kWh/m^2) and 150 ft lines is just above the 800W$_p$ system line, so in practice it might be sufficient. The 800W$_p$ curve crosses the line at approximately the 3.8 point on the horizontal axis. Therefore, the flow would be approximately 3.8 x 750 = 2850 gallons. This would need to be discussed with the user because there will be days when the irradiation is higher and days when it will be lower than the figure used to determine the flow, so the smaller amount might be acceptable. If the user wants to be conservative, then the larger system of 1400W$_p$ would be required however this would be more expensive and it would provide over 5000 gallons per day.

When using graphs and curves provided by the manufacturer/supplier the system designer must use the solar irradiation for the actual site. As shown in Table 2 and Appendix 1 the solar irradiation varies monthly and is also dependent on the tilt of the array frame.

8.2 Data Provided For Fixed and Tracking Array Frames.

It is generally estimated that tracking mounts will provide up to 30% more water using a tracking mount compared to a stationary/fixed array mounting.

When using a tracking mount and the data is based on fixed mounts then the flow values can be multiplied by 1.3.

When using a fixed mount and the data is based on a tracking mount then the flow values can be multiplied by 0.77 (1/1.3).

However, it is recommended that the designer uses the manufacturer's software, if available, when they are using a mounting system different from that used in the data sheets.

8.3 Determining the Irradiation.

When the required daily flow (volume of water) is constant throughout the year then the array should be tilted so that maximum irradiation is obtained in the month when the irradiation is at its lowest.

Worked Example 20

The irradiation for Suva was shown in Table 2 and reproduced as Table 10 in this example.

Table 10: Solar Irradiation (Energy) for Suva: latitude 18 Degrees

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt¹	6.29	6.2	5.54	4.67	4.05	3.72	3.89	4.44	5.08	6.04	6.32	6.38	5.21
18° Tilt²	6.27	5.88	5.55	4.99	4.61	4.38	4.51	4.88	5.21	5.83	6.1	6.41	5.38
33° Tilt²	5.95	5.4	5.33	5.03	4.84	4.7	4.8	5	5.1	5.43	5.71	6.13	5.28

A solar water pump system is to be installed at a site near Suva and the required water volume is constant throughout the year. What should be the tilt angle of the array and what irradiation figure should be used to select the solar water pumping system?

From Table 10 it can be seen that June is the month with lowest irradiation figure. The lowest month at other tilt angles is still June and the highest figure for June is obtained when the array is tilted at 33 degrees. So the array should be tilted at 33 degrees and 4.7kWh/m^2 should be used as the irradiation figure for selecting the solar water pumping system.

When the required daily flow (volume of water) varies from month to month then the system will need to be designed on the worst month. The worst month will be when the ratio between solar energy available and flow required is smallest. The solar energy available during that worst month and the required flow of the worst months should be chosen as the design basis for selecting the solar water pumping system.

However, since the available irradiation varies based on the tilt of the array, a number of calculations may be required to determine which is the worst month and hence what irradiation and flow requirements are used for selecting the appropriate water pumping system.

Worked Example 21

The required monthly flows are shown in Table 11, second row, for a site near Suva. The highest flow rates are required in December and January. Since these months are not the months with the lowest irradiation then the tilt angle selected would be that of the latitude angle because it provides the highest average for the year.

Using the irradiation data in from Table 10, the ratio of energy output from a solar photovoltaic (PV) system (which is proportional to available irradiation) to required flows is shown in Table 11:

Table 11: Ratio of PV energy output (proportional to available irradiation) to flow requirement (metric)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irradiation (kWh/m^2) 18° tilt	6.27	5.88	5.55	4.99	4.61	4.38	4.51	4.88	5.21	5.83	6.1	6.41
Daily flow (m^2 or 1000s of US gallons	14	13	12	11	10	10	10	10	11	12	13	14
Irradiation/ daily water flow	0.448	0.452	0.463	0.454	0.461	0.438	0.451	0.488	0.474	0.486	0.469	0.458

Based on a tilt angle of 18 degrees, the lowest ratio is 0.438 so June will be the design month. If this is finalised as the design month, the solar water pumping system must then be selected based on an irradiation of 4.38kWh/m^2 and the required flow of 10 m^3 or 10000 litres (2,642 gallons).

However, since the ratios was determined using the latitude (18 degrees) as the tilt angle, tilting the array at 33 degrees does provide a higher irradiation value in June, so the ratios should also be compared for that tilt angle. This is shown in Table 12:

Table 12: Ratio of PV energy output (proportional to available irradiation) to flow requirement (Imperial)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irradiation (kWh/m^2) 33° tilt	5.95	5.4	5.33	5.03	4.84	4.7	4.8	5	5.1	5.43	5.71	6.13
Daily flow (m^2 or 1000s of US gallons	14	13	12	11	10	10	10	10	11	12	13	14
Irradiation/ daily water flow	0.425	0.415	0.444	0.457	0.484	0.470	0.480	0.500	0.464	0.453	0.439	0.438

The lowest ratio is 0.415, so February will be the design month and the available irradiation in February is 5.4kWh/m^2 and the required flow from the system would be 13 m^3 or 13000 litres (3,434 gallons).

So, should 13m^3 or 13000 litres (3434 gallons) @ irradiation of 5.4kWh/m^2 be used for selecting a solar water pumping system or should 10 m^3 (or 2642 gallons) @ irradiation of 4.38 kWh/m^2 be used? In reality both could be used and it is possible that the same system would be selected for both. If this is the case, then the array could either be tilted at 18 or 33 degrees.

Many of the manufacturers/suppliers provide systems selection software. It is recommended that the system designer uses this software to help select the most appropriate system.

8.4 Examples of Software

Some manufacturers provide sizing software online to assist individuals/communities to select the most appropriate solar water pumping system. This section of the guideline provides some examples.

8.4.1 Grundfos Pumps

Grundfos Pumps provides their sizing tool through the following link:
https://product-selection.grundfos.com/front-page.html.

On that screen select: Sizing (in blue) and then “Advanced sizing by application” and select “solar water solutions”. That will bring up a screen where the data for a site is entered for either a surface or borehole/well pump and the program will select the solar water pumping system.

The two programs Grundfos has developed are Grundfos WinCAPS and WebCAPS. These contain all the Grundfos pumps and can be used for selecting the most appropriate Grundfos type of solar water pumping system.

8.4.2 Mono Pumps

The Mono Pumps sizing software is called CASS (computer aided solar simulation), downloadable from http://www.solarcass.com/. It includes their main solar pumping products.

Steps to download and use the CASS software:

1. Follow the link: http://www.solarcass.com/ on an Internet browser. It will take you to the CASS website

NOV - CASS 5.0.0.0
.Exe (74 Mb)

If you Do Not Already have CASS installed.
Click the Download button above.

NOV - CASS 5.0.0.0
.Msi (17 Mb)

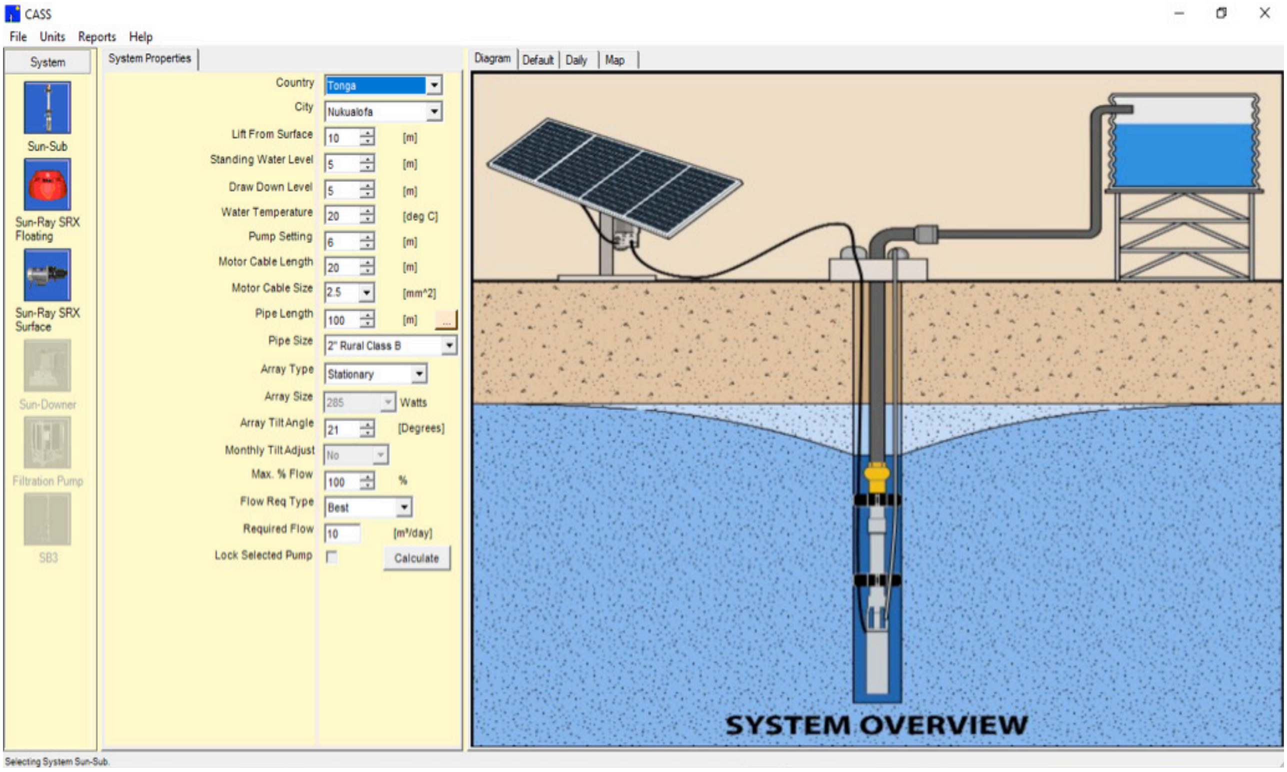
If you Already have CASS installed and wish to Update.
Click the Download button above.

Figure 17: Computer aided solar simulation (CASS)
(Source: Mono Pumps)

2. Next, you need to download the software: click on download.

3. Once successfully downloaded to your computer, locate the CASS icon on your desktop. Double click the CASS icon to open it.

4. Upon opening, you will see a screen as below:



Country: Tonga
City: Nukualofa
Lift From Surface: 10 [m]
Standing Water Level: 5 [m]
Draw Down Level: 5 [m]
Water Temperature: 20 [deg C]
Pump Setting: 6 [m]
Motor Cable Length: 20 [m]
Motor Cable Size: 2.5 [mm^2]
Pipe Length: 100 [m]
Pipe Size: 2" Rural Class B
Array Type: Stationary
Array Size: 285 Watts
Array Tilt Angle: 21 [Degrees]
Monthly Tilt Adjust: No
Max. % Flow: 100 %
Flow Req Type: Best
Required Flow: 10 [m³/day]
Lock Selected Pump: ☐

Selecting System Sun-Sub.

Figure 18: CASS program system overview
(Source: Mono Pumps)

5. Now select your location through the drop-down menu and enter all relevant information that is requested.

6. Finally, click on calculate.

The user can select a Pacific city/country that is close by and input the site parameters. The software will then calculate an average daily flow and hourly flow for each month, and suggest the appropriate Mono products to suit the requirements.

9. Installation of the Solar Water Pumping System

The installation of the solar pumping system should be performed safely and according to the equipment manufacturer's instructions. Many solar pump manufacturers/suppliers offer complete packaged systems including the wires/cables between the array, pump controller and water pump so that electrically the system is just a plug and play type system. In these systems it is only the water pipe and associated fittings, along with any material required for the array frame installation that need to be supplied by the system installer.

Though the electrical wiring may be supplied there are still some key principles for working with solar electricity that needs to be understood by the system installer:

- In some Pacific Island countries, any electrical work on sections of the system that have a voltage greater than 120V dc or 50V rms ac must be performed by a licensed electrician or similarly qualified person. Many of the larger water pumping systems will be operating in excess of 120V dc so any additional electrical wiring to that provided with the system will need to be undertaken by a suitably qualified person for that country.
- In Pacific countries following the National Electrical Code from USA, extra low voltage is defined as 60V dc and below. It is recommended that in all Pacific countries with any system operating greater than that voltage that all care shall be undertaken to never come in contact with the live wires.
- Solar modules will produce electricity at full voltage whenever they are exposed to sunlight, even early in the morning or late in the evening. Attempting to cover them (e.g. with a blanket) to stop them from generating is not a safe practice.
- All wiring should be treated as live at all times.

9.1 Array Installation

Solar water pumping systems are typically provided with an array mounting frame, either for pole mounting or fixed on the ground. The array could possibly be roof mounted but often the location of the pump is not necessarily near a building or the building roof is shaded or not of proper materials. If the array is mounted on a roof, then the installer shall follow the relevant installation requirements as detailed in the two guidelines:

- Grid Connected PV Systems- Installation Guidelines
- OFF Grid PV Power Systems- Installation Guidelines

The installer shall follow the instructions provided by the manufacturer/supplier.

9.1.1 Orientation and tilt of the array

If there is no data indicating a better orientation, in general the best year-round performance a fixed PV array mounted facing true north (± 10°) in the South Pacific and true south (± 10°) in the North Pacific at an inclination equal to the latitude angle or at an angle that will produce the greatest flow in the worst month (refer to section 8.3). Seasonal cloud patterns, local shading and environmental factors need to be taken into consideration when orienting the array. In the tropics shading could vary due to the sun being in both north and south parts of the sky at different times of the year. If available, it is best to use a solar survey instrument like Solar Pathfinder that clearly shows where shading will occur at different times of the year.

Between latitudes 10° South and 10° North the orientation of the array does not have to be exactly north or south and it should be tilted at a minimum of 10°. If the tilt angle is less than 10°, water will not run off quickly enough to clean accumulated dirt and it may pool at the bottom frame of the solar modules resulting in dirt build up and reduced power output.

9.1.2 Array Structure Installation

Typically, the array frame structure is provided with the solar water pumping system. If not, the support frame may be made of galvanised steel, aluminium or wood that has been chemically treated to prevent rotting, If the installer is sourcing the solar modules and array frame separate from the water pumping system, then the installer shall ensure:

- The array mounting frames must be wind rated in accordance with relevant wind loading standards. For those countries that have experienced Category 3 to Category 5 cyclones/typhoons then the frames shall be designed and installed in a manner that will remain intact in the wind speeds expected in a Category 5 cyclone/typhoon
- The array structures shall be designed to withstand the aggressively hot and salty atmosphere of the Pacific Islands.
- Installation of footings, posts, screws and/or in-ground fasteners shall follow manufacturer's instructions and associated installation manuals.

9.1.2.1 Installing a Post Array

A number of solar water pumping systems are provided with a single post mount array frame. Others are provided with frames to be connected to one or more posts. It is important to follow the instructions of the manufacturer and use the recommended materials and procedures in installing the posts.

In general, to install the post(s) first dig the appropriately sized hole. To comply with wind loading standards, drill a hole in the base of the post and insert a reinforcing rod through the hole with it extending at least 15 cm (6 inches) on both sides of the post, and pour concrete around the post in the hole ensuring that the concrete extends past the end of the rods at least 5 cm (2 inches) on both sides. Ensure the post is vertical and the array mount when attached to the post will be facing due north (not magnetic north) in the southern hemisphere and due south in the northern hemisphere. Vertical reinforcing rods should be inserted into the concrete as shown in Figure 19.

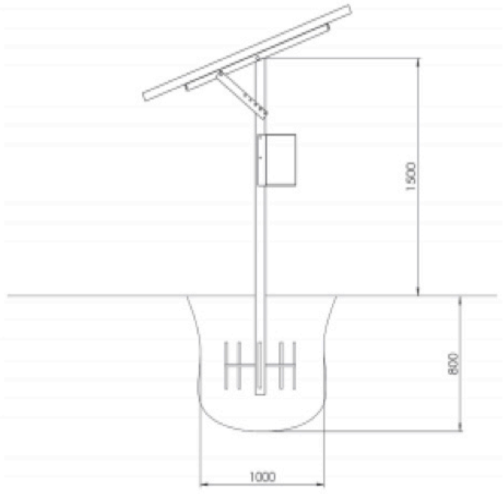


Figure 19: Typical single post array installation (Source: Mono pumps)

Note: The post should meet the manufacturer's minimum requirements. If using a wooden post, ensure that it is treated against rot or insect damage. When using a metal pipe, ensure that it is galvanised iron and is corrosion resistant. The depth in ground and the height above ground should be in accordance with manufacturer's instructions for the solar water pumping system that is chosen for that site.

9.1.2.2 Installing a Ground Mounted Array

The array frame should be mounted on a suitable foundation to meet the wind loading requirements. This will usually include concrete footings or even a concrete slab covering the area under the array. Consideration should be provided on how to minimise plant growth in the vicinity of the ground mounted structure that will grow and shade the solar modules and seriously reduce the system's performance. The area under the solar modules should be accessible for maintenance of the solar modules and for control of the growth of vegetation under the array.

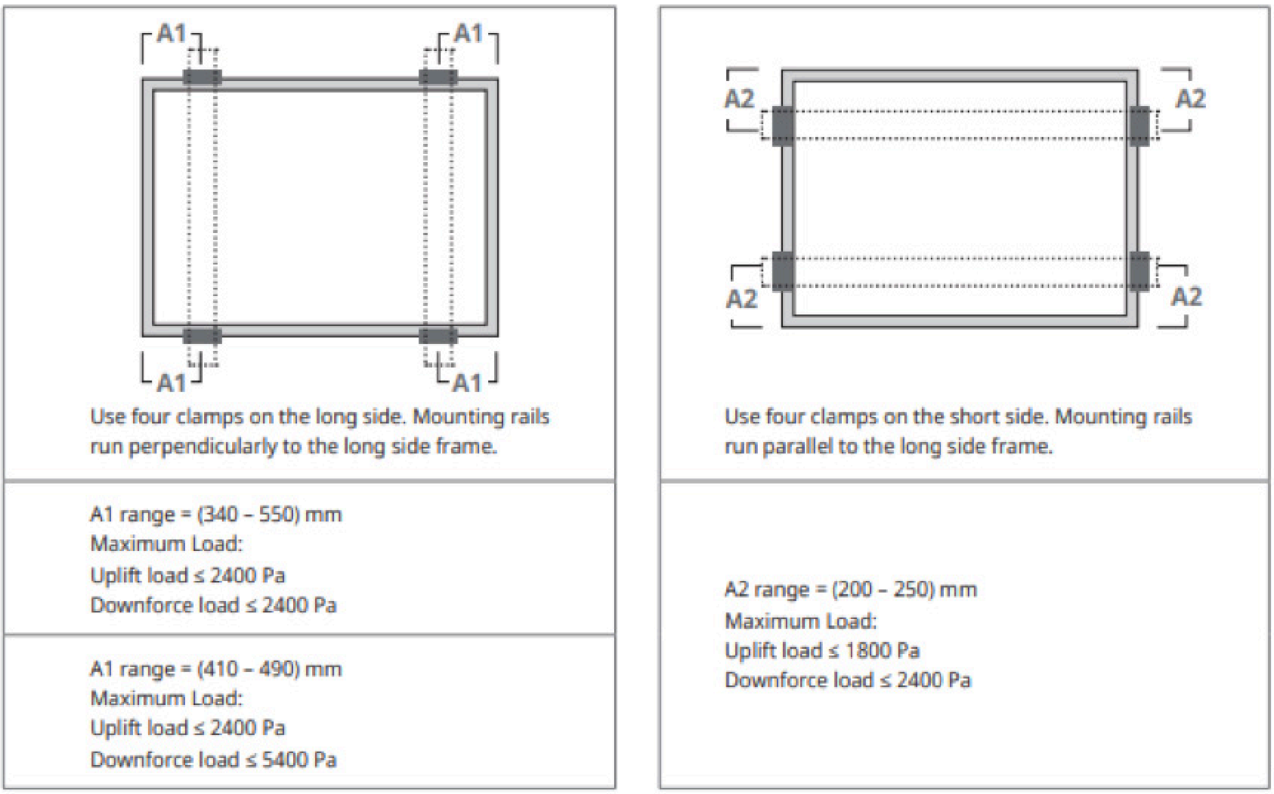
9.1.2.3 Mounting the Modules Onto the Array Frame

The installer shall follow the instructions of the manufacturer/supplier when mounting the modules onto the array frame.

The fixing of the solar modules to the mounting frame is important. The manufacturer's instructions will dictate the allowable clamping points to the solar modules and the recommended installation methods to be followed. If the array and framing are not installed according to the manufacturer's instructions and are not sufficient to suit the prevailing conditions, the structural loadings of this equipment under severe weather conditions may result in damage to the array.

If the system installer is sourcing the array frame and modules separately from the solar water pumping system then the installer shall follow the following basic rules:

- Solar modules should be attached to the array structure either using the mounting holes provided by the solar module manufacturer or via the size and number of frame clamps that are suitable for the maximum wind conditions at the site.
- The mounting of the PV modules should allow for the expansion and contraction of the PV modules due to temperature changes under the expected operating conditions.
- Where modules are installed in such a way that a junction box is mounted to the side or at the bottom of the module, care must be taken to ensure this is permitted by the manufacturer.
- Drilling holes in the frame of the solar modules is likely to void the manufacturer's warranty.
- When considering using clamps, the solar module manufacturer's installation instructions shall be followed. The installer shall consider the following:
    - amount of overhang allowed from clamp to the end of the module
    - size of clamp required
    - If the array frame is steel, the aluminium solar module frame must be electrically isolated from the steel using a layer of non-conductive material (e.g. Teflon film).
    - Stainless steel screws, washers and nuts should always be used to fasten solar modules to the array frame.



Use four clamps on the long side. Mounting rails run perpendicularly to the long side frame.	Use four clamps on the short side. Mounting rails run parallel to the long side frame.
A1 range = (340 – 550) mm Maximum Load: Uplift load ≤ 2400 Pa Downforce load ≤ 2400 Pa	A2 range = (200 – 250) mm Maximum Load: Uplift load ≤ 1800 Pa Downforce load ≤ 2400 Pa
A1 range = (410 – 490) mm Maximum Load: Uplift load ≤ 2400 Pa Downforce load ≤ 5400 Pa	

Figure 20: Example of Array Clamps
(Source: Canadian Solar)

④ Ensure the clamps overlap the module frame by at least 5 mm (0.2 in)

⑤ Ensure the clamps overlap length is at least 40 mm (1.57 in)

⑥ Ensure the clamp's thickness is at least 3 mm (0.12 in).

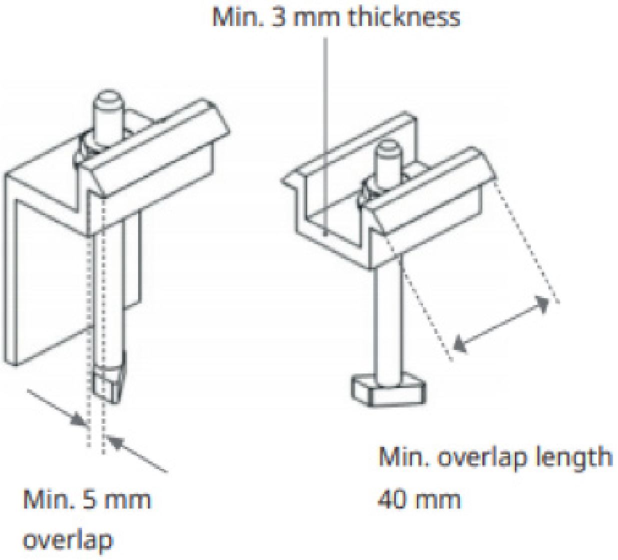


Figure 21: Module Clamps
(Source: Canadian Solar)

Note: Attaching a solar module in such a manner (e.g. drilling, pop riveting) that causes a hole in the anodised aluminium frame of the solar module typically voids the manufacturer's product warranty with respect to defects in material and workmanship. If the installer intends to undertake an installation in this manner, they shall obtain written verification from the manufacturer that it does not affect the warranty. This shall be included in the system documentation supplied to the customer.

Experience in the last few years has shown that in countries that experience category 3 plus cyclones, modules should have single module clamps on each module instead of dual module clamps. There have been a number of failures of dual module clamps due to cyclones which have resulted in a "zipper" effect whereby one clamped module comes loose then the rest of the modules in that string also come loose.

Therefore, it is important that the array frame selected has been designed to be suitable for installation to withstand Category 5 cyclones. Array frames that are designed for winds experienced in Category 5 cyclones typically have mid-clamps longer than 50 mm (2 inches) in length and there can be as many as 3 railings per module. In a large system, consideration shall be given to using an end clamp for every fourth module so if one does become loose then only a few other modules would be affected, not necessarily the whole array.

Bolting modules directly to the mounting frame and not using clamps in areas where typhoons/cyclones are likely should be considered.

9.2 System Wiring

Solar water pumping systems are typically provided with all wiring appropriate for the installation. This is why it is important to determine the distances between the solar array and water pump during the site visits. This is particularly important for borehole/well pumps because of the water-resistant cable that must be used to connect the pump.

The installation of the electrical components should be performed according to all applicable standards and the manufacturer's instructions.

9.2.1 Wiring of the Array and Pump Controller

Many solar pumping system packages will include solar modules with interconnecting cables/connectors set up for 'plug and play' by using plug and socket connectors. These modules should be installed and connected according to the manufacturer's instructions.

The output of the array shall be connected to the pump controller with the plug that has been supplied by the manufacturer/supplier.

Precaution: Some solar arrays can deliver voltage levels over 60 dc. Always unplug the solar motor pump controller from the array before working on any electrical wiring on the solar motor pump controller or motor cables.

When wiring the array frame and the cable to the pump controller:

- Plastic cable ties are not to be used as the primary means of wiring support.
- Cables shall not lay on the ground without an enclosure or conduit.
- Cables shall be protected from mechanical damage. Where the presence of fauna (e.g. rats) is expected to constitute a hazard, either the wiring system shall be selected accordingly, or special protective measures shall be adopted.
- All external wiring must be protected from UV from the sun either by using UV rated cables or installing the cables in UV rated enclosures/conduit that totally shields the cable insulation from UV exposure.
- All conduits exposed to direct sunlight shall be suitably UV rated.
- The installer shall ensure that all cable connectors are connected securely to avoid the possibility of a loose connection or the entry of moisture that may cause corrosion of the connection.
- If the array voltage is greater than 60 V dc then the cables to the pump controller should be:
    - o installed in conduit or a suitable enclosure;
    - o double insulation of each conductor shall be maintained within the enclosure; and
    - o the wiring enclosure shall be labelled 'SOLAR' on the exterior surface of the enclosure at an interval not exceeding 2 metres.

The size of the cable in cross sectional area (mm^2 for metric cables and AWG for US cables) should be specified by the solar water pump manufacturer/supplier for the required length of cable. Under maximum load conditions the voltage drop from the most remote module in the array to the input of the pump controller should not exceed 3% of the maximum power point voltage (V_{mp} at Standard Test Conditions) of the array.

Correctly sized cables in an installation will produce the following outcomes:

- o No excessive voltage drops (which equates to an equivalent power loss) in the cables.
- o The current in the cables will not exceed the safe current handling capability of the selected cables known as current carrying capacity (CCC) or ampacity.

9.2.1.1 Wiring of Arrays Provided by the Installer

If the solar modules/array have been supplied separately to the water pumping system then the cables used within the PV array wiring shall:

- Be suitable for dc applications,
- Have a voltage rating equal to or greater than the PV array maximum voltage (calculated based on the modules open circuit voltage adjusted for the minimum temperature of the site)
- Have a temperature rating according to the application.
- If exposed to the environment, cables should be UV-resistant, be protected from UV light by appropriate protection, or installed in UV-opaque conduit that is itself UV-resistant,
- Be water resistant.
- If exposed to salty environments, use tinned copper, multi-stranded conductors to reduce degradation of the cable over time due to corrosion.
- In all systems operating at voltages above 60V dc, cables shall be selected so as to minimise the risk of earth faults and short-circuits. This is commonly achieved using reinforced or double-insulated cables, particularly for cables that are exposed or laid in a metallic tray or conduit. This can also be achieved by reinforcing the wiring.
- It is recommended that module string cables be flexible to allow for thermal/wind movement of arrays/modules.
- Cables should comply with PV1-F requirements or UL 4703 or VDE-AR-E-2283-4.

Figure 22: Double insulated solar DC cable

In addition to the requirements specified in section 9.2.1 the installers shall ensure that

- All cable connectors used are waterproof and connected securely to avoid the possibility of a loose connection.
- Only cable connectors that are the same type/model from the same manufacturer are allowed to be interconnected.
- That the correct plug is used when interconnecting the array to the pump controller.

9.2.2 Wiring of Pump Controller to the Pump.

The wiring between the pump controller and the water pump should be installed according to applicable standards and the manufacturer's instructions.

If the surface pump or borehole/well is not near the solar array/pump controller then the cable shall either be installed:

- as an aerial cable; or
- direct in the ground in appropriate conduit to a depth least 500 mm (20 inches); or
- installed in metal conduit on the ground surface.
  Whichever way the cable is installed it shall be well supported and suitably mechanically protected to prevent any damage to the cable.

The connection to a surface water pump shall be with the connectors provided by the manufacturer.

The cable connected to a submersible pump shall be suitable for installation in water. It shall not be used to support the weight of the submersible pump unless specifically designed and intended for that purpose. The connection to the pump motor shall use the waterproof connectors provided by the manufacturer. The pump cable should be tied to the pump's discharge water pipe (sometimes called the rising main) every 3 metres (9.8 feet) with stainless steel cable ties. Leave a minimum of 100 mm (4 inches) of slack in the electrical cable between each cable tie to allow for stretch of the riser main pipe.

9.2.3 Earthing/ Grounding of the Array Frame.

- All exposed metal module frames and array mounting frames shall be earthed (grounded) if the PV array has a PV array maximum voltage greater than 120V dc (Note this should be 60V dc in countries adopting NEC standards)
- A minimum cable size of 4 mm² (NEC states it shall be no smaller than 14 AWG) shall be used but if the array structure is to be earthed (grounded) for lightning protection then it should be at least 16 mm² (6 AWG).
- Please check with the manufacturer's instructions because some pump controllers need to have the array frames earthed/grounded for lightning protection.
- Earth/ground connections shall be:
    - arranged so that the removal of a single module earth connection will not affect the continuity of the earthing/grounding or bonding connections to any other module;
    - by purpose-made fittings providing earthing/grounding or bonding connections for dissimilar metals and fitted according to the manufacturer's instructions, or
    - by purpose-made washers with serrations or teeth for the connection between the PV module and mounting frame and fitted according to the manufacturer's instructions.
- Self-tapping screws shall not be used.
- Ensure that rail joiners (splices) provide earth (ground) continuity. Some rail manufacturers state that the use of a rail joiner (splice) provides earth continuity between rails. If the manufacturer does not provide this information, an earthing strap shall be installed across the joint.
- The earth/grounding cable can be insulated unsheathed cable. If exposed to direct sunlight the cable shall have a physical barrier to prevent exposure to direct sunlight.
- The earth/grounding cable should be installed in parallel with and in close proximity to the PV array cables (both positive and negative) and the pump controller cables until connected to an earth rod connected in the ground.

9.3 Pump Controller Installation

The pump controller is designed to interconnect the solar arrays dc output to the water pump. For dc water pumps the pump controller will include a maximum power point tracker (MPPT) to maximise the power transferred from the array and a dc motor pump controller. For ac water pumps the pump controller will include an MPPT and an inverter to convert the solar array dc power to ac.

These are typically installed on a bracket on the array frame or on the array mounting pole. They should be mounted as per the manufacturer's instructions and should be suitably mechanically supported.

The solar pump controller shall meet the appropriate ingress protection (IP) rating for outdoor usage at the site. A minimum of IP56 is required and IP66 or higher is preferred.

9.3.1 Sensor Installations

The solar installer shall install all sensors that are recommended by the manufacturer.

Water pumping systems that are pumping water into a storage tank generally include a float switch which is installed in the water tank. This will include two sensing wires that interconnect with the pump controller. When the tank is full the float switch disconnects the power to the water pump and turns the pump back on when the water level falls to a lower level. These cables will be installed between the tank and the pump controller, often this is done by physically tying the sense wires to the discharge piping system.

Surface pumps can be installed with flow monitoring valves to protect the pump from operating dry if there is a concern that the inlet might get blocked due to the local conditions. If these are provided as part of the system, the valve will be installed on the outlet side of the water pump and the two sense wires would be interconnected to the pump controller. The pump controller will then turn power off the water pump in the event there is no water flow. Note: This would require manual resetting the valve after the inlet has been cleaned.

Borehole/well pumps will include two sensors as shown in Figure 25. Both are sensing whether there is water in the borehole/well. The lower sensor is located above the pump and will disconnect power to the pump if water falls below the level of the sensor. The higher sensor is located just below the recommended drawdown level and it will restart the pump when water covers that sensor. The sensor cables are tied to the discharge water pipe as are the pump's electrical cable.

9.4 Water Pump and Water Pipe Installation

The system installer(s) should have experience with the installation of water pipes of the type being used. The installer shall follow all manufacturer's instructions.

9.4.1 Surface Pump and Associated Pipe Installation

9.4.1.1 Pump Installation

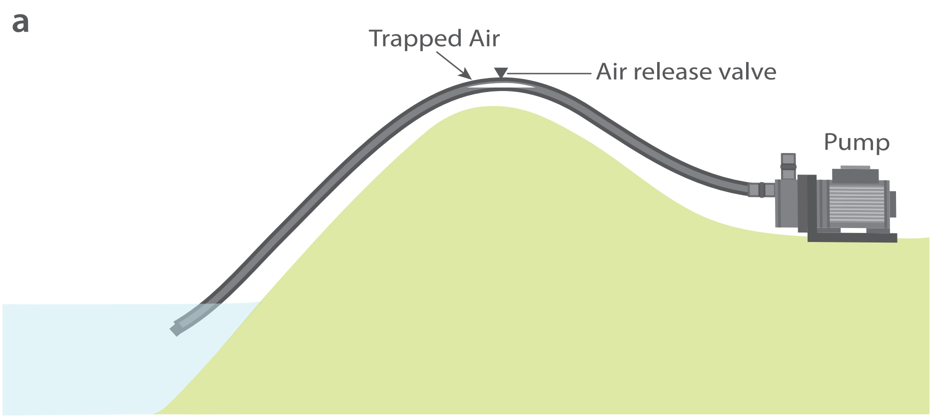
It is recommended that all pumps be protected from direct sunlight. This can be done using a sheet metal cover.

All surface pumps are to be mounted on a secure base such as a concrete pad. This will ensure pumps do not vibrate or move and thereby put stress on the water pipes.

9.4.1.2 Suction Pipe Installation

When installing the suction pipe:

- the length of the pipe shall be kept at a minimum and if using rigid pipe keep the number of bends to a minimum using sweeping bends instead of right-angle bends where practical.
- Unless the manufacturer recommends otherwise, a foot valve shall be installed at the end of the suction pipe to ensure the suction pipe does not drain when the pump is not operating
- the suction pipe shall be installed such that the end of the suction pipe is clear from obstruction (e.g. the bottom of the water source) and at a suitable depth below the water surface, so as not to suck in any air or floating debris.
- the suction pipe and pump shall be full of water (primed) prior to commissioning the pump.
- The suction pipe should be buried if it is a long length of pipe, e.g. longer than 3 metres (9.8 feet). Unburied pipe may result in the sun heating the water in the suction line which can affect pump performance.
- if possible, ensure that no point in the suction pipe that the pipe is higher than the inlet of the pump nor should there be a point where the pipe (on the water source side) is higher than another section of the pipe between that point and the pump. This may result in air being trapped as shown Figures 23 (a) and (b)



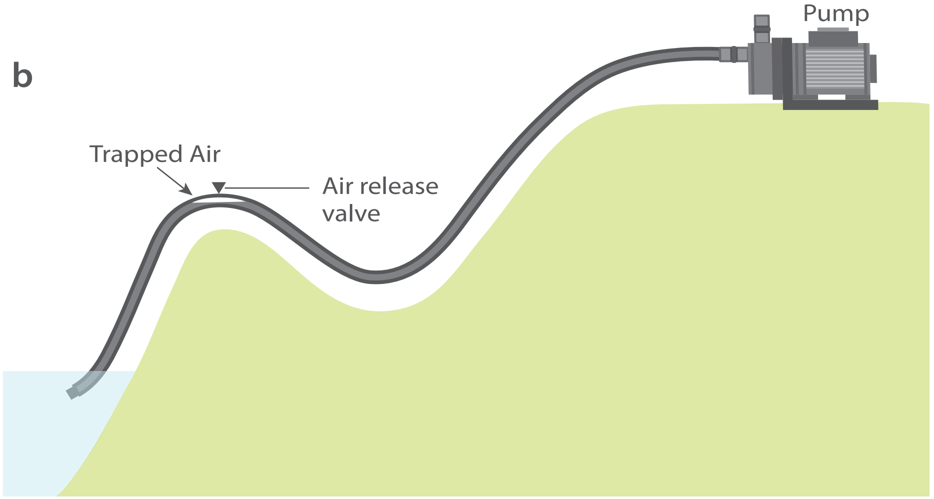


Figure 23: (a) Suction Pipe with Trapped Air (b) Suction Pipe with Trapped Air

If the piping systems shown in Figures 23 (a) or (b) are unavoidable then an air release valve should be located in the highest point (or points) of the pipe where the air can be trapped. It is important that all air is removed from the system before the pump is started. This is achieved by ensuring there is a stop valve (foot valve) on the suction inlet and that the line is "primed" – filled with water such that all air is removed before the air release valve is closed.

The suction pipe should always be as large as the inlet on the pump. If it has to be larger, then an eccentric reducer should be used; a concentric reducer should not be used. See Figure 24.

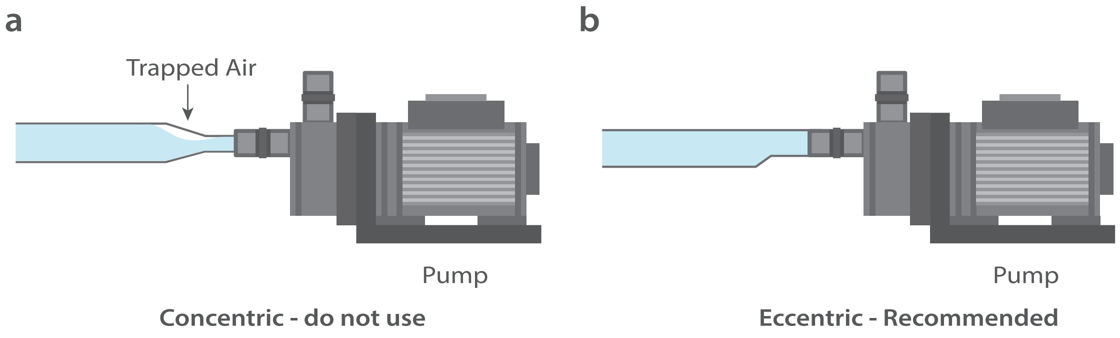


Figure 24: Suction Pipes at inlet of Pumps

9.4.1.3 Discharge Pipe Installation

A gate valve shall be installed at the outlet of the pump.

The pipe should be installed such that it is continually rising to the tank if possible.

9.4.2 Submersible Pump Installation and Associated Pipe Installation.

A typical installation is shown in Figure 25.

9.4.2.1 Pump Installation

The pump should be located at least 1 metre (3.3 feet) above the bottom of the borehole/well and sufficiently below the "drawdown level" so as not to allow the pump to operate dry.

It is recommended that a water level sensing system (as described in section 9.3.1) be incorporated into the system to prevent the pump ever operating dry.

A stainless steel cable should be connected to the pump and fastened to the borehole cap to support the weight of the pump and to reduce the strain on the discharge pipe.

9.4.2.2 Pipe Installation

If recommended by the pump manufacturer, a non-return (check) valve should be installed in the discharge pipe just above the pump.

The discharge pipe should be screwed into the outlet of the pump to help support the weight. If the discharge pipe is a poly pipe it is recommended that it has a rating of PN 12.5 or higher.

A gate valve should be installed in the discharge pipe after it exits the borehole.

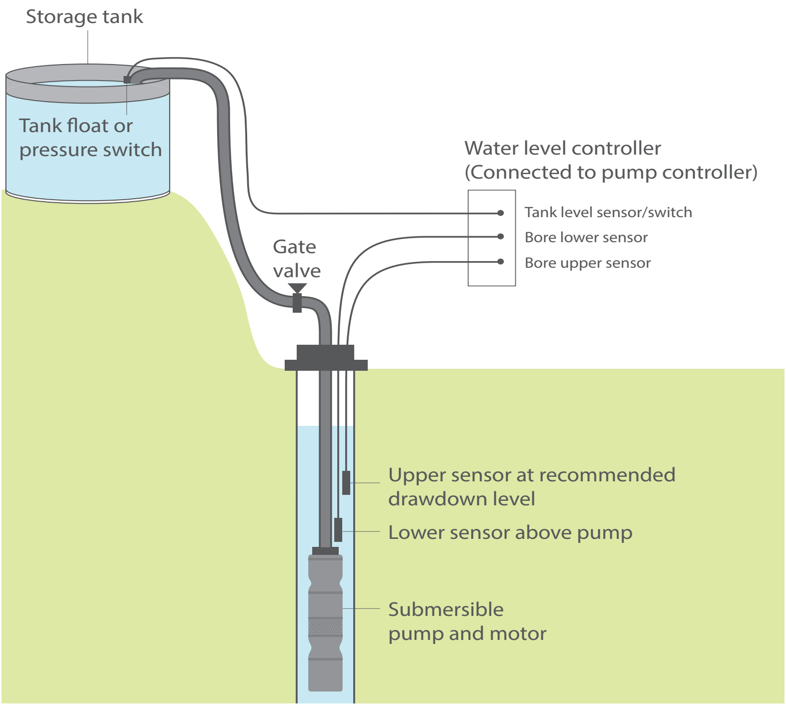


Figure 25: Typical submersible pump installation

10. Maintenance

It is recommended that regular maintenance is carried out on the system to prevent failure of the water supply due to an unexpected system shutdown. The following are some generic tips for carrying out maintenance. However, the manufacturer may require additional specific procedures which also must be carried out.

Solar Arrays and Modules:
- Clean modules (regularly as required);
- Check array structure for loose mounting connections;
- Check inter-module cables and other cables for mechanical damage;
- If the pump controller includes a data readout, check the array output voltage and current and compare to what would be expected under the existing conditions.

Pump controller:
- keep the unit clean and minimise the possibility of dust. Clean when required;
- Ensure the unit is not “invaded” by insects;
- Ensure all electrical connections are kept clean and tight;
- Follow manufacturers recommendations.

Pumps:
- Follow manufacturer’s recommendations.

Cables and Pipes
- Check that there is no visible damage.

Appendix 1: Solar Irradiation Data

Table showing Peak Sun Hours (PSH) for various Pacific Island sites and tilt angles

Alofi, Niue

Latitude: 19°04' South | Longitude: 169°55' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.47	6.2	5.67	4.81	4.26	3.86	4.01	4.61	5.35	6.02	6.53	6.46	5.34
19° Tilt[2]	6.43	5.88	5.7	5.2	4.96	4.46	4.75	5.14	5.53	5.81	5.98	6.47	5.53
34° Tilt[2]	6.06	5.39	5.47	5.24	5.24	4.78	5.08	5.29	5.41	5.41	5.35	6.15	5.41

Apia, Samoa

Latitude: 13°50' South | Longitude: 171°46' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.39	5.47	5.16	5.09	4.63	4.46	4.71	5.25	5.77	5.91	5.76	5.51	5.25
13° Tilt[2]	5.32	5.24	5.12	5.31	5.06	4.99	5.23	5.60	5.85	5.72	5.67	5.46	5.38
28° Tilt[2]	5.14	4.86	4.93	5.37	5.34	5.40	5.62	5.79	5.74	5.35	5.45	5.3	5.36

Hagåtña, Guam

Latitude: 13°28' North | Longitude: 144°45' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.33	5.87	6.73	7.12	7.04	6.44	6	5.3	5.42	5.46	5.16	5.05	5.9
13° Tilt[2]	5.94	6.27	6.85	6.88	6.97	6.43	5.95	5.17	5.38	5.7	5.66	5.69	6.07
28° Tilt[2]	6.40	6.48	6.75	6.39	6.71	6.27	5.77	4.90	5.18	5.77	6.00	6.19	6.06

Honiara, Solomon Islands

Latitude: 09°27' South | Longitude: 159°57' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt¹	5.99	5.55	5.61	5.41	4.76	4.59	4.45	5.19	5.81	6.26	6.4	6.22	5.52
9° Tilt²	5.98	5.47	5.54	5.52	5.00	4.90	4.69	5.36	5.81	6.15	6.38	6.24	5.59
24° Tilt²	5.92	5.29	5.34	5.58	5.26	5.28	4.98	5.52	5.71	5.88	6.29	6.22	5.61

Koror, Palau

Latitude: 07°20' North | Longitude: 134°28' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt¹	5.19	5.59	6.18	6.3	5.71	5.01	5.12	5.2	5.56	5.39	5.26	4.93	5.45
7° Tilt²	5.4	5.7	6.16	6.22	5.7	5.01	5.11	5.15	5.49	5.45	5.44	5.16	5.5
22° Tilt²	5.74	5.85	6.06	6.01	5.67	5.03	5.11	5.03	5.3	5.3	5.73	5.53	5.55

Lae, Papau New Guinea

Latitude: 06°44' South | Longitude: 147°00' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt¹	5.13	4.85	5.03	4.85	4.58	4.29	4.17	4.51	4.97	5.27	5.35	5.13	4.84
6° Tilt²	5.2	4.88	5.03	4.93	4.73	4.47	4.32	4.61	5	5.28	5.41	5.21	4.92
21° Tilt²	5.2	4.77	4.86	4.97	4.96	4.77	4.55	4.72	4.91	5.12	5.39	5.25	4.96

Majuro, Marshall Islands

Latitude: 7°12' North | Longitude: 171°06' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt¹	5.26	5.86	6.11	5.89	5.66	5.31	5.35	5.63	5.42	5.15	4.88	4.84	5.44
7° Tilt²	5.47	5.98	6.09	5.81	5.65	5.32	5.35	5.58	5.35	5.2	5.03	5.05	5.49
22° Tilt²	5.83	6.16	5.99	5.62	5.62	5.35	5.35	5.46	5.16	5.24	5.27	5.4	5.53

Nauru

Latitude: 0°32' South | Longitude: 166°56' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.77	6.24	6.27	6.04	5.99	5.75	5.85	6.25	6.7	6.5	6.12	5.5	6.07
15° Tilt[2]	5.94	6.26	6.08	6.05	6.28	6.15	6.20	6.39	6.51	6.46	6.28	5.69	6.19

Noumea, New Caledonia

Latitude: 22°16' South | Longitude: 166°27' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	7.31	6.7	5.73	4.97	3.94	3.47	3.91	4.73	6.05	7.09	7.41	7.6	5.73
22° Tilt[2]	6.61	6.34	5.83	5.55	4.75	4.19	4.69	5.50	6.44	6.88	6.77	7.54	5.92
37° Tilt[2]	5.74	5.8	5.59	5.62	5.02	4.48	4.99	5.69	6.32	6.37	5.94	7.03	5.72

Nuku'alofa, Tongatapu, Tonga

Latitude: 21°08' South | Longitude: 175°12' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.69	6.3	5.62	4.65	4.04	3.58	3.78	4.43	5.23	6.28	6.69	6.7	5.32
21° Tilt[2]	6.1	5.96	5.69	5.1	4.81	4.25	4.41	5.03	5.46	6.07	6.16	6.65	5.47
36° Tilt[2]	5.35	5.47	5.45	5.14	5.08	4.55	4.67	5.18	5.34	5.64	5.45	6.25	5.3

Pago Pago, American Samoa

Latitude: 14°16' South | Longitude: 170°42' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.87	5.93	5.54	5.18	4.63	4.4	4.59	5.2	5.78	6.05	6.11	5.93	5.43
14° Tilt[2]	5.79	5.66	5.51	5.43	5.11	4.98	5.14	5.59	5.87	5.84	6.01	5.87	5.57
29° Tilt[2]	5.57	5.22	5.29	5.48	5.4	5.39	5.51	5.77	5.76	5.45	5.75	5.69	5.53

Palikir, Pohnpei FSM

Latitude: 6°54' North | Longitude: 158°13' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	4.97	5.57	5.91	5.79	5.44	5.33	5.51	5.54	5.66	5.29	5.03	4.83	5.4
6° Tilt[2]	5.11	5.65	5.88	5.72	5.42	5.34	5.51	5.49	5.59	5.32	5.15	4.99	5.43
21° Tilt[2]	5.42	5.81	5.79	5.55	5.41	5.39	5.54	5.40	5.40	5.38	5.42	5.34	5.49

Port Moresby, Papua New Guinea

Latitude: 9°29' South | Longitude: 147°9' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.71	5.14	5.32	5.33	4.98	4.67	4.75	5.29	5.95	6.42	6.51	6.04	5.51
9° Tilt[2]	5.81	5.15	5.33	5.5	5.29	5.03	5.09	5.53	6.03	6.4	6.61	6.17	5.66
24° Tilt[2]	5.72	4.96	5.12	5.55	5.58	5.43	5.43	5.69	5.91	6.1	6.5	6.13	5.68

Port Vila, Vanuatu

Latitude: 17°44' South | Longitude: 168°19' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.68	6.2	5.76	4.98	4.2	3.79	4.04	4.75	5.65	6.47	6.67	6.93	5.5
17° Tilt[2]	6.69	5.89	5.77	5.32	4.75	4.41	4.65	5.21	5.82	6.25	6.47	7.01	5.69
32° Tilt[2]	6.38	5.42	5.55	5.38	5.01	4.74	4.97	5.37	5.7	5.82	6.08	6.74	5.6

Rarotonga, Cook Island

Latitude: 21°12' South | Longitude: 159°47' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.45	6.14	5.78	4.59	3.86	3.54	3.73	4.46	5.16	5.94	6.63	6.56	5.23
21° Tilt[2]	5.9	5.82	5.86	5.04	4.56	4.2	4.34	5.07	5.38	5.74	6.11	6.51	5.38
36° Tilt[2]	5.19	5.34	5.62	5.08	4.8	4.48	4.6	5.22	5.26	5.34	5.41	6.11	5.2

Suva, Fiji

Latitude: 18°08' South | Longitude: 178°25' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.29	6.2	5.54	4.67	4.05	3.72	3.89	4.44	5.08	6.04	6.32	6.38	5.21
18° Tilt[2]	6.27	5.88	5.55	4.99	4.61	4.38	4.51	4.88	5.21	5.83	6.1	6.41	5.38
33° Tilt[2]	5.95	5.4	5.33	5.03	4.84	4.7	4.8	5	5.1	5.43	5.71	6.13	5.28

Tarawa, Kiribati

Latitude: 01°28' North | Longitude: 173°02' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.58	5.98	5.99	5.87	5.82	5.7	5.87	6.15	6.52	6.4	6.1	5.5	5.95
16° Tilt[2]	5.9	6.1	5.83	5.79	5.95	5.93	6.06	6.17	6.28	6.45	6.43	5.88	6.06

Vaiaku, Tuvalu

Latitude: 8°31' South | Longitude: 179°13' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.16	5.27	5.33	5.29	4.93	4.66	4.76	5.3	5.72	5.8	5.57	5.23	5.25
8° Tilt[2]	5.14	5.2	5.26	5.37	5.14	4.92	4.99	5.45	5.71	5.71	5.55	5.23	5.31
23° Tilt[2]	5.09	5.05	5.08	5.43	5.41	5.29	5.32	5.61	5.61	5.49	5.48	5.21	5.34

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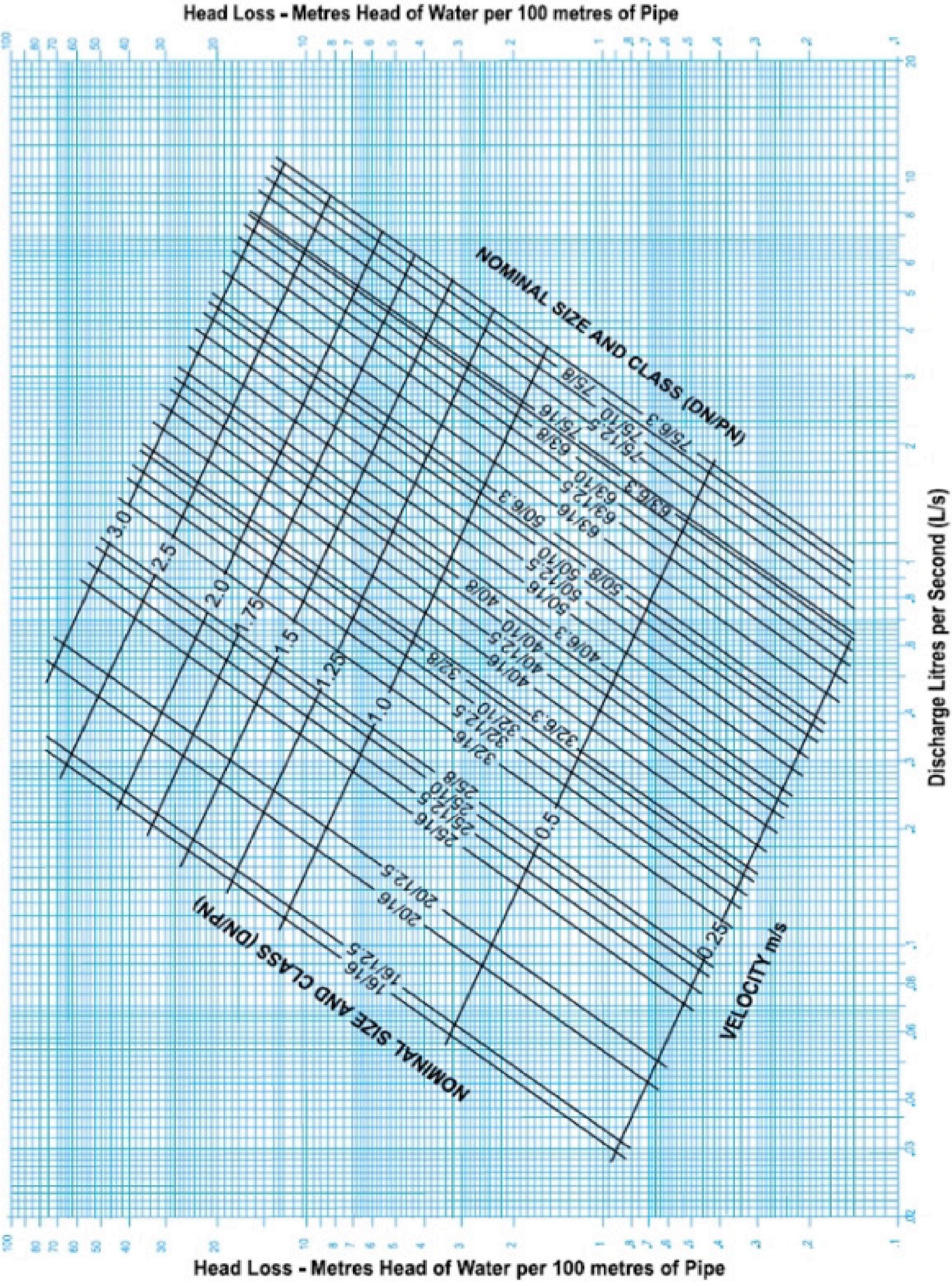
[1] *Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day)*

[2] *Monthly Averaged Radiation Irradiance for Equator Facing Tilted surface tilted at an angle equal to the latitude of the location and at an angle equal to the latitude of the location plus 15 degrees (kWh/m²/day)*

These data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program. (https://power.larc.nasa.gov/)

Appendix 2: Flow Chart for Small Bore Polyethylene Pipe



(Source: Vinidex Pty Limited)