Solar-powered pumping in agriculture:
A guide to system selection and design
Acknowledgements

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Cover Photo: Solar panels powering pumps for a travelling irrigator on an irrigation property in the Liverpool Plains. Credit: Cotton CRC
INTRODUCTION

Solar PV power can replace a significant proportion of the mains electricity and diesel currently used in rural water pumping. This opportunity lies in two areas:

- stock and domestic pumping
- bulk water pumping for irrigation

Whether your pumping task is large or small, it is important that you approach solar from an informed position.

This guide aims to help you gain greater familiarity with the technology, avoid potential traps and realise the many benefits that flow from using solar PV on-farm.

Structure of the guide:

- **Section 1: Opportunities for solar pumping.** This section outlines the general opportunities and factors that determine suitability for different farms and pumping tasks.
- **Section 2: Technical background.** A general reference guide to solar PV technology and the various elements of solar pumping systems. We don’t expect you to read this straight up; on the other hand, you might find it fascinating.
- **Section 3: The design process.** Like Section 2, this section is quite technical: we recommend skimming it for an overview, with a view to returning to this section when you are further down the track.
- **Section 4: System installation and commissioning.** A guide to the key factors and processes involved in installing and commissioning a solar PV system.
- **Sections 5: Maintenance.** Good to know and essential reading once you have commissioned a system.
- **Section 6: Financial analysis.** Developing and reviewing the financial case of a solar PV system.
- **Appendices** include a glossary of terms, definitions of units of measurement and a solar pumping design checklist.

Scope and limitations

This guide has been designed to help inform farmers and other interested parties about solar-powered pumping solutions available in Australia, how solar PV technology works, and where it may be best deployed. It also includes information on the design process and factors that must be considered with regard to feasibility and return on investment (ROI).

Despite the technical detail provided, this guide is not intended as an installation or design manual and should not be relied upon when commissioning a specific solar PV pumping solution or in the actual installation process. Every farm’s existing pumps and electricity infrastructure differs and each farm has specific needs that must be taken into account when choosing a solar pumping system.

Safety, maintenance and quality of equipment

Working with electricity is hazardous and electrical equipment must always be installed by qualified professionals. We strongly advise that you engage professional assistance in evaluating the suitability of solar power for your specific pumping tasks and in relation to any resulting design, selection and installation process.

Correctly installed, solar power equipment is reliable, safe and low-maintenance. Poorly installed systems can result in low performance and can present a safety risk. We have seen instances in which poor installation or low-quality components have resulted in serious issues with performance and risk. In these cases, it is the farmer’s usual electrician who has to solve any problems with the system. We recommend that you use a reputable supplier that stands behind the quality of its components and offers solid after-sales support.
We also recommend that you involve your regular electricity professional in the process of design and installation. A good solar supplier will work with your electrician or electrical engineer in the design and installation process.

**Note that any grid connected system must be installed in accordance to the required standards and by an installer accredited by the Clean Energy Council (CEC).**

**Terminology - What is a ‘solar pump’?**

Any electric pump can be powered by a solar array. For larger pumping tasks and irrigation systems, the optimal solution may involve powering the same pumps from both network and solar power sources. In certain cases this may require additional power control systems.

A number of suppliers offer small integrated solar pumping packages, which they refer to as ‘solar pumps’. These solar pumps are simply an electric pump and controller optimised to receive power from a solar PV array.
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SECTION 1: OPPORTUNITIES FOR SOLAR POWERED PUMPING

There are as many opportunities for using solar power for agricultural water pumping as there are pumping tasks. The pumping task can be small, for example to replace a windmill on a remote stock watering point, or it could be very large, for example, to meet the bulk water transfer needs of an entire irrigation district.

Naturally, different sizes of solar system and complexity of project are involved, depending on the amount of energy required, the kinds of pumps used and whether of not the solar array is integrated with general farm electricity supply and grid connected.

Integrated solar pumping packages are on the market for small pumping tasks. These include a solar array and an electric pump that has been matched to the array. These off-the-shelf solutions may be the simplest way to implement a small scale solar pumping solution and are worth considering. It is important to understand, however, that there is no such thing as a “solar pump”, which is how such systems are typically marketed. Your existing electric pumps or electric pumps not marketed as solar may be well suited for use in a solar powered pumping project.

What ever the size of the project, we recommend that farmers gain familiarity with the technology, assess a range of options and make return on investment comparisons.

1.1 Why use solar-power?

Generating electricity on farm using solar Photovoltaic (PV) technology can be an important step towards increasing the resilience and sustainability of your business.

Solar PV is scalable. Additional modules can easily be added to systems. Solar technology is proven, well understood and widely adopted across Australia and internationally.

On most farms, solar PV can provide cost effectively at least some proportion of energy needs. Benefits to implementing solar as a source of power for irrigation pumping include:

- Reduced bills for mains electricity and diesel
- Reduced connection and infrastructure costs when new power lines and poles can be avoided if fully replacing mains electricity
- No noise, fumes or fuelling runs if replacing diesel,
- Scalable – additional panels can be added to increase output
- Flexible – solar power can be integrated with mains electricity supply if desired
- Low maintenance. Aside from tracking systems, traditional solar generators have no moving parts and are generally very reliable.
- Low maintenance. Aside from tracking systems, traditional solar generators have no moving parts and are generally very reliable.
- Protection from rising energy costs. Sunshine is free so generating energy on farm reduces exposure to rising electricity and diesel prices.

1.2 What pumping tasks suit solar power?

Solar PV arrays provide power whenever the sun is shining. Designed properly, solar PV systems can ensure a steady and reliable power supply, even on cloudy days.

Solar has potential to reduce your pumping energy bill and maintenance costs if any of the following apply:

✓ You already use electric pumps for irrigation and are grid connected
✓ You pump water to header tanks for stock or domestic use
✓ You have potential to load shift (eg use solar during the day to reduce total electricity demand and...
enable a more favourable tariff structure)

✓ You have substantial and efficient water storage (solar is ideal for transfer pumping tasks)

✓ You have a discrete day time pumping task as part of your broader irrigation system that is suitable for a solar power solution.

1.3 Livestock drinking-water supply

The necessity to provide continuous (year-round) water supply for livestock and the relatively small volumes required for stock watering makes this a pumping task well suited to solar PV power. Water can be pumped during the daytime from a bore, dam or stream into a stock dam or elevated tanks for on-demand supply to troughs.

![Figure 1: Sheep station near Griffith, NSW. A PV system provides power to a bore pump to lift water to storage tank. Water from the storage is gravity-fed to drinking-water troughs for cattle (NSW Farmers, 2014).](image)

1.4 Domestic water and cleaning farm buildings

Installing solar PV to meet all or some domestic and cleaning pumping needs can provide significant savings to most farms. In typical installations solar is used to transfer water to header tanks during the day. If pressurised water is needed at night time, a grid connection or battery storage will also be needed to power pressure pumps.

Domestic solutions can be commissioned solely for water pumping but often are specified to supply total domestic electricity as part of an integrated system.

1.5 Irrigation pumping – lifting and distributing bulk water

The cost of pumping bulk water using mains electricity or diesel has become a significant burden on Australian agricultural productivity with most irrigation farmers having to cover six figure energy bills.

Irrigated agriculture produces more than 20 percent of the total value of Australian agricultural production on less than one percent of agricultural land. To achieve this, approximately five million megalitres (ML) of irrigation water is applied every year in NSW alone (ABS, 2014). Diesel or grid connected electric pumps are used to lift water from rivers and ground water, and to pressurise distribution systems.
While electricity is more efficient for pumping than diesel, high network charges and connection costs in rural areas have inhibited growth in the electrification of irrigation pumping. Increasingly, therefore, irrigators across all farming systems are looking to solar power for solutions.

Technically, there is no limit to the volume of water that can be pumped using solar power as a solar array can be sized to meet any scale of power demand. The business case for solar powered irrigation on a given farm depends on factors including the number of months of pumping per year, the time of day when irrigation occurs and the potential to export and sell unused energy.

A solar PV system capable of providing the required amount of energy for an irrigated farming enterprise can entail significant investment and detailed site-specific analysis.

Irrigation water requirements vary markedly, depending on the crop to be watered. Orchards, for example, typically require year-round irrigation, with increased water requirements during fruit production. Solar pumping solutions are naturally well suited to such horticultural irrigation systems, especially if the crops grown need more water during summer months, such as blueberries and fruit trees. For example, see Figure 2: The water requirements of a blueberry tree (L/day per plant).

![Blueberry water requirements graph](image)

**Figure 2: The water requirements of a blueberry tree (L/day per plant).**

Irrigation for broadacre crops usually occurs during certain periods of the year. Some broadacre crops, such as rice and lucerne, require irrigating over six to eight months of the year whereas the irrigation period for crops such as wheat and mung beans is shorter.

When pumping is seasonal or irregular, it is essential to identify how your solar power will be used when it is not needed for irrigation. If you do not have other uses for electricity on farm or the ability to export and sell unused power, consider installing a smaller system that is integrated with other power supply.

A great strength of solar is its ability to be integrated with electricity from other sources. This means that it is not strictly necessary to install a system that is large enough to meet your peak seasonal irrigation load. Solar can be used to supplement mains power, reducing bills in high tariff periods. Alternatively, a free standing system (not grid connected) could be sized to meet year round base load, with diesel generation used to top up total power in peak load periods.

There are many possible configurations and site specific analysis is essential to identifying the optimal design and size for your particular property and farming system.
Figure 3: The water requirements of a cotton crop with an irrigation scheme that runs for approximately six months of the year (Source: WATERpak, Cotton Research and Development Corporation).

Is solar pumping right for my farm? If so, which configuration is likely to be most suitable?

To help you decide whether solar pumping is a technically feasible and financially viable option for your farm, consider the following questions:

- **Are your current pumps suitable?** Diesel pumps cannot be integrated with solar power and would need to be replaced, incurring extra costs. However, there are good opportunities to integrate solar with diesel generators.

- **What is the cost of operating your existing pumps?** Solar power has high up-front costs but low operating costs. A solar PV system can result in significant savings over the life of the system. Integrating solar with your existing power supply can substantially reduce operating costs.

- **How far from the electricity grid is the proposed pump site?** Solar can be used to power pumps that are far from the grid. Such solar pumps can transfer water to locations near the electricity grid for grid-powered pumping or pressurisation.

- **How often is the pump used?** Solar pumping suits applications requiring regular operation. It may be more economical to employ mobile fuel generators for pumps that are used for only a couple of periods a year.

- **At what time of day do you need water?** A solar PV system powers pumps only during daylight hours. For applications that require water at night or on-demand, consider combining solar with water or battery storage. It may also be more economical to use a different pump technology.

- **Is there existing water storage?** Solar pumps are well suited to pumping water to some form of water storage (such as a dam or tank) where it can be used when needed.

- **Will the water be pressurised?** Pressurised systems require consistent energy sources. Combining solar with battery power could provide this otherwise integration with other power will be necessary.

- **How much water must be pumped?** Solar can provide power for large volumes of water; however, with such applications, it may be more economical to install solar to reduce the size of the main energy source rather than as your sole power source.
SECTION 2: SOLAR PV POWERED PUMPING SOLUTIONS

A typical solar powered pumping system contains the following equipment: a solar array, which converts sunlight into electricity; system controllers, which control the array and the pump; an electric motor, which drives the pump; and a water pump, which moves the water from a source to its delivery point (Figure 4).

Figure 4: The basic components of a solar PV water pumping system.

The solar array provides the energy supply for the system. Levels of solar radiation fluctuate during the day and there are none at night, so a solar pumping system needs to be designed to pump daily water requirements within these energy limitations. The size of the solar pumping system is determined by the amount of water that needs to be moved and by how far and to what elevation this water must be moved.

Figure 5: The energy flows in a solar pumping system.
The energy, power and water flows in a simple solar water pumping system are shown above in Figure 5: The energy flows in a solar pumping system. If desired, energy or water storage can be included in the system to store excess energy generated on days when solar energy is greater than the average, either by pumping extra water and storing it, or by storing the extra electricity generated in batteries. Water can then be provided on very cloudy days or even overnight.

Below are brief explanations of the key components in a solar PV pumping system.

- **Solar radiation.** The amount of energy received from the sun at a given location. This determines how much power each solar module will generate in a day and the size of array needed to pump a required volume of water. A site with low solar radiation levels will need a larger array than a site with high solar radiation levels.

- **Solar array.** A generator that converts solar radiation into electricity. An array consists of solar modules (the generation components), a mounting structure and electrical safety equipment (‘electrical protection’).

- **Control systems.** The units that control the array and the pump. The array control system optimises the production of electricity from solar energy and matches the electricity to the pump’s motor requirements. The pumping control system controls when and for how long the pump operates.

- **Pump and motor.** The pump moves the water from a source to its delivery point. It needs to be powerful enough to move the necessary volume of water the required distance.

- **Battery storage and other generators.** Backup electricity can be provided by batteries that store excess solar energy or by additional generators, such as wind turbines or diesel generators.

1.6 **System configurations**

There are four main configurations for solar pumping described in the following subsections. Note that the configurations and applications detailed below are not exhaustive; they are designed to give an overview of what’s available. You may wish to seek further information from local irrigation engineers and solar pumping suppliers.

1.6.1 **Solar alone**

In this configuration, the solar array provides power to a DC electric pump via an array and motor control system (Figure 6). This configuration is well suited to applications where a consistent volume of water must be pumped each day from a water source to the application or to water storage. This configuration is one of the simplest, most commonly deployed and cost-effective configurations. It is covered in detail in this report.

![Solar pumping configuration, using just solar as the energy source.](image)

1.6.2 **Solar combined with batteries**

This configuration includes batteries and a battery control system (Figure 7). Adding batteries increases the system complexity and adds significant costs, but batteries ‘smooth out’ the solar array output and provide power required at night. A solar-battery configuration works well for on-demand, pressurised water systems.

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The use of batteries in a solar pumping system is covered briefly in this report. Using batteries to store solar-generated power can involve complex design considerations, including accurate sizing, electrical compatibility between the solar array and the battery bank, electrical protection, and maintenance.

![Solar pumping configuration](image)

*Figure 7: A solar pumping configuration that uses a combination of solar and batteries as the energy source.*

Different chemistries and types of batteries (lead-acid, Lithium-Ion, flow batteries, etc.) each hold competitive advantages but Australian industry leaders have cautioned that there is ‘no clear winner’ yet.

However, developments in battery technology are being spearheaded by the automotive industry and it is expected to flow on to better batteries for stationary purposes. Meta analyses by the University of Melbourne and IBM Research – Australia show that the price for lithium ion batteries is forecasted to drop from around $600 USD/kWh today, to $250 USD/kWh in 2025.

![Cost predictions for full automotive Li-ion packs](image)

*Figure 8: Cost predictions for full automotive Li-ion packs (Muenzel, Mareels, & Hoog, 2014)*

These price drops may mean that a combined solar PV + battery system may soon be able to deliver power (if used continuously through the year) at a levelised cost of electricity that is competitive with diesel and eventually even grid-power. In many cases, the competitive threshold of a PV + batteries system against purely diesel-generated power has already been breached.

1.6.3 **Solar combined with diesel generation**

This configuration includes a diesel generator and operates on an AC electrical system (*Figure 9*). Using an AC electrical system requires the use of a solar ‘multimode’ inverter (a DC to AC converter) to regulate the flow of energy to the pump from both the solar array and the generator. This type of system is well suited to applications where some night time pumping is required and mains electricity is not available.
1.6.4 Solar combined with power from the electricity grid

This configuration powers the pump with a combination of power generated by a solar array and electricity from the grid (Figure 9). Having solar power reduces the amount of grid electricity required, which can reduce the cost of running the pump. The grid provides reliability and enables the pump to be operated in a flexible way to meet changing requirements.

Combining solar PV power with power drawn from the electricity grid requires significant design considerations and additional standards. A certified solar designer/installer should be engaged for this configuration; a list of these can be found on the Clean Energy Council website at www.solaraccreditation.com.au/installers.html.

An additional benefit of a grid-connected system entails the possibility of exporting excess power and utilising solar-generated electricity for other purposes on-farm. This can help improve the financial viability a solar system, by providing a revenue stream (from exported power) and by offsetting electricity from other loads when pumping isn’t required.

In NSW, exported electricity from new PV systems is currently rewarded by feed-in tariffs at levels of around 4-8 c/kWh. However, any power that the PV system displaces will result in savings of 20-30 c/kWh during peak hours. This is why it is important to maximise the use of power generated by the PV system, as it will help pay back the investment more quickly.
A grid connected system is one of the most viable approaches to meet the needs of larger, and more intermittent, pumping needs such as those for irrigated broadacre farms. Technical background on solar arrays

A solar photovoltaic (PV) array is an electrical configuration of solar modules that produce DC electricity when exposed to solar radiation. The solar engineer or installer will consider the following factors when designing an array to meet the electricity needs of your pumps:

- Electrical characteristics: the I-V curve and the maximum power point
- Operating conditions: the effects of solar radiation levels and temperature
- Configuring an array: connecting modules in series and in parallel
- Datasheet values: ratings of a PV module
- Efficiency and power
- Composition and types of solar modules
- Solar array positioning: taking into account the movement of the sun
- Array positioning: shading
- Solar array output: system yield according to solar resource
- Mounting systems

1.6.5 Electrical characteristics: I-V curve and maximum power point

Solar modules contain photovoltaic (PV) cells that convert energy from the sun into electrical energy. These cells produce DC electricity that can be used either by AC-compatible appliances such as many household electrical items, or by an AC water pump.

The electricity produced by a PV module is characterised by the I-V curve: this depicts the relationship between the current (I) and the voltage (V) of the cell (Figure 11 a). For a given set of operating conditions, the PV module can be manipulated at any point along the I-V curve; for every operating voltage, as shown on the x-axis, there is a corresponding current output, as shown on the y-axis.

One point along the curve will produce the most power. This point is known as the maximum power point (MPP) and is located at the ‘knee’ of the curve (Figure 11 b). Operating a PV module at its maximum power point will result in the greatest possible amount of power. Sometimes, however, it is more beneficial to operate the PV module at a specific voltage or current value that does not correspond to the maximum power point. A maximum power point tracker (MPPT) is the most common way to control the electrical output of a PV module.

![Figure 11: a) The I-V curve of a PV module (current is typically abbreviated as ‘I’ although its units of measure are Amps); b) the maximum power point of the I-V curve is at the red dot. Note: This point corresponds to the maximum point on the blue ‘power output’ curve.](image-url)
Operating conditions: the effect on solar PV pumping of solar radiation levels and temperature

The operating conditions – namely, the solar radiation levels and temperature of the module, affect the I-V curve of a module (Figure 12 a). In essence, as solar radiation (technical name: ‘irradiance’) levels increase, more current is available; hence, there is more available power. As cell temperature increases, less voltage and hence less power is available (Figure 12 b).

![Figure 12: a) Module power output increases with levels of solar radiation (irradiance); b) module power output decreases with the temperature of the module.](image-url)
Floating arrays: can these increase output?

The ideal operating conditions for a solar array are high levels of solar radiation and cool temperatures. Days with high solar radiation are usually hot which inevitably means will heat up.

Floating solar arrays are gaining popularity. The array can float above or sit just below the surface of the water. The water underneath helps cool the modules, resulting in higher power output. This particular example shown below showed a 40% improvement in efficiency and reduced evaporation by 1-3 mpa. The additional advantage of reducing evaporation is especially useful.

The amount of solar radiation at a site varies throughout the day but typically, lower levels of solar radiation are emitted in the mornings and afternoons, and higher levels occur in the middle of the day. The total daily solar radiation received at a site also varies throughout the year: daily solar radiation levels are greater in the summer, when there are more daylight hours and higher solar radiation levels throughout the day (Figure 14). Cloud cover will reduce the amount of solar radiation able to reach the array, but solar arrays will continue to generate some power even on cloudy or overcast days.
1.6.6 Configuring an array: connecting modules in series and in parallel

A solar array is the electrical combination of a number of solar modules. The power output of this array will be the sum of the power outputs of the combined solar modules.

The method by which the solar modules are configured will determine the electrical output characteristics (namely, current and voltage) of the solar array. Modules can be connected in series (Figure 15 a), in parallel (Figure 15 b) or in a combination of the two.

Simply put, (i) connecting modules in series means that the voltages of the modules are summed but the current output stays the same, and (ii) connecting modules in parallel means that the currents of the modules are summed but the voltage output stays the same.
The implications of this are that two arrays can have the same power output but will operate at different current and voltage outputs according to their configuration. Simply matching an array’s rated power output to the power requirements of the pump or motor is not enough: when designing a solar PV array, you must ensure that the array’s voltage and current outputs match the pump’s requirements.

**Key notes:**
- The way in which modules are electrically configured determines the electrical output of the array.
- Designing an array to power a pump or motor involves more than matching the array’s rated power output to the power requirements of the pump. Voltage and current outputs must be matched.

**Datasheet values: ratings of a PV module**
As explained in Section 1: opportunities for solar powered Pumping, the output of a PV module is affected by the amount of sunlight it receives and the daytime temperature. The manufacturer will stated output of a PV module is calculated using a standard set of operating conditions known as Standard Test Conditions (STC). These conditions are as follows:

- solar radiation levels (irradiance) = 1,000 W/m²,
- cell temperature = 25 °C, and
- air mass (a unit of air volume) = 1.

As all modules are tested under these conditions, different modules can be compared using their ‘rated’ outputs – that is, their outputs as calculated under STC. Standard Test Conditions do not necessarily represent ‘real-world’ conditions; the STC solar radiation level is higher than that normally experienced and the STC cell temperature is very low (‘cell’ temperature is not the ambient temperature; it represents the operating temperature of the module’s silicon cells). Therefore, modules should not be expected to produce their rated power in all instances.

**Key notes:**
- The datasheet values of a PV module (its ‘rated’ values) are calculated under Standard Test Conditions (STC). Real world conditions generally produce less favourable results, i.e. you can generally expect to get lower outputs from solar modules than their rated outputs.
Efficiency and power

The efficiency value given in a solar PV module’s datasheet relates to the relationship between the amount of sunlight received (W/m²) and the amount of power generated (W) by that module. So a module’s efficiency value relates to the size (i.e. surface area) of the module that is needed to produce a certain amount of power (Figure 16). It does not mean that a lower-efficiency module will produce less power than a higher-efficiency one.

![Figure 16: When two modules have the same power output, the more 'efficient' module will take up less space.](image)

High-efficiency modules are usually pricier and are best suited to applications where installation space is limited.

Example

A farmer is going to install a 1kW solar PV array and has a choice between two brands of module. Both modules are approximately the same physical size.

- Module #1 has a rated power of 250W with an efficiency of 16% and costs $280.
- Module #2 has a rated power of 200W with an efficiency of 10% and costs $210.

Array configuration

If the farmer chooses module #1, the array will be made up of 4 x 250W modules to give a rated power of 1kW. If they choose module #2, their array will be made up of 5 x 200W modules to give a rated power of 1kW.

Power output

The power output of the array will be 1kW under standard test conditions, regardless of which modules are chosen. The difference between the arrays will be that an array comprising the low-efficiency modules will need an additional module to achieve a 1kW output under STC and will hence take up a greater surface area.

Cost

If the farmer chooses module #1, the cost of the modules will be 4 x $280 = $1,120. If he or she chooses module #2, the cost of the modules will be 5 x $210 = $1,050. The farmer should also take into consideration, however, that installation costs for module #2 will be greater, as there is an extra module to mount, wire up, et cetera.

Key notes:

- A module’s quoted efficiency determines the size of the array and how many modules are needed.
- A module’s quoted efficiency does not affect the output power.
### 1.6.7 Composition and types of solar modules

Photovoltaic modules are made up of PV cells electrically connected and sandwiched between a backing sheet and a glass front, with transparent glue holding it all together. Most modules have an aluminium frame that provides mechanical protection for the modules. Three main types of solar modules are available commercially: monocrystalline, polycrystalline and thin-film.

**Monocrystalline modules**

Monocrystalline cells (*Figure 17*) are dark blue in colour and almost square, missing corners due to the method of production. They are produced from a single cylindrical crystal of silicon cut into thin circular wafers. To increase the cell density in a module, four edges are then cut from each of the round cells, allowing them to be packed closely.

Monocrystalline modules are typically more efficient than other types of solar modules, with commercial efficiency levels of around 18 to 21 percent. They also tend to have higher cost-to-power ratios than other solar modules.

![Figure 17: A monocrystalline module.](image)

**Polycrystalline modules**

Polycrystalline (or multicrystalline) cells (*Figure 18*) are usually dark or light blue in colour and are easily identifiable by their distinctive grain structure that glitters in sunlight. They are created by allowing molten silicon to cool in a block, forming various crystal structures in the process, then slicing the block into thin wafers that are processed into PV cells.

Typically, polycrystalline modules are less efficient than monocrystalline ones, with commercial efficiency levels of around 15 to 18 percent; however, they also tend to have lower cost-to-power ratios than monocrystalline modules.

![Figure 18: A polycrystalline module.](image)

**Thin-film modules**

Thin-film modules (*Figure 19*) can vary a lot in appearance. Commonly, they have a smooth, glassy finish and no cell division lines. They are made by applying a photoactive semiconductor in thin layers to a substrate that may be glass, metal or plastic.
Thin-film modules are typically the least efficient type of solar module; however, they have lower production costs and function well in low light conditions. They are less affected by high operating temperatures, which can make them well suited to very hot climates.

![Figure 19: A thin-film module.](image)

**Key notes:**
- Monocrystalline modules are the most efficient but also the most expensive solar PV modules.
- Polycrystalline modules are slightly less efficient and less expensive than monocrystalline modules.
- Thin-film modules are the least efficient type of solar PV module but are the least expensive. They can perform better than crystalline modules in very hot climates and perform well in weak light conditions.

### 1.6.8 Solar array positioning: taking into account the movement of the sun
A solar module will receive the most amount of solar radiation – and therefore produce the greatest amount of power – if it faces directly into the sun; however, the sun moves throughout the day and the year.

- **Daily movement:**
  Each day, the sun moves from the east, where it rises, to the west, where it sets. In New South Wales, the sun will nearly always be in the northern part of the sky except in the morning and evening hours of the summer months. The compass position of the sun is known as its ‘azimuth’ and is measured in degrees.

- **Yearly movement:**
  - In the summer months (*Figure 20 a*), the sun rises approximately in the south-east of the sky and sets in the south-west. Shortly after rising, it moves into the northern part of the sky, and in the middle of the day it is very high in the sky.
  - In the winter months (*Figure 20 b*), the sun rises approximately in the north-east of the sky and sets in the north-west, staying in the northern part of the sky, and is lower in the sky in the middle of the day than it is in the summer.
There are three main options for maximising the amount of direct solar radiation received by a solar module:

- fixing the array in the optimal tilt and orientation,
- using a manual tilting frame, and
- using a single- or dual-axis tracker that follows the sun.

**Fixed array**

Fixing the array so it has the optimal tilt and orientation is generally the cheapest option and the one that involves the least maintenance. The greatest possible annual power output from the array will be obtained if the array is orientated to the north and tilted at an angle equal to that of the site's latitude. However, it may be better to orient and tilt the array so that it generates more power at times that match your particular pumping regime, even if it will generate less power over the year.

The latitude of Tamworth, for example, is 31° S, so tilting the array at 31° would give the highest annual solar radiation and hence, the highest annual power output at this location (as shown in Table 1).

If the array is installed so that it sits at a higher elevated tilt (i.e. at a steeper angle), it will have greater exposure to sun in winter, when the sun traces a lower arc across the sky. A steeply tilted array will receive more direct solar radiation and hence will produce more power in winter. During the summer months, however, such an array will receive less direct solar radiation and will produce less power than its potential maximum (as shown in Table 1 and Figure 21 as ‘Tilted at 46°’).

Installing a solar PV array that gives preference to the sun’s trajectory over winter could suit farmers whose water pumping requirements are higher in winter or are year-round.

If an array is installed so that it sits at a lower-than-optimal (flatter) tilt angle, it will receive less direct solar radiation and produce less power over the winter months but in summer, flatter arrays will receive more direct solar radiation and produce more power than their steeper equivalents (shown in Table 1 and Figure 21 as ‘Tilted at 16°’). An array installed to preference the summer-sun could be suitable if your pumping requirements increased over summer.

An explanation of how to calculate levels of solar radiation received by arrays at different tilts is given in Section 8.2.
Table 1: Average daily solar radiation in Tamworth, latitude 31° S, at different tilts. Maximum values for summer and winter, and average annual values, in red (Source: NASA Surface Meteorology and Solar Energy website).

<table>
<thead>
<tr>
<th>Season</th>
<th>Month</th>
<th>Tilted at 16° (PSH)</th>
<th>Tilted at 31° (equal to latitude) (PSH)</th>
<th>Tilted at 46° (PSH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>December</td>
<td>7.25</td>
<td>6.62</td>
<td>5.63</td>
</tr>
<tr>
<td></td>
<td>January</td>
<td>7.18</td>
<td>6.63</td>
<td>5.71</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>6.7</td>
<td>6.43</td>
<td>5.80</td>
</tr>
<tr>
<td>Autumn</td>
<td>March</td>
<td>6.16</td>
<td>6.24</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>5.22</td>
<td>5.63</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>4.22</td>
<td>4.77</td>
<td>5.11</td>
</tr>
<tr>
<td>Winter</td>
<td>June</td>
<td>3.87</td>
<td>4.51</td>
<td>4.96</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>4.06</td>
<td>4.67</td>
<td>5.07</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>4.92</td>
<td>5.43</td>
<td>5.54</td>
</tr>
<tr>
<td>Spring</td>
<td>September</td>
<td>5.98</td>
<td>6.21</td>
<td>6.12</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>6.49</td>
<td>6.35</td>
<td>5.87</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>6.98</td>
<td>6.5</td>
<td>5.67</td>
</tr>
<tr>
<td></td>
<td>Average daily solar radiation for the year (PSH)</td>
<td>5.75</td>
<td>5.83</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Average annual solar radiation (PSH)</td>
<td>2,098</td>
<td>2,128</td>
<td>2,045</td>
</tr>
</tbody>
</table>

Figure 21: Tilting the modules at an angle less than the site’s latitude (16°) means they will receive more solar radiation in summer and less in winter. Tilting them at an angle greater than the site’s latitude (46°) means they’ll receive more solar radiation in winter, less in summer.

Minimum tilt for self-cleaning = 10 degrees.
It is recommended that solar modules be installed at a minimum tilt angle of 10° so that any build-up of dirt on the modules will be washed off naturally by rain and what remains can be removed easily with a bucket of water. Without this self-cleaning, modules accumulate dirt and dust that reduces their power output.

The optimal orientation for a solar PV array in the Southern Hemisphere is facing north. This orientation will result in the greatest possible generation of power throughout the day. Alternatively, modules could be positioned to face
east or west so as to maximise morning or afternoon power generation. This orientation might be suitable for a pumping application that requires water to be pumped directly to it (such as drip irrigation) and for situations requiring more water in the morning (in which case, the array should be east-facing) or in the afternoon (in which case a west-facing array may be preferable).

For applications incorporating water storage, it is usually better to angle solar PV modules to the north, to maximise solar generation and so your water storage can be the water-delivery source in the mornings and/or afternoons.

**Manual tilt**

Using a frame that can adjust the tilt of the array is a cost-effective option if you’re seeking to maximise the amount of power generated by an array. The array is tilted manually at the start of each month or season so that it receives more direct solar radiation for that period. This option requires routine servicing of its moving parts.

The optimal tilt angle for each month/set of months is calculated according to changes in the altitude of the sun over the months. Four key times of year can be used to determine this:

- Every year, there are two equinoxes (days when the sun is directly above the equator), occurring in the months of March and September. In these months, the optimal array tilt is equal to the latitude of the site.
- The winter solstice (shortest day of the year) occurs in June. In this month, the optimal tilt for a solar array is approximately 23° higher (steeper) than it is during an equinox; i.e. optimal tilt = latitude of the site + 23°.
- The summer solstice (longest day of the year) occurs in December. During this month, the optimal array tilt is approximately 23° lower (flatter) than it will be during an equinox; i.e. optimal tilt = site latitude – 23°.

**Example:**

The angles of a solar PV array can be split up across the year to yield a tilt plan, as detailed in Table 2 below.

<table>
<thead>
<tr>
<th>Month</th>
<th>Tilt</th>
<th>Example: Tamworth (latitude 31° S)</th>
<th>Quarterly Tilt</th>
<th>Example: Tamworth (latitude 31° S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>Latitude – 15°</td>
<td>16°</td>
<td>Nov-Jan</td>
<td>Latitude – 15°</td>
</tr>
<tr>
<td>December</td>
<td>Latitude – 23°</td>
<td>8°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>Latitude – 15°</td>
<td>16°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>Latitude – 7°</td>
<td>24°</td>
<td>Feb–Apr</td>
<td>Latitude</td>
</tr>
<tr>
<td>March</td>
<td>Latitude</td>
<td>31°</td>
<td></td>
<td>31°</td>
</tr>
<tr>
<td>April</td>
<td>Latitude + 7°</td>
<td>38°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>Latitude + 15°</td>
<td>46°</td>
<td>May–July</td>
<td>Latitude + 15°</td>
</tr>
<tr>
<td>June</td>
<td>Latitude + 23°</td>
<td>55°</td>
<td></td>
<td>46°</td>
</tr>
<tr>
<td>July</td>
<td>Latitude + 15°</td>
<td>46°</td>
<td>Aug–Oct</td>
<td>Latitude</td>
</tr>
<tr>
<td>August</td>
<td>Latitude + 7°</td>
<td>38°</td>
<td></td>
<td>31°</td>
</tr>
<tr>
<td>September</td>
<td>Latitude</td>
<td>31°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>Latitude – 7°</td>
<td>24°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Tracking systems**

A tracking system moves the array so that it directly faces the sun as much as possible. Installing a tracking system along with a solar PV array is a more expensive option that should result in greater generation of power, especially in the mornings and afternoons.

There are two main forms of trackers:

- **Single-axis trackers:** These rotate the array in the east-west axis only, following the sun at a fixed angle of elevation from the time it rises in the east until it sets in the west (Figure 22). Installing a single-axis tracker for your solar PV array results in higher power output in the mornings and evenings (Figure 23).

- **Dual-axis trackers:** These rotate the array on an east-west axis and tilt it on a second axis so that it is angled directly towards the sun at all parts of the day.

![Figure 22: The single-axis tracker follows the sun from east to west.](image_url)

![Figure 23: A single-axis tracker will result in higher power output from a solar PV array in the early mornings and evenings.](image_url)

Cooler morning temperatures mean that the array’s morning output will be slightly higher than its evening output; a module’s power output reduces as it heats up.
The main advantage of using a tracker with a solar-powered pump is that it enables the pump to generate sufficient power to operate earlier in the mornings and later in the afternoons: for this, the pumping system uses a solar controller (for more information on solar controllers, go to Section 2: System controllers).

The main disadvantage of installing a tracker is that it will need to be checked and serviced regularly. Without regular maintenance the tracker may break down, leaving the array stationary and operating at low efficiency. Also, tracker systems may be more vulnerable to damage by high winds than fixed arrays.

An alternative to installing a tracking system is to install a larger static solar array or an array made up of modules facing both east and west to capture morning and afternoon sun. Lack of space is rarely an issue for rural solar arrays and the incremental cost of adding modules is relatively small, so usually this is a more cost-effective option.
Example
To illustrate the differences in output between a fixed tilt system, a manual tilt system, a single-axis tracker and a dual-axis tracker, the average daily solar output for each month has been calculated for Sydney, NSW (Table 3 and Figure 24). Data was sourced from the PVWatts v.1 calculator supplied by the National Renewable Energy Laboratory (NREL) (rredc.nrel.gov/solar/calculators/pvwatts/version1).

The benefit derived from increased solar array output when using a tracker should be weighed against the increased equipment and maintenance costs of having to install a more complex tracking system. It could be more economical to install a larger fixed array than a manual tilt or tracker.

<table>
<thead>
<tr>
<th>Month</th>
<th>Fixed tilt, equal to site latitude (PSH)</th>
<th>Manual tilt, adjusted each month (PSH)</th>
<th>Single-axis tracker (PSH)</th>
<th>Dual-axis tracker (PSH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>6.05</td>
<td>6.52</td>
<td>7.48</td>
<td>8.06</td>
</tr>
<tr>
<td>February</td>
<td>5.57</td>
<td>5.72</td>
<td>6.79</td>
<td>7.05</td>
</tr>
<tr>
<td>March</td>
<td>5.43</td>
<td>5.43</td>
<td>6.55</td>
<td>6.62</td>
</tr>
<tr>
<td>April</td>
<td>4.79</td>
<td>4.84</td>
<td>5.63</td>
<td>5.70</td>
</tr>
<tr>
<td>May</td>
<td>3.74</td>
<td>3.89</td>
<td>4.23</td>
<td>4.36</td>
</tr>
<tr>
<td>June</td>
<td>3.30</td>
<td>3.54</td>
<td>3.67</td>
<td>3.88</td>
</tr>
<tr>
<td>July</td>
<td>3.88</td>
<td>4.12</td>
<td>4.38</td>
<td>4.61</td>
</tr>
<tr>
<td>August</td>
<td>4.96</td>
<td>5.08</td>
<td>5.83</td>
<td>5.99</td>
</tr>
<tr>
<td>September</td>
<td>5.46</td>
<td>5.46</td>
<td>6.44</td>
<td>6.47</td>
</tr>
<tr>
<td>October</td>
<td>5.90</td>
<td>5.99</td>
<td>7.17</td>
<td>7.33</td>
</tr>
<tr>
<td>November</td>
<td>5.68</td>
<td>6.02</td>
<td>6.79</td>
<td>7.17</td>
</tr>
<tr>
<td>December</td>
<td>5.69</td>
<td>6.35</td>
<td>7.14</td>
<td>7.83</td>
</tr>
<tr>
<td>Yearly average</td>
<td>5.04</td>
<td>5.25</td>
<td>6.01</td>
<td>6.25</td>
</tr>
<tr>
<td>Percentage increase</td>
<td>-</td>
<td>4.2%</td>
<td>19.3%</td>
<td>24.2%</td>
</tr>
</tbody>
</table>

Figure 24: Average daily solar radiation received each month for different mounting options.
Array positioning: shading

If the solar array is shaded in any way, its power output will be reduced. If there is continuous shading at the same position on the solar modules, the modules can develop ‘hot spots’ that can damage them permanently. Incidental shading is not static, as it moves throughout the day and year, following the movement of the sun. It is important that a comprehensive analysis is undertaken to pinpoint possible sources of shading and to confirm where shading will impact the modules at different times of the day and year.

Possible sources of shading include:

- vegetation – trees, bushes, long grass, leaves
- structures – buildings, shelters, fences, telegraph poles,
- landforms – hills, rocks, and
- the array itself – not leaving enough room between rows of tilted modules can cause one row to shade the row behind it.

There are professional shading analysis tools available that enable you to determine shading accurately across a full year. Examples of these tools include Solar Pathfinder and Solmetric Suneye.

Table 4 provides an estimate of the shadow that would be imposed by an object a metre high at six different latitudes in NSW in June (as shadows are the longest in winter).

Key notes:

- A solar array produces its maximum power if the array faces the sun directly.
- To make an informed decision about the optimal orientation and tilt of an array, it’s important that you understand the movement of the sun throughout the day and year.
- If your water pumping requirement has a seasonal or diurnal preference, for instance, if more water is needed in summer or winter, or at the start or the end of the day, the orientation and tilt of the array should be determined to suit that preference.
- A fixed array is the cheapest mounting option. For optimum power output, the array should be north facing and tilted at an angle equal to the latitude of the site.
- A manual tilt framing system is a cost-effective option for maximising power output. The array can be tilted monthly or every couple of months, according to the required scheduling.
- A solar PV array with a single- or dual-axis tracking system is the most expensive option and requires the most maintenance, but can deliver optimal pumping performance and overall power output.
- A system with multiple arrays with different fixed tilts and orientations can also be implemented. In such cases, the devices controlling the output of the system must be fit to maximise power. These devices could be DC optimisers, micro-inverters (on each panel), inverters with multiple maximum point trackers or even multiple inverters (for each orientation).
Figure 25: As shown in Table 4, the shadow of a metre-tall tree in Lismore at 1pm on a June day would be 1.4m long and its direction would be 1.3m south and 0.5m east.
Table 4: Shadow length of a 1m object for various cities in NSW on an average June day.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shadow length</td>
<td>8.00 am 3.8m South 2.3m; 3.8m South 2.3m</td>
<td>9.00 am 2.2m South 1.6m; 2.2m South 1.6m</td>
<td>10.00 am 1.6m South 1.4m; 1.6m South 1.4m</td>
<td>11.00 am 1.3m South 1.3m; 1.3m South 1.3m</td>
<td>12.00 pm 1.3m South 1.3m; 1.3m South 1.3m</td>
<td>1.00 pm 1.4m South 1.3m; 1.4m South 1.3m</td>
</tr>
<tr>
<td>Shadow direction</td>
<td>west 3m; 3.8m South 2.3m</td>
<td>west 1.5m; 2.2m South 1.6m</td>
<td>west 0.8m; 1.6m South 1.4m</td>
<td>west 0.3m; 1.3m South 1.4m</td>
<td>west 0.0m; 1.3m South 1.4m</td>
<td>east 0.5m; 1.4m South 1.3m</td>
</tr>
<tr>
<td>Shadow length</td>
<td>4.5m South 2.7m; 4.5m South 2.7m</td>
<td>2.5m South 1.8m; 2.5m South 1.8m</td>
<td>1.7m South 1.5m; 1.7m South 1.5m</td>
<td>1.4m South 1.4m; 1.4m South 1.4m</td>
<td>1.4m South 1.4m; 1.4m South 1.4m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow direction</td>
<td>west 3.6m; 4.5m South 2.7m</td>
<td>west 1.7m; 2.5m South 1.8m</td>
<td>west 0.9m; 1.7m South 1.5m</td>
<td>west 0.4m; 1.4m South 1.4m</td>
<td>west 0.0m; 1.4m South 1.4m</td>
<td>west 0.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow length</td>
<td>6m South 3.5m; 6m South 3.5m</td>
<td>2.9m South 2.1m; 2.9m South 2.1m</td>
<td>2m South 1.6m; 2m South 1.6m</td>
<td>1.6m South 1.5m; 1.6m South 1.5m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow direction</td>
<td>west 4.9m; 6m South 3.5m</td>
<td>west 2m; 2.9m South 2.1m</td>
<td>west 1m; 2m South 1.6m</td>
<td>west 0.5m; 1.6m South 1.5m</td>
<td>west 0.0m; 1.5m South 1.5m</td>
<td>west 0.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow length</td>
<td>5.5m South 3.3m; 5.5m South 3.3m</td>
<td>2.8m South 2.1m; 2.8m South 2.1m</td>
<td>2m South 1.7m; 2m South 1.7m</td>
<td>1.6m South 1.6m; 1.6m South 1.6m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow direction</td>
<td>west 4.4m; 5.5m South 3.3m</td>
<td>west 1.9m; 2.8m South 2.1m</td>
<td>west 1m; 2m South 1.7m</td>
<td>west 0.4m; 1.6m South 1.5m</td>
<td>west 0.0m; 1.5m South 1.5m</td>
<td>west 0.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow length</td>
<td>8.1m South 4.6m; 8.1m South 4.6m</td>
<td>3.4m South 2.4m; 3.4m South 2.4m</td>
<td>2.1m South 1.7m; 2.1m South 1.7m</td>
<td>1.6m South 1.6m; 1.6m South 1.6m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
<td>1.5m South 1.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow direction</td>
<td>west 6.7m; 8.1m South 4.6m</td>
<td>west 2.4m; 3.4m South 2.4m</td>
<td>west 1m; 2.1m South 1.7m</td>
<td>west 0.4m; 1.6m South 1.5m</td>
<td>west 0.0m; 1.5m South 1.5m</td>
<td>west 0.5m; 1.5m South 1.5m</td>
</tr>
<tr>
<td>Shadow length</td>
<td>7.6m South 4.4m; 7.6m South 4.4m</td>
<td>3.4m South 2.4m; 3.4m South 2.4m</td>
<td>2.3m South 1.9m; 2.3m South 1.9m</td>
<td>1.8m South 1.7m; 1.8m South 1.7m</td>
<td>1.8m South 1.7m; 1.8m South 1.7m</td>
<td>1.8m South 1.7m; 1.8m South 1.7m</td>
</tr>
<tr>
<td>Shadow direction</td>
<td>west 6.1m; 7.6m South 4.4m</td>
<td>west 2.4m; 3.4m South 2.4m</td>
<td>west 1.2m; 2.3m South 1.9m</td>
<td>west 0.6m; 1.8m South 1.7m</td>
<td>west 0.5m; 1.8m South 1.7m</td>
<td>west 0.5m; 1.8m South 1.7m</td>
</tr>
</tbody>
</table>

To use: This table gives two key parameters for the shadow of a metre-tall object: the length of the shadow and its direction (as shown in Figure 24). For a taller or shorter object, multiply these values by the height of the object in metres.

1.6.9 Solar array output (system yield) according to solar resource

The amount of power generated by a solar array is directly proportional to the solar resource available throughout the day. Two key calculations can be performed to determine the system yield:

Power output (instantaneous output)

\[
\text{Power output} = \text{instantaneous solar radiation (kW/m}^2\text{)} \times \text{rated array power (kW)} \times \text{system efficiency}
\]

Energy output (output over time)

\[
\text{Hourly energy output} = \text{hourly solar radiation (kWh/m}^2\text{)} \times \text{rated array power (kW)} \times \text{system efficiency}
\]

\[
\text{Daily energy output} = \text{daily solar radiation (kWh/m}^2\text{ or PSH)} \times \text{rated array power (kW)} \times \text{system efficiency}
\]

Note: The total array power is equal to the sum of all the modules’ power, as shown in the datasheet.

System efficiency relates to factors that reduce the power/energy output of the modules. Several factors can affect system efficiency; they include:

- **temperature** – a higher cell temperature will reduce the power output,
- **shading** – any shading will reduce the power output,
- **dirt** – any soiling of the modules will reduce the power output,
- **cable losses** – power is lost as electricity runs through cables,
- **orientation and tilt losses** – the orientation and tilt of the modules affect the amount of solar radiation that hits the modules, in turn affecting the power output.

Is system efficiency different to module efficiency?

System efficiency relates to losses in the equipment’s operation. This is different to PV module efficiency, which relates to how well a solar PV module converts solar radiation into electricity. The module’s efficiency is already taken into account in the array’s rated power.
For some low-volume solar pumping installations, the solar array is intended to drive a DC pump directly. A pump motor will have an initial start-up power requirement that is greater than the motor’s running power. In such an installation, the power output of the array must match the start-up power required. If the solar PV array cannot supply that initial power requirement, the pump will not start even if the array has enough power to run the motor once started.

### Example 1
A 1.2kW array has been installed to run a bore pump. The measured sunlight intensity is 0.76kW/m² and the system efficiency has been calculated to be 70%. The power output of the array is:

\[
1.2\text{kW} \times 0.76\text{kW/m}^2 \times 0.7 = 0.638\text{kW}
\]

### Example 2
The 1.2kW system installed to run a bore pump is exposed to 5.28kWh/m² over the course of one day, with a system efficiency of 70%. The energy output of the array over the day is:

\[
1.2\text{kW} \times 5.28\text{kWh/m}^2 \times 0.7 = 4.52\text{kWh}
\]

For some low-volume solar pumping installations, the solar array is intended to drive a DC pump directly. A pump motor will have an initial start-up power requirement that is greater than the motor’s running power. In such an installation, the power output of the array must match the start-up power required. If the solar PV array cannot supply that initial power requirement, the pump will not start even if the array has enough power to run the motor once started.

### Key notes:
- The power output of an array gives the instantaneous output.
- Power output = instantaneous solar radiation (kW/m²) x rated array power (kW) x system efficiency.
- The energy output of an array is its output over a period of time.
- Hourly energy output = hourly solar radiation (kWh/m²) x rated array power (kW) x system efficiency.
- Daily energy output = daily solar radiation (kWh/m² or PSH) x rated array power (kW) x system efficiency.

### 1.6.10 Mounting systems
Solar arrays can be installed on structures (roof-mounted), on the ground, on poles or on trackers. The suitability of various mounting options is summarised in Table 5.

**Table 5: Mounting options for solar PV arrays.**

<table>
<thead>
<tr>
<th>Mounting Options</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof-mounted</td>
<td>A roof-mounted array can be installed on a suitable existing structure (such as a shed). This is the standard mounting option for urban grid-connected solar PV systems, so there are many competitively priced products available. The size of the array that’s possible is limited by the available installation area on the roof.</td>
</tr>
<tr>
<td>Ground-mounted</td>
<td>A ground-mounted array can be positioned for best exposure to sunlight. This option requires a suitable area of ground area and type of soil, however. Many installation methods and products (eg. pile-driven, concrete foundations) are available to suit different scenarios. This option may require extra maintenance to prevent vegetation from growing up and shading the modules and requires protection from stock.</td>
</tr>
<tr>
<td>Pole-mounted</td>
<td>A potential installation method for solar PV power in areas where ground- or roof mounting is not suitable is to mount the array on poles; however, available products will limit the maximum number of solar modules that can be pole-mounted, and there are relatively few products available for this type of installation. Installing a pole-mounted solar PV array is a more detailed operation than other forms of mounting, and the structural loading on a pole-mounted array must be determined in advance.</td>
</tr>
</tbody>
</table>
### Floating system

A floating or fixed system on top of a body of water can offer multiple benefits. The array can help to slow evaporation of valuable reservoir water by covering it. The solar cells on the array will also remain cooler and therefore operate more efficiently as heat is more easily absorbed by the surrounding water. Most importantly, a floating system will not require relinquishing valuable farm land. This can be particularly beneficial for horticultural or other farms with high-value produce.

However, farmers should consider the additional expenses entailed, such as the cost of appropriate ballasting, pontoons, anchoring, and additional factors pertinent to this solution. For instance, system components may be affected by water entry, animals nesting, flooding, etc.

### Tracking system

Tracking devices enable a solar array to ‘track’ the sun through the sky, optimising the solar contribution to the pumping system. Tracking systems are more expensive than any of the ‘fixed’ options and while trackers can boost output, they may also introduce a point of failure for the pumping system because of the tracker’s moving parts and ongoing maintenance requirements.

---

A solar PV array could also be installed on a mobile structure, such as a trailer, for a smaller solar pumping system that can be moved around. Care must be taken that the structure can support the array and that it is suitably earthed to prevent the risk of electrocution.

In all options, the mounting structure must be strong enough to withstand the forces of wind on the array, known as wind loading. Australian standard AS 1170.2 covers wind loading of a structure and the array-mounting structure you choose should adhere to this standard.

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**Key notes:**

- There are four mounting options for installing a solar PV array: roof-mounted, ground-mounted, pole-mounted, and installing an array with a tracking system.
- A ground-mounted array is usually a good option for solar pumping as long as it is not susceptible to damage from stock and the ground chosen can support the array. Typically, ground-mounted arrays get high exposure to sun, and they are a comparatively cheap option.

### 1.7 System controllers

A solar pumping system can include solar controllers and pump controllers. These components control the operation of the system so that the water pumping operates according to the design parameters and the water delivery requirements.

A solar pumping system can also be configured to run as an AC system and to use an inverter, a DC to AC converter.
1.7.1 Maximum power point tracker/solar controller

The power output of a solar array is used or manipulated by components to which it is connected. A maximum power point tracker (MPPT) can be installed between the array and the electric motor to match the array’s output with the required current or voltage of the motor to be operated. A MPPT is effectively an electronic DC power to DC power converter and is often called a ‘maximiser’. There are other similar devices for smaller pumping usage, one of which is known as a ‘linear current booster’ or a ‘booster’.

Without an MPPT, the PV array would need to be oversized so that it can provide the start-up current requirement of the motor even though, once the motor has started, the pump’s current requirements drop and, at that point, the array can then produce more power than is needed (Figure 27: a). If the array has not been oversized to include some redundancy, in cloudy weather, the array may not operate at a high enough current to start the motor, even though it would have enough current/power to run the motor once it has started (Figure 27: b).

An MPPT can be provided as a separate component or as part of a pump controller unit (Figure 28).
1.7.2 Pump controller

The term ‘pump controller’ can be used to mean any one of the following:

- The controller that functions to turn the pump on and off electrically. This device can simply be a programmable timing device or its ‘on-off’ function can be activated by a ‘float’ switch triggered by the level of water storage in, or discharge into a tank, dam or other storage facility (Figure 29).
- A more complicated device that incorporates a maximum power point tracker (MPPT) and provides the functions explained previously. The MPPT converts the DC power produced by the solar array to match the voltage and current operating requirements of the system’s solar pump. The MPPT ensures that (i) the pump operates at its maximum performance levels and (ii) the pump will operate in less-than-perfect sun conditions, such as on cloudy days.

When the pump controller is operating as described in the first point above – that is, when it is triggered by a float switch – this controller is able to track the water level using various options, from a simple float switch to an electronic pressure control.

The pump controller provided must be compatible with the pump it is to operate. Most pump manufacturers and suppliers will recommend controllers suitable for use with their proprietary pumps or will manufacture controllers for use with their range of pumps.

![Figure 29: a) The water level is not high enough to switch off the float switch, so the pump remains on; b) the water level has reached a point high enough to switch off the float switch, which in turn turns off the water pump.]

1.7.3 Inverter

An inverter is a DC-to-AC converter. AC solar pumping systems are growing in popularity, with new AC solar water pumping systems able to power standard 3-phase pumps with power ratings up to 375kW.

Key notes:
- A maximum power point tracker (MPPT) is used to match the array’s output with the required current or voltage of the motor/pump.
If the pump is to be powered by an alternative power source, such as the electricity grid, a diesel generator or wind turbine, an AC inverter-based system may be required. This AC output could be combined with other AC electrical sources. An AC motor/pump would also be required.

**Key notes:**
- An inverter is a DC-to-AC converter.
- A quality inverter will carry a 10 year warranty.

### 1.8 Electric motor

In a solar pumping system, the water pump needs to be driven by an electric motor, as it is powered by the electrical output of the solar array; in a non-solar system, the pump could be driven by a diesel or petrol motor or directly, by a windmill. For the purposes of this report, which focuses on solar PV-powered water-pumping systems, it is assumed that all the pumps discussed have electric motors installed. The term ‘solar water pump’, as used in this guide, refers to a motor-driven water pump for use with a solar PV array.

The solar water pump you select must be compatible with the power source provided (Figure 31). Solar modules produce DC electricity; therefore, if the pump motor is to be powered directly from the solar array, this motor should be a suitably rated DC motor. If the pump motor is to be powered by a combination of power sources, such as solar + wind + generator+ grid, it will need to be a suitably rated DC motor or a suitably rated AC motor, depending on the configuration. Some electric motors are able to run off either DC or AC electricity, but the ratings of such a motor may differ depending on whether it is powered by DC or AC.
1.9 Water pump

The pump moves the water from the water source, which could be a river, dam or bore, through pipes to either a point of usage or a storage facility, such as a water tank or an irrigation system. The pump in a solar-powered pumping system is driven by an electric motor and the solar array provides the power source.

A vast range of pumps is available: there are pumps of different types, capacities and physical sizes, and numerous pump product manufacturers. To select a suitable pump, you must first determine the pumping requirements of the intended application. This includes working out your daily water needs as well as gathering information about the water source, discharge point and the journey between the two.

If not supported by other power sources like the electricity grid or battery storage, the pump must be able to move enough water each minute during sunlight hours to meet your operation’s daily water requirements. The pump also

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**Key notes:**
- The electric pump drives the water pump.
- In this guide, it is assumed that the water pump has an electric motor already installed.
needs enough power to move the required amount of water from the water source over the required distance and through the required vertical lift (the head).

**How a pump works**

A pump is defined as a system that is used to move liquid. It can be as simple as a spray bottle or as complex as a human heart. Pumps move liquid by using energy to increase the amount of pressure in the system, shown in simplified form in *Figure 33*.

![Figure 33: The principle of how a pump moves water.](image)

### 1.9.1 Pumping Methods

There are two types of pumping methods: dynamic pumps and positive displacement pumps. Dynamic pumps generally provide better efficiency and flexibility and are suitable for large pumping tasks, such as broad acre irrigation.

**Dynamic pumps**

A dynamic pump uses a set of rotating blades called an impeller to increase or decrease the pressure in the system concept (*Figure 34*). By rotating specially crafted blades in either a clockwise or an anticlockwise direction, the flow of the liquid can be changed, thereby changing the pressure of that liquid.

An electric fan illustrates this. Its specially-shaped blades allow it to change the flow of the surrounding air, forcing it in a specific direction.

![Figure 34: An electric fan works in a similar fashion to a dynamic pump.](image)

A centrifugal pump is a type of dynamic pump most commonly used in solar water-pumping systems.
**Positive-displacement pumps**
Positive-displacement pumps operate by changing the volume in a closed system. As the volume is reduced, the pressure increases; as the volume is increased, the pressure decreases. These changes in pressure cause the fluid to be sucked into the system, then pushed out in the desired direction.

To illustrate this concept, consider an open plastic bottle, held underwater and squeezed, thus reducing its volume. As pressure on the bottle is released, it increases in volume, decreasing the pressure and causing water to be sucked into the bottle. Then, a lid is put on the bottle and it is taken out of the water. The closed bottle is squeezed, reducing its volume and increasing the pressure on its contents. When the lid is opened, this pressure is released, causing the water to be pushed out of the opening.

Helical rotor pumps and diaphragm pumps are the most commonly used positive-displacement pumps in water-pumping applications (See Figure 35 and Figure 38).

![Figure 35: A diaphragm pump is an example of a positive-displacement pump](image)

**Key notes:**
- The two pump types used most commonly in water-pumping applications are dynamic (such as centrifugal) pumps and positive displacement (e.g. helical rotor and diaphragm) pumps.

### 1.9.2 Pump technologies
There are three main pumps used in rural water pumping applications: centrifugal, helical rotor and diaphragm. Each of these pump technologies has different pumping characteristics which means they are suitable for different applications (*Table 6*).

**Table 6: Pumping characteristics of the three main pump technologies.**

<table>
<thead>
<tr>
<th>Pump type</th>
<th>Pumping method</th>
<th>Description</th>
<th>Key operating characteristics</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Centrifugal</strong></td>
<td>Dynamic</td>
<td>A centrifugal pump uses an impeller that throws water at a high speed.</td>
<td>A centrifugal pump can move a lot of water in a short time (high flow) but only through small heights (low head). The efficiency of a centrifugal pump is dependent on its operating voltage.</td>
<td>A centrifugal pump could be used to draw a large amount of water from a dam to a storage tank at sites where the water doesn’t need to travel up any significant hills.</td>
</tr>
</tbody>
</table>

**NSW Farmers** - Solar powered pumping: A guide to system selection and design
## Pump Type: Helical Rotor

(Figure 36b)

**Pumping method**: Positive displacement

**Description**: A helical rotor pump uses a screw to lift water through cavities.

**Key operating characteristics**: A helical rotor pump can move smaller amounts of water (low flow) up large heights (high head). They can operate at their maximum efficiently at many different operating voltages. This makes them well suited to solar pumping.

**Example**: A helical rotor pump could be used to draw water from a deep bore, or to move water from a dam to a water tank located high on a hill.

## Pump Type: Diaphragm

(Figure 36c)

**Pumping method**: Positive displacement

**Description**: A diaphragm pump draws water into a chamber as the diaphragm moves out, and forces water out as the diaphragm moves in.

**Key operating characteristics**: A diaphragm pump can pump more viscous (thicker) liquids and is rarely damaged by solids or dry running. They can move the smallest amounts of water (low flow) but only through a short height (low head) compared to centrifugal and helical rotor pumps.

**Example**: Diaphragm pumps are often used for pumping viscous liquids such as oil, honey and mud. For agricultural water pumping, they could be suitable for systems at sites where the water source is susceptible to draining dry or is very muddy.

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**Figure 36**: a) A centrifugal pump operation; b) a helical rotor pump operation; c) a diaphragm pump operation.
1.9.3 Pumping installation types: surface and submersible pumps

There are two types of water pumping installation: surface pumps and submersible pumps (Figure 37).

- **Surface pumps**: This type of pump is mounted on the ground above the water level, such as on a dam wall. The pump draws the water from the water source, then pushes the water to the point of storage or usage.

- **Submersible pumps**: This pump type is installed below the source water level, such as in a dam or a bore. The pump pushes water directly from the source to the point of storage or usage.

There is a limit to the maximum distance between a surface pump and its water source: it is more difficult for a pump to draw water upwards than for a pump to push the water is has drawn uphill. The practical suction lift limit is about 25 feet (7.62 metres) but pump manufacturers should provide a suction lift limit figure for each pump model. This limitation needs to be considered when designing a solar water pumping system.

![Figure 37: a) A surface pump needs to draw water out from the dam and then push it up to the delivery point; b) a submersible pump only needs to push water from the pump to the delivery point.](image)

Pumps that are exposed to the elements need to be protected: this applies mainly to pumps installed in rivers or dams, rather than to bore pumps. A surface pump could be protected easily with a shelter as this type of pump is usually mounted on the ground. Protecting a submersible pump may be more challenging as these are located in water, preferably in the middle of the source where the water is deepest. Some manufacturers provide floating pontoons that are designed to protect submersible pumps in these situations.
1.9.4 Pump design parameters: flow and head

There are three key parameters of a pumping system: flow, head and power. Flow refers to the rate at which water can be pumped through the system; the head refers to the amount of resistance to the water movement (primarily vertical height); and the power is the amount of energy required to meet a certain flow rate and head combination. In general, a high head means the pump may deliver only a low flow rate, and a low head means the pump may deliver a high flow rate. The parameters of flow and head are explored further in the following sections:

Flow rate

The flow rate is the amount of water pumped in a certain time period. The flow rates able to be met by a pump are usually quoted in L/min or m³/day (where 1m³ = 1,000L).

In a solar pumping system, the anticipated flow rates of the pump must be estimated according to the variability of the site’s solar radiation levels:

- If a minimum daily flow rate is required every day, regardless of the available sun hours, the system design would need to increase the required daily flow rate to compensate for reduced pumping performance on sun-reduced days. The calculations for adjusting the daily flow rate are given in the design section.
- The hourly flow rate should take into consideration that there is a limited number of sun hours per day to pump the water. The estimated flow rate also needs to take into consideration that the levels of solar radiation vary from hour to hour. For example, for a north-facing array, more water will be pumped in the middle of the day when the solar radiation levels are higher compared to the morning or afternoon when the solar radiation levels are lower. The calculations for estimating an hourly flow rate are given in the design section.

The flow rate is a critical figure in the design of a solar pumping system and it must be accurately determined to optimise the pumping system design.

Total dynamic head

The total dynamic head (TDH) represents the sum of the resistances experienced by the pumped water (Figure 38). The required system’s TDH is a specification that the pump must meet in order to move the required amount of water. The TDH includes both the height (elevation loss) through which the water needs to be lifted (static head) and the friction of the water running through the pipes (dynamic head).

- **Static head:** This is the vertical distance that the water travels. In a submersible pump, it would be the height difference between the water pump and the water destination. In a surface pump, it would be the height difference between the top of the water source and the water destination.
Why doesn’t static head include the horizontal distance of the pipe?

Static head doesn’t include the horizontal distance of the pipe. This is because it only takes a very small amount of energy to move water horizontally and energy is only needed to overcome the friction in the pipes (part of the dynamic head calculation). On the other hand, it takes a lot of energy to move water vertically against the force of gravity.

- **Dynamic head** represents the friction losses in the pipes. The main contributors to this parameter are the velocity of the water (flow rate), the diameter of the pipe, the length of the pipe and the pipe material. The dynamic head should also allow for the effect of inline piping accessories such as filters, valves, elbows and inlet pipes.
The total dynamic head is equal to the sum of the static head and the dynamic head:

\[ \text{Total dynamic head} = \text{static head} + \text{dynamic head} \]

The relationship between static head, dynamic head and total dynamic head is shown in Figure 40.

![Figure 40: The relationship between static head (green), dynamic head (blue) and total dynamic head (red). Dynamic head increases as flow rate (velocity of water) increases but static head is the same regardless of flow rate. The total dynamic head is equal to the sum of these.](image)

**Key notes:**
- The total dynamic head is a core parameter for sizing the pump.
- The total dynamic head represents all of the resistances experienced by the pumped water, both the height through which the water needs to be lifted (static head) and the friction experienced by the water as it runs through the pipes (dynamic head).

### 1.9.5 Pump priming

Pump priming refers to filling the pump with water before starting to remove any air. This is important for pumps that cannot operate if there is air inside them. Positive displacement pumps (helical rotor and diaphragm types) do not need priming as they naturally remove any air inside when they start and are not damaged by having air inside them. Dynamic (centrifugal) pumps cannot operate with any air inside them and so need some form of priming.

Most dynamic pumps available for water pumping are self-priming. These pumps need to have their casings filled manually with water when they are initially installed. After that, this type of pump can use the casing water to remove any water that’s inside the pump mechanism each times it starts up. A dynamic pump would also need re-priming if the pump’s casing water was emptied for maintenance.

When starting up any pump, the manufacturer’s instructions should always be followed.
1.9.6 Pump issues: cavitation

One of the principal causes of damage to a pumping system is cavitation: the implosion of air bubbles in a liquid. Cavitation can have such force that it tears apart metals or ages pump materials prematurely.

Air bubbles in pumping applications are caused by water boiling when subjected to low pressures. This occurs because at low pressures, water boils at a lower temperature than normal, and boiling water releases air bubbles. As water moves from a low-pressure area to a high-pressure area, these air bubbles can implode, damaging the pump.

To prevent cavitation, it is important to ensure that the flow rate of the pump will remain on its prescribed curve, as given in the specification sheet. This will prevent excessive pressure drops in the water that is being pumped, minimising the risk of cavitation.

Key notes:
- Running a pump at a too-high flow rate could cause it to be damaged by cavitation.
- Cavitation can be prevented by following the flow rate specifications of the pump.

1.10 Other forms of solar power generation and energy storage

![Diagram of solar power generation and energy storage system]

Depending on the water reliability requirements, and accepting that solar availability can vary from what is predicted, a solar pumping system can be designed to include additional power generation and/or storage. Note, however, that the addition of either will increase the technical complexity and cost of the system.

Diesel generators

 Diesel and petrol generators are commonly used in agriculture for several purposes: as portable 240VAC power sources; peak load power supplies; and as supplementary power supplies for various applications. Such generators could be used in conjunction with solar PV systems to provide reliable power for water pumping systems.
Usually, it is inefficient to run a pump directly from a generator. This is because most pumps require only a small percentage of the output power of a generator. This means that the rest of the generator’s power will not be used and will be wasted.

Instead, the pump could be run from a battery bank that is charged by a solar PV system and a generator. The generator would operate only intermittently, and the battery could be designed to take the full power of the generator when it is running. This would result in a more efficient system, although adding battery storage increases the complexity and cost of that system.

Adding a generator would also increase the up-front and ongoing costs of the system. Generators require fuel, which is subject to price hikes, and require ongoing maintenance and service. These additional costs would need to be included in your economic analysis.

Battery storage

Improvement in the efficiency and pricing of battery storage mean that is worth considered the incorporation of batteries in a solar powered pumping solution. Batteries can play a role where:

- you need to pump water during the night,
- you are unable to store water at a sufficiently high head using solar power alone,
- you need to maintain highly specific pressurisation within tanks or networks,

you can use surplus solar energy for other night time loads. Using batteries to store excess power means that this electrical power is available for use whenever it is needed. Having battery storage reduces the need for the solar PV system to provide any pumping redundancy as the batteries, having been charged during times of high generation, can supply the pumping system during times of low solar generation. Having battery storage also increases the user’s control over the pumping system.

Note that a solar PV-battery pumping system needs to be designed so that it has the capacity to operate the pumping system as well as providing power backup as required. Correct sizing and suitable housing is essential, as is regular maintenance and servicing. A solar pumping system with battery storage also requires a more detailed design. Installing the system requires reference to additional Australian Standards (such as the AS/NZS 4509: 2009). Battery storage can provide 10 to 15 years of reliable operation.

To determine whether a solar PV pumping system incorporating battery storage is a cost-effective investment, you would need to estimate the up-front and operating costs of the proposed system, including maintenance of the system and replacement of components.

Key notes:

- Other energy sources (such as generators) or battery storage can be used to provide backup power to balance out the variations in solar power.
- If they are to provide sufficient supplementary power, wind-power generators require a well-documented, constant and strong prevailing wind resource.
- Diesel generators can be used alongside solar PV systems to provide reliable power supply, but will add to your up-front and operating costs.
- Battery storage is costly but can help to balance out the variations in available solar power.
**Grid electricity**

Another important and common setup is to install a grid-connected system that will help provide power to any loads on-site (including pumping) and allow excess generated electricity to be exported back to the grid. A grid-connection can make the case for a solar system for an intermittent pumping regime more viable. When pumping isn’t required, the energy from the solar system can either earn some revenue by exporting to the grid or meeting other electricity needs on farm. Refer to section ‘Solar combined with power from the electricity grid’ (page 8) for more information.
SECTION 3: THE DESIGN PROCESS

A correctly specified and installed solar powered irrigation solution can provide long and trouble free service and excellent return on investment.

When assessing feasibility, size and configuration, key factors include the timing of pumping, the volume and reliability of water supply required, water storage capacity, and the potential to integrate solar with other power sources.

Farms that have relatively continuous and predictable day time irrigation needs are ideal candidates for solutions that fully replace mains power. As a result, many horticultural growers have already adopted solar. However, in most broad acre irrigation systems, pumping requirements are seasonal and vary in response to climate. These systems require more complex assessment and design.

Where pumping is irregular or not always in day light hours, return on investment and optimal system size should be calculated with reference to external factors such as other electricity demand on farm, ability to export and sell unused electricity and ability to offset night time mains electricity cost with savings on day time usage.

Prior to committing to a major system we recommend that you undertake the following steps:

- Commission a general energy assessment of your farm. This should include accurate documentation of the quantity, cost and timing of energy used by your irrigation system.
- Address energy efficiency savings first. Poor layouts, pipe diameters, pump size and maintenance are typical energy wastage points.
- Check the capacity of your water storage infrastructure and minimise leakage and evaporation.
- Involve your irrigation engineer to clarify priorities and technical requirements (eg dynamic pumping head, pressure, control systems).

Having this information at hand will prepare you to discuss options with suppliers and obtain accurate quotes. It is essential that suppliers have experience with solar irrigation applications.

A solar PV pumping system should be designed to optimise efficiency and cost. The steps involved in the design process are shown in Figure 42.
Some of the calculations involved in the design of a solar pumping system are very complicated and require a highly technical understanding of the complexities in both pump and array design. The design process above aims to explain the key principles of solar pumping design so that an informed decision can be made about a suitable solar pump supplier and the packages they offer.

1.11 Worked examples

Throughout this section, we have used two worked examples to help explain the design process and illustrate the application of the required steps (see the series of coloured boxes embedded in the text entitled ‘Dairy farm in Tamworth’ and ‘Small farm in Griffith’). These examples describe the solar PV pumping solutions adopted by two NSW-based farming operations: a Tamworth dairy farm and a mixed livestock and horticulture farm in Griffith.
Example: Dairy farm in Tamworth

A dairy farm in Tamworth, NSW, uses a solar pumping system to move water from a river into a stock dam to be used as drinking water for 1200 cattle. Dairy cows have high daily water needs for milk production, and pumping a large amount of water requires a lot of power. The water for these cattle is lifted through a small height, increasing the system’s power requirements by a corresponding amount. The solar pumping system for this farm was designed so that each day, it is able to move the large amount of water the cattle need over the required distance and height.

Figure 43: The Tamworth dairy farm solar PV pump.
Example: Small farm in Griffith

A small farm in Griffith, NSW, uses a solar PV-powered water pumping station to move water from a bore into a storage tank. From here, the water is gravity-fed into troughs for 50 sheep and to drip irrigate a small orange orchard. The pump is designed to move the daily water requirements of the livestock and crops as well as excess supply that is stored in the tank for days when solar radiation is lower. The farm’s total daily pumping requirement is reasonably low; it requires only a small amount of pump power. The water storage tank is located high on a hill, enabling water stored here to be gravity-fed. Moving water to the top of this hill requires a significant amount of pump power. The Griffith farm’s solar pumping system is designed to move the required amount of water through the required distance and height each day.

A design checklist is included in Appendix C: Solar pump design checklist.

1.12 Step 1: Site assessment

An accurate site assessment is critical to successful solar pump design. This ensures that system design and installation locations are site-specific so that the system delivers the required pumping outputs, with the least amount of wasted energy.
A site assessment involves gathering accurate information about your farm daily water requirements, the site's historical solar resource, possible water sources and the water delivery point.

### What information do I need to take to a solar pump supplier?

Information typically required by solar pump suppliers includes:

- **Water requirements:**
  - for what purpose(s) the water will be used (for example, livestock, irrigation),
  - your daily water requirements, and
  - monthly/seasonal variation.

- **Locations for the solar pumping system:**
  - the proposed location (geographical coordinates) for your solar pumping system,
  - the proposed location of the solar array, and
  - potential sources of shading.

- **Water sources:**
  - the type of water source (a bore, dam or river),
  - the recovery rate of the proposed water source,
  - the depth of the water source, and
  - the distance from the top of this water source to the ground.

- **Water delivery:**
  - the location to which the water will be pumped to (such as a storage tank or dam, directly to troughs, or to drip irrigation),
  - the vertical lift between the pump and the water delivery point, and
  - the length of the route between the pump and the water delivery point.

### 1.12.1 Daily water requirements

The farm’s daily water requirements form the central design criterion of a solar pumping system. The capability of a solar PV pumping system to deliver these daily water requirements, given site-specific parameters, will determine the success of the system design. These requirements will influence:

- the choice of water source,
- the delivery point for the pumped water,
- whether water storage is needed or not,
- which types of water pumps will be suitable for the application,
- the required size of the pump, and
- the solar array design.

The intended water application – for example, the daily water needs of livestock or the irrigation requirements of a crop – will determine the overall daily water requirements. Monthly and seasonal variations should be considered in your calculation of daily water requirements, as these will also impact on the pumping system design (Table 7).

A table provided by the NSW Office of Water is attached in Appendix D: Office of Water – Water Needs for a Rural Property. This document gives estimates of the water needs of various animals at different stages of their development. Appendix B gives a brief explanation of the various units of measurements for water volume.
Example: Dairy farm in Tamworth

The dairy farm in Tamworth introduced at the start of this section has 1,200 cattle that need to be supplied by the solar PV-powered water pump. There are approximately 900 milk-producing cows and 100 calves, with the remaining 200 head of cattle made up of dry dairy cows and bulls.

The NSW Office of Water report (Appendix D) assesses the water requirements of these cattle as follows:

- milk-producing cows = 22m³/head/yr
- calves = 8m³/head/year
- dry dairy/bulls = 15m³/head/yr

The water requirements of these animals vary little from season to season, increasing slightly in summer and decreasing marginally in winter. However, increased solar radiation over summer naturally results in a greater capacity to pump water in a solar-powered system, so we can assume the daily water requirements in each month will be the same.

<table>
<thead>
<tr>
<th>Animal type</th>
<th>No. of animals</th>
<th>Annual water requirement per animal</th>
<th>Annual water requirement (no. of animals x annual water requirement per animal)</th>
<th>Daily water requirement (annual water requirement ÷ 365)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk-producing cows</td>
<td>900</td>
<td>22m³/head/yr</td>
<td>900 x 22 = 19,800m³/yr</td>
<td>54.25m³/day</td>
</tr>
<tr>
<td>Calves</td>
<td>100</td>
<td>8m³/head/yr</td>
<td>100 x 8 = 800m³/yr</td>
<td>2.19m³/day</td>
</tr>
<tr>
<td>Dry dairy/bulls</td>
<td>200</td>
<td>15m³/head/yr</td>
<td>200 x 15 = 3,000m³/yr</td>
<td>8.22m³/day</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>23,600 m³/yr</strong></td>
<td><strong>64.66 m³/day</strong></td>
</tr>
</tbody>
</table>

Note: For ease of calculations, this daily water requirement will be rounded up to 65m³/day.

Table 7: Basic template to fill out average daily water requirements for each month of the year.

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily water requirement for the month</th>
<th>Month</th>
<th>Average daily water requirement for the month</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>____ L/day</td>
<td>July</td>
<td>____ L/day</td>
</tr>
<tr>
<td>February</td>
<td>____ L/day</td>
<td>August</td>
<td>____ L/day</td>
</tr>
<tr>
<td>March</td>
<td>____ L/day</td>
<td>September</td>
<td>____ L/day</td>
</tr>
<tr>
<td>April</td>
<td>____ L/day</td>
<td>October</td>
<td>____ L/day</td>
</tr>
<tr>
<td>May</td>
<td>____ L/day</td>
<td>November</td>
<td>____ L/day</td>
</tr>
<tr>
<td>June</td>
<td>____ L/day</td>
<td>December</td>
<td>____ L/day</td>
</tr>
</tbody>
</table>

Table 8: Water requirements of cattle herd, Tamworth dairy farm.
Example: Small farm in Griffith

The small farm in Griffith has 0.25 hectares planted with orange trees and 50 head of sheep to be supplied by its solar-powered water pump. The water requirements of the sheep vary little from season to season, but those of the orange trees vary significantly from month to month. The annual water requirement of the farm’s sheep is 1,900L. Multiplying this figure by 50 (the number of sheep) and dividing it by 365 (the number of days in a year) gives a daily water requirement for the sheep of 260L/day. The water requirements of the farm’s 0.25 hectares of orange orchards (with the addition of 260L/day for sheep) are detailed in the following table.

Table 9: Average daily water requirements, month by month, Griffith small farm.

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily water requirement for each month</th>
<th>Month</th>
<th>Average daily water requirement for each month</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>12,340 L/day + 260 L/day = 12,600 L/day</td>
<td>July</td>
<td>2,470 L/day + 260 L/day = 2,730 L/day</td>
</tr>
<tr>
<td>February</td>
<td>11,840 L/day + 260 L/day = 12,100 L/day</td>
<td>August</td>
<td>4,110 L/day + 260 L/day = 4,370 L/day</td>
</tr>
<tr>
<td>March</td>
<td>8,230 L/day + 260 L/day = 8,490 L/day</td>
<td>September</td>
<td>5,950 L/day + 260 L/day = 6,210 L/day</td>
</tr>
<tr>
<td>April</td>
<td>5,100 L/day + 260 L/day = 5,360 L/day</td>
<td>October</td>
<td>8,230 L/day + 260 L/day = 8,490 L/day</td>
</tr>
<tr>
<td>May</td>
<td>3,290 L/day + 260 L/day = 3,550 L/day</td>
<td>November</td>
<td>10,200 L/day + 260 L/day = 10,460 L/day</td>
</tr>
<tr>
<td>June</td>
<td>2,550 L/day + 260 L/day = 2,810 L/day</td>
<td>December</td>
<td>11,520 L/day + 260 L/day = 11,780 L/day</td>
</tr>
</tbody>
</table>

Note: The monthly water requirements of orange orchards were estimated using tools published in NSW Department of Primary Industries report ‘Managing citrus orchards with less water’, published December 2006.

Figure 45: Average daily water requirement for each month.

1.12.2 Solar resource

The solar resource available at a site determines the energy output of a solar PV array installed on that site, and the amount of time for which a solar-powered water pump will be able to operate on a typical day.
To assess the solar resource at a site, you can use historical solar radiation data, usually given as solar radiation levels received by a horizontal surface. There are several reliable sources for this data.

- The **Bureau of Meteorology** (BoM) ([www.bom.gov.au](http://www.bom.gov.au)) has measured solar data for most of its weather stations around Australia. This is the best source of accurate historical solar data for anyone designing a solar pumping system in Australia. In Appendix E, we explain how to use the BoM website to collect historical solar data.
- The **NASA Atmospheric Science Data Center** web portal ([eosweb.larc.nasa.gov/sse](http://eosweb.larc.nasa.gov/sse)) includes a calculator that enables you to predict average solar data for any location worldwide, using latitude and longitude. This website is a useful resource but does not contain measured historical solar data.
- The **Australian Solar Radiation Data Handbook** (ASRDH) is a quality source of measured solar radiation data for cities and towns throughout Australia. The data for a specific location can be purchased from Exemplary Energy ([www.exemplary.com.au](http://www.exemplary.com.au)).
- Some **online solar-pump sizing tools** contain solar data for many locations around Australia.

When purchasing a solar pumping system package, however, you should not be expected to have site-specific solar data; the supplier should be able to provide the correct historical solar data for the system design.

Establishing the average daily solar radiation levels for each month will provide you with enough information to enable an informed assessment of the proposed solar PV pumping system *(Figure 38)*. Average daily solar radiation levels on site can be measured in peak sun hours (PSH) or in kWh/m². These units of measurements are equivalent and hence, will yield the same values. (Note: If these are given in MJ/m², the numbers will need to be divided by 3.6 to give PSH.)

### What effect will the array tilt have on the solar resource data?

Usually, historical solar radiation levels are provided as the total solar energy for a day, where sunlight is falling on a horizontal (flat) surface; however, solar arrays are not installed horizontally but are tilted, and the angle of tilt changes the actual amount of solar energy that will be received by the array. To calculate the available solar resource more accurately, select the proposed tilt of the array and correct the historical solar data accordingly. The method for doing this is described in *Step 2: Selecting the array tilt*.

### 1.12.3 Water resource

The water resource available at a site needs to be assessed so that a suitable source can be selected for the solar pumping system. In many cases, the water source will have been chosen already. The solar pumping system must be designed with the limitations of the proposed water source in mind.

Many types of water source can be considered. The most common are dams, bores or aquifers, and rivers or creeks. Each source has characteristics that need to be considered when planning a pumping system. For example, bore water may be located deep underground and if so, it will have a higher head and will pump at a lower flow rate. On the upside, bore water has a more stable availability as it is less affected by seasonal changes.

When selecting a suitable water source, we suggest you consider the following characteristics (outlined in *Figure 46*).
Table 10: Key characteristics of a water source.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Why is this characteristic important?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static water level</td>
<td>The static water level is the level the water source reaches without pumping applied to it. This figure forms the basis for calculating the total dynamic head.</td>
</tr>
<tr>
<td>Water source depth</td>
<td>The depth of the water source must be known in order to determine its volume.</td>
</tr>
<tr>
<td>Recovery rate</td>
<td>The recovery rate is the rate at which water enters the source from natural processes. The recovery rate must exceed the proposed pumping rate or the water source will run dry.</td>
</tr>
<tr>
<td>Topography</td>
<td>The topography of the site must be known in order to determine distances and gradients of water movement. This information is used to determine pump sizing and the location of components.</td>
</tr>
<tr>
<td>Water quality</td>
<td>The quality of the available water can affect pump selection as well as whether the water is suitable for its intended usage.</td>
</tr>
<tr>
<td>Seasonal variations</td>
<td>Seasonal variations in the available water source must be known in order to evaluate a pump’s performance over the whole year.</td>
</tr>
<tr>
<td>Other water losses</td>
<td>Other potential water losses, such as evaporation, must be considered when planning a pumping system.</td>
</tr>
</tbody>
</table>

*Figure 46: Key characteristics of a water source.*
Example: Dairy farm in Tamworth

The manager of the Tamworth dairy farm plans to use a river to supply the farm’s cattle with water (Figure 47):

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static water level</td>
<td>1m</td>
</tr>
<tr>
<td>Depth of river</td>
<td>2m</td>
</tr>
<tr>
<td>Recovery rate</td>
<td>~ 10,000 L/hr in summer and ~8,000 L/hr in winter. This farm has a daily water pumping allocation of 100m³/day.</td>
</tr>
<tr>
<td>Topography</td>
<td>This river is a reliable source of water. It is located approximately 100m from the stock dam.</td>
</tr>
<tr>
<td>Water quality</td>
<td>The water contains minimal solids and has a salt content of less than 5,000ppm.</td>
</tr>
<tr>
<td>Seasonal variations</td>
<td>The river has a greater flow in the summer months than in the winter ones. There may be some flooding in the summer months.</td>
</tr>
<tr>
<td>Other water losses</td>
<td>There are no other major sources of water loss.</td>
</tr>
</tbody>
</table>

Figure 47: Water resource of the dairy farm in Tamworth.
1.12.4 Water delivery point

The water in a solar PV water-pumping system can be delivered directly to the application (for example, drip irrigation) or delivered to a form of water storage, such as a dam or water tank. The location of this water delivery point will form the head requirement of the pump. The higher or further away from the source the delivery point, the greater pumping power the system will require to move water from the source to its point of delivery.

For a system that will have water storage, it’s important to consider the capacity of this storage. This is especially the case if the pumping system will be designed to pump more water on sunny days to compensate for reduced water pumping on cloudy ones.

This concept is shown for a water tank in Figure 49 but can also apply to water stored in a dam.

Example: Small farm in Griffith

The manager of the small Griffith farm plans to use a bore to supply water its orchard and sheep (Figure 48):

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static water level</td>
<td>15m</td>
</tr>
<tr>
<td>Pump depth (drawdown level)</td>
<td>5m</td>
</tr>
<tr>
<td>Recovery rate</td>
<td>2,200 L/hr</td>
</tr>
<tr>
<td>Topography</td>
<td>The bore is located on a flat approximately 200m from the water tank.</td>
</tr>
<tr>
<td>Water quality</td>
<td>The water contains minimal solids and has a salt content of less than 5,000ppm.</td>
</tr>
<tr>
<td>Seasonal variations</td>
<td>There are no significant seasonal variations.</td>
</tr>
<tr>
<td>Other water losses</td>
<td>There are no other sources of major water loss.</td>
</tr>
</tbody>
</table>

Figure 48: Water resource of the farm in Griffith.
Figure 49: The daily pumping rate of this system has been determined for an average solar day (middle). On these days, the water pumped is equal to the water used. On above-average solar days (left), more water is pumped and stored. This helps supply water on below-average solar days (right). The storage tank needs to be sized so that it can store enough water on sunny days to compensate for the water not pumped in on very cloudy days.

A common configuration for a solar pumping system is to install a water tank in an elevated location. The stored water can be discharged and gravity-fed as required, which means there will be water available even when the solar PV array is producing less power than is needed, such as on cloudy day or overnight. If the tank is not elevated and is unable to gravity-feed water, the system will need additional power to move water from the tank as required.

**Example: Dairy farm in Tamworth**

The dairy farm in Tamworth is going to pump water to a stock dam. The capacity of the stock dam is approximately 1ML (1,000,000L), which is more than 10 times the daily pumping rate of 65,000L/day. The stock dam is approximately 100m from the river, with a vertical lift of 10m.

**Example: Small farm in Griffith**

The small farm in Griffith is going to pump its water to a water tank. The owner would like to have the equivalent of one day’s pumped water stored in the tank to compensate for days with low solar radiation. The daily water requirement in summer (the farm’s highest daily water requirement) is 12,600L/day. Therefore, a 10,000L or a 15,000L tank could be suitable.

1.13 Solar PV pumping system layout: location of the components

Once the solar resource, the water resource and the water delivery point have been assessed, an initial system layout can be created. When devising a solar pumping system layout, it is important that distances – horizontal and
vertical – between all the system parts are minimised. Both electrical cabling and water pipes experience energy losses, so keeping their lengths to a minimum will reduce energy losses in the system and will result in the most efficient solar PV pumping system possible for your site and needs.

- **Water source:** It is usual to select the location of the water source first. Generally, it is the least flexible part of the system.

- **Water pump:** The water pump should be situated so as to minimise pipe lengths and electric cable lengths. If using a surface pump (a pump installed on the ground above the water), the distance between the pump and the water source will need to meet the manufacturer’s operating specifications.

- **Solar PV array:** The solar array should be located to avoid shading and to minimise incidental shading, away from tall vegetation and structures. The array should be located so as to minimise the length of electrical cabling needed to reach the water pump. Whether it is roof-mounted or ground-mounted, the solar PV array must be installed on a suitable surface that can adequately support the array.

- **Water delivery point:** The water delivery point should be selected to minimise the head (vertical height) and water-piping distance, while still fulfilling the water delivery requirements. For example, if a water tank is to be used for gravity-feeding, it will need to be located at a height sufficient to enable it to supply the required water application (*Figure 50*).

*Figure 50: The water tank is sited on a hill so it is able to gravity-feed all the farm’s water applications. The pump has been sited inside a bore hole, with the solar PV array located nearby in a location with minimal shading.*
Step 2: Selecting the array tilt and orientation

The tilt of the array will affect the amount of solar radiation it receives throughout the year and the orientation will affect the amount of solar radiation it receives throughout the day. These, in turn, will affect calculations of the flow rate that will be needed for water pumping. Therefore, the next step in the design of a solar PV pumping system is to determine the array tilt and orientation and calculate the resulting solar radiation levels. The size of the array does not need to be ascertained at this point.

To select an appropriate array tilt and orientation, you need to consider your seasonal/monthly water requirements. If your farming enterprise has significantly greater pumping needs in summer than in winter, the array should be designed to receive more solar radiation during the summer months than in the winter ones. A fixed tilt equal to the latitude of the site is generally a good choice. For a fixed tilt array, this will result in the greatest possible amount of solar radiation over the year, with more solar radiation received in the summer months than in the winter ones.

If your farm’s pumping needs are similar year-round or you have significantly greater pumping needs in winter than in summer, the tilt should be set so that the modules receive a more even spread of solar radiation throughout the year (Figure 51). If you want a fixed array to receive more winter and less summer radiation, consider a slightly steeper tilt. A manual tilting or tracking array could also be suitable.
A single-axis tracking system increases the output of a solar array in the mornings and afternoons; a dual-axis tracking system would, additionally, increase the output of the array in winter and in summer. It should be remembered, however, that a tracking system increases the costs and maintenance requirements of the array. It is often more cost-effective to install a larger, static array. To give increased morning and afternoon output, consider an array made up of east, north and west-facing solar PV modules.

There is more than one method by which to calculate the amount of solar radiation your array is likely to receive once the module tilt has been selected.

- The NASA Atmospheric Science Data Center (eosweb.larc.nasa.gov/sse) can predict monthly averages for your location for the following tilts: (i) equal to the latitude of the site, (ii) equal to the latitude of the site plus 15°, and (iii) equal to the latitude of the site minus 15°. For Tamworth, NSW (latitude 31°), it can predict average daily radiation levels for each month for the following tilts: (i) 31°, (ii) 46°, and (iii) 16°. (See Table 13).
- The Clean Energy Council (CEC) provides tables for Australian capital cities that show increases or decreases in monthly radiation levels according to the tilt and orientation of a solar PV array (www.solaraccreditation.com.au/installers/compliance-and-standards/accreditation-guidelines.html). An extract of these tables is shown in Table 14.
- The Australian Solar Radiation Data Handbook (ASRDH) contains the monthly and annual radiation levels that would be received by a solar PV array using every possible combination of tilt and orientation, for cities and towns throughout Australia. The data for a specific location can be purchased from Exemplary Energy (www.exemplary.com.au).
Once you have selected the optimal tilt for the proposed solar array using the suggested methods, you’ll have the information you need to complete Table 12.

### Table 12: Average daily solar radiation levels for each month, depending on the array tilt.

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily solar radiation levels (PSH or kWh/m²) on a tilted surface</th>
<th>Month</th>
<th>Average daily solar radiation levels (PSH or kWh/m²) on a tilted surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>__________ PSH</td>
<td>July</td>
<td>__________ PSH</td>
</tr>
<tr>
<td>February</td>
<td>__________ PSH</td>
<td>August</td>
<td>__________ PSH</td>
</tr>
<tr>
<td>March</td>
<td>__________ PSH</td>
<td>September</td>
<td>__________ PSH</td>
</tr>
<tr>
<td>April</td>
<td>__________ PSH</td>
<td>October</td>
<td>__________ PSH</td>
</tr>
<tr>
<td>May</td>
<td>__________ PSH</td>
<td>November</td>
<td>__________ PSH</td>
</tr>
<tr>
<td>June</td>
<td>__________ PSH</td>
<td>December</td>
<td>__________ PSH</td>
</tr>
</tbody>
</table>

To calculate the corrected average PSH, multiply the initial average daily PSH values on a horizontal surface from Table 13 (in page 58) by the percentage from this table for each month. If the tilt of your proposed array is not shown, use Table 11 to estimate the values.
Example: Dairy farm in Tamworth

The Tamworth farm (latitude 31°) has large and consistent water requirements (65m³/day) year-round. To maximise the amount of solar radiation received in winter as well as summer, they’ve chosen a manually tilting array that will be tilted approximately 15° every three months in line with the calculations in Table 2: Monthly and quarterly manual tilt plan. This will give them the average daily solar radiation levels shown in Figure 52. Data on horizontal and tilted radiation was sourced from NASA Atmospheric Science Data Centre.

Table 13: Average daily solar radiation on horizontal and tilted array surfaces (Source: NASA Atmospheric Science Data Center).

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily solar radiation levels on a horizontal surface (kWh/m²)</th>
<th>Tilt each month</th>
<th>Average daily solar radiation levels on a manually tilted surface (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>7.1</td>
<td>16°</td>
<td>6.91</td>
</tr>
<tr>
<td>February</td>
<td>6.4</td>
<td>31°</td>
<td>6.18</td>
</tr>
<tr>
<td>March</td>
<td>5.5</td>
<td>31°</td>
<td>5.95</td>
</tr>
<tr>
<td>April</td>
<td>4.2</td>
<td>31°</td>
<td>5.22</td>
</tr>
<tr>
<td>May</td>
<td>3.2</td>
<td>46°</td>
<td>4.67</td>
</tr>
<tr>
<td>June</td>
<td>2.8</td>
<td>46°</td>
<td>4.51</td>
</tr>
<tr>
<td>July</td>
<td>2.9</td>
<td>46°</td>
<td>4.50</td>
</tr>
<tr>
<td>August</td>
<td>3.8</td>
<td>31°</td>
<td>4.91</td>
</tr>
<tr>
<td>September</td>
<td>5.1</td>
<td>31°</td>
<td>5.81</td>
</tr>
<tr>
<td>October</td>
<td>6.1</td>
<td>31°</td>
<td>6.12</td>
</tr>
<tr>
<td>November</td>
<td>6.7</td>
<td>16°</td>
<td>6.54</td>
</tr>
<tr>
<td>December</td>
<td>7.3</td>
<td>16°</td>
<td>7.02</td>
</tr>
</tbody>
</table>

Figure 52: Average daily solar radiation levels on a manually tilted array.
Example: Small farm in Griffith

The small farm in Griffith (latitude 34.29°) has significantly greater water requirements in summer (around 12,600 L/day) than in winter (around 2,800 L/day). The owner would like to install a fixed-tilt array, tilted at an angle of 20°, slightly flatter than the location’s latitude. This will result in higher solar radiation levels in summer than in winter (Figure 54). The radiation data was calculated using the CEC table for Canberra, which has a latitude (35.3°) and climate similar to those of Griffith.

*Table 14: Average daily solar radiation levels for a horizontal and a tilted array in Griffith, NSW.*

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily solar radiation levels on a horizontal surface (kWh/m²)</th>
<th>Percentage from CEC table (tilt of 20°, orientation north)</th>
<th>Average daily solar radiation levels on a tilted surface (column 1 x column 2 ÷ 100) (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>7.9</td>
<td>100%</td>
<td>7.9</td>
</tr>
<tr>
<td>February</td>
<td>6.8</td>
<td>106%</td>
<td>7.2</td>
</tr>
<tr>
<td>March</td>
<td>5.8</td>
<td>116%</td>
<td>6.7</td>
</tr>
<tr>
<td>April</td>
<td>4.2</td>
<td>128%</td>
<td>5.4</td>
</tr>
<tr>
<td>May</td>
<td>3.1</td>
<td>142%</td>
<td>4.4</td>
</tr>
<tr>
<td>June</td>
<td>2.4</td>
<td>147%</td>
<td>3.5</td>
</tr>
<tr>
<td>July</td>
<td>2.6</td>
<td>146%</td>
<td>3.8</td>
</tr>
<tr>
<td>August</td>
<td>3.5</td>
<td>134%</td>
<td>4.7</td>
</tr>
<tr>
<td>September</td>
<td>4.8</td>
<td>121%</td>
<td>5.8</td>
</tr>
<tr>
<td>October</td>
<td>6.2</td>
<td>110%</td>
<td>6.8</td>
</tr>
<tr>
<td>November</td>
<td>7.0</td>
<td>102%</td>
<td>7.1</td>
</tr>
<tr>
<td>December</td>
<td>7.7</td>
<td>99%</td>
<td>7.6</td>
</tr>
</tbody>
</table>
### 1.15 Step 3: Calculate the required flow rates

As explained in the earlier section on pumping, flow rate is the amount of water that can be pumped within a certain time period, for example, per day or per hour. For a solar PV-powered pumping system, the required daily and hourly flow rates may need to be adjusted to account for variations in levels of solar radiation that are experienced at the site over the course of the day and the year.

Generally, a pump is selected based on one flow rate, which is quoted in the product’s specifications. You will need to select just one flow rate from the range of monthly flow rates predicted by the solar pumping system.

#### 1.15.1 Calculate the required daily flow rate

The required daily flow rate determines the size of the pump required as well as the size of the solar array that will be needed to power the pump.

Solar radiation levels can vary substantially from one day to the next. On some days, there will be less solar power generated to pump the required water, while on other days, excess solar power will be produced and additional water will be pumped.

Following are two methods by which you can calculate the daily flow requirements your system will need to cater for variable solar radiation levels at the site.

**Option 1: Design the daily flow rate around a day of average solar radiation.**

If you choose this option, the performance of your solar pumping system will be based on an average solar day. On some days, the water pumped will be less than your operation’s average daily water requirement; on others, the water pumped will be more than the daily requirement. On average, though, the daily water requirement will be delivered.

If designing the system around an average solar day, you must accept that the solar resource will vary. Unless you build a system that is sized to compensate for this variability, your worst-case scenario could be a run of multiple days of low solar radiation levels or, in any one year, solar levels that are less than the predicted historical averages.

This option best suits farmers planning a solar PV-powered pumping system that incorporates some form of water storage, or with pumping requirements that are not highly sensitive to variations in the amount of water pumped from day to day.

In this option, the daily flow rate would be equal to the daily water requirements, as calculated in the site assessment section on ‘Daily water requirements’ (page 46).

**Option 2: Design the daily flow rate around a day of lower-than-average solar radiation.**

If you select this option, the performance of the pumping system will be based on a day of lower-than-average solar radiation. There may be some days when pumping output will be less than average but the system will be designed so that, on these days, the system will pump more water than it would if you’d chosen Option 1. On sunny days, the system will pump more than the average requirement, and this additional water can be stored for later use. This means that, on average, the pumping system’s daily flow rate will be greater than the daily water requirements.

This is a solar pumping system that is able to compensate for solar variability, and one that makes it possible for multiple days of low solar radiation levels to be compensated by a combination of higher pumping levels and water storage on sunny days.

This option would be most suitable for a solar PV pumping system that is reasonably sensitive to variations in the amount of water pumped, or for a system that is unable to include a storage facility.
In this option, daily flow rate would be greater than daily water requirements as calculated in the site assessment section Daily water requirements (page 46).

Daily flow rates can vary monthly and/or seasonally.

*Table 15: The daily flow rate that is required each month.*

<table>
<thead>
<tr>
<th>Month</th>
<th>Required daily flow rate each month</th>
<th>Month</th>
<th>Required daily flow rate each month</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>_________ L/day</td>
<td>July</td>
<td>_________ L/day</td>
</tr>
<tr>
<td>February</td>
<td>_________ L/day</td>
<td>August</td>
<td>_________ L/day</td>
</tr>
<tr>
<td>March</td>
<td>_________ L/day</td>
<td>September</td>
<td>_________ L/day</td>
</tr>
<tr>
<td>April</td>
<td>_________ L/day</td>
<td>October</td>
<td>_________ L/day</td>
</tr>
<tr>
<td>May</td>
<td>_________ L/day</td>
<td>November</td>
<td>_________ L/day</td>
</tr>
<tr>
<td>June</td>
<td>_________ L/day</td>
<td>December</td>
<td>_________ L/day</td>
</tr>
</tbody>
</table>

1.15.2 Estimate the required flow rate per hour and per minute

Many manufacturers provide pump specifications using measured flow rates (m³/hr, L/hr or L/min), so it can be useful to have estimates of the required flow rate per hour and per minute at hand.

These flow rate figures can be estimated by using average solar energy per day, measured in peak sun hours (PSH). The greater the number of PSHs at a site on an average day, the more solar resource is available at that site per day. This means that for a given total pumping requirement, a pump with a lower flow rate can be selected for that site (if the solar resource is less, a pump with a higher flow rate could be required).
As average daily PSH changes throughout the year and required daily flow can also vary significantly over that period, it is useful to calculate flow rates separately for each month.

To calculate the flow rate per hour, use the following equation, remembering that 1m³ = 1,000L.

\[
\text{Flow rate (m}^3/\text{hour)} = \frac{\text{required daily flow (m}^3/\text{day)}}{\text{average daily PSH}}
\]

This equation can be used to fill in the following table (Table 16).

**Table 16: Estimated flow rate per hour each month.**

<table>
<thead>
<tr>
<th>Month</th>
<th>Estimated flow rate per hour</th>
<th>Month</th>
<th>Estimated flow rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>__________ m³/hr</td>
<td>July</td>
<td>__________ m³/hr</td>
</tr>
<tr>
<td>February</td>
<td>__________ m³/hr</td>
<td>August</td>
<td>__________ m³/hr</td>
</tr>
<tr>
<td>March</td>
<td>__________ m³/hr</td>
<td>September</td>
<td>__________ m³/hr</td>
</tr>
<tr>
<td>April</td>
<td>__________ m³/hr</td>
<td>October</td>
<td>__________ m³/hr</td>
</tr>
<tr>
<td>May</td>
<td>__________ m³/hr</td>
<td>November</td>
<td>__________ m³/hr</td>
</tr>
<tr>
<td>June</td>
<td>__________ m³/hr</td>
<td>December</td>
<td>__________ m³/hr</td>
</tr>
</tbody>
</table>

To calculate the flow rate per minute, use the following equation:

\[
\text{Flow rate (L/min)} = \frac{\text{Required daily flow (L/day)}}{\text{Average daily PSH} \times 60}
\]

In general, a solar PV pump will be selected on a single flow-rate value, with different flow rates calculated for each month. There are a few options for arriving at a single flow-rate value:

i) use the highest flow-rate value, which will mean that the pump should deliver the required daily water quantity in even the worst month for solar radiation, and will pump an excess quantity of water in other months,
(ii) use the lowest flow rate, which means that the pump should deliver the required daily quantity of water only in the best month for solar radiation and less in other months, or
(iii) use an in-between flow rate, which means that the pump will deliver less than the required quantity of water in the worst months for solar radiation, and more in the sunniest months.

When choosing among these options, base your selection on the sensitivity of the application to receiving less water in some months.
Example: Dairy farm in Tamworth

The flow rate per hour for each month for the dairy farm in Tamworth is as detailed in Table 17.

Table 17: Flow rate per hour for each month at the Tamworth, NSW dairy farm.

<table>
<thead>
<tr>
<th></th>
<th>Required daily flow (m³/day)</th>
<th>Average daily peak sun hours on tilted modules (PSH)</th>
<th>Flow rate (m³/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>65</td>
<td>6.91</td>
<td>9.4</td>
</tr>
<tr>
<td>February</td>
<td>65</td>
<td>6.18</td>
<td>10.5</td>
</tr>
<tr>
<td>March</td>
<td>65</td>
<td>5.95</td>
<td>10.9</td>
</tr>
<tr>
<td>April</td>
<td>65</td>
<td>5.22</td>
<td>12.5</td>
</tr>
<tr>
<td>May</td>
<td>65</td>
<td>4.67</td>
<td>13.9</td>
</tr>
<tr>
<td>June</td>
<td>65</td>
<td>4.51</td>
<td>14.4</td>
</tr>
<tr>
<td>July</td>
<td>65</td>
<td>4.50</td>
<td>14.4</td>
</tr>
<tr>
<td>August</td>
<td>65</td>
<td>4.91</td>
<td>13.2</td>
</tr>
<tr>
<td>September</td>
<td>65</td>
<td>5.81</td>
<td>11.2</td>
</tr>
<tr>
<td>October</td>
<td>65</td>
<td>6.12</td>
<td>10.6</td>
</tr>
<tr>
<td>November</td>
<td>65</td>
<td>6.54</td>
<td>9.9</td>
</tr>
<tr>
<td>December</td>
<td>65</td>
<td>7.02</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Due to the critical need to provide water for stock, the highest flow rate should be selected for the pump that corresponds to the flow rate given for June/July, that is, 14.4 m³/hr.

Example: Small farm in Griffith

For the small orange grove and sheep farm in Griffith, the flow rate per hour for each month is as detailed in Table 18.

Table 18: Flow rate for the small farm in Griffith, NSW.

<table>
<thead>
<tr>
<th></th>
<th>Required daily flow (m³/day)</th>
<th>Average daily peak sun hours on tilted modules (PSH)</th>
<th>Flow rate (m³/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>12.60</td>
<td>7.9</td>
<td>1.6</td>
</tr>
<tr>
<td>February</td>
<td>12.10</td>
<td>7.2</td>
<td>1.7</td>
</tr>
<tr>
<td>March</td>
<td>8.49</td>
<td>6.7</td>
<td>1.3</td>
</tr>
<tr>
<td>April</td>
<td>5.36</td>
<td>5.4</td>
<td>1.0</td>
</tr>
<tr>
<td>May</td>
<td>3.55</td>
<td>4.4</td>
<td>0.8</td>
</tr>
<tr>
<td>June</td>
<td>2.81</td>
<td>3.5</td>
<td>0.8</td>
</tr>
<tr>
<td>July</td>
<td>2.73</td>
<td>3.8</td>
<td>0.7</td>
</tr>
<tr>
<td>August</td>
<td>4.37</td>
<td>4.7</td>
<td>0.9</td>
</tr>
<tr>
<td>September</td>
<td>6.21</td>
<td>5.8</td>
<td>1.1</td>
</tr>
<tr>
<td>October</td>
<td>8.49</td>
<td>6.8</td>
<td>1.2</td>
</tr>
<tr>
<td>November</td>
<td>10.46</td>
<td>7.1</td>
<td>1.5</td>
</tr>
<tr>
<td>December</td>
<td>11.78</td>
<td>7.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

In this case the critical needs of both the orchard and the animals also justify selecting the highest flow rate, which in this case is the flow rate in February (1.7 m³/hr).
1.16 Step 4: Calculate total dynamic head

As explained in the pumping section earlier, the total dynamic head (TDH) represents the total resistance experienced by the water in the journey from water source to delivery (or storage) point. The pump must have the operating capacity to overcome the total dynamic head to be able to move the water to the required destination. The TDH includes the height through which the water needs to be lifted (static head) as well as the friction of the water running through the pipes (dynamic head).

- **Static head**: This is the total difference in elevation between the pump and the water destination.
- **Dynamic head**: This refers to friction losses in the pipes on the journey from water source to delivery point.

The TDH is equal to the sum of the static head and the dynamic head:

\[
\text{Total dynamic head (TDH)} = \text{static head} + \text{dynamic head}
\]

The design of your solar PV pumping system should include a safety margin for the calculated TDH. It would be appropriate to add 20 to 30 percent to the TDH for this margin.

1.16.1 Calculating the static head

The static head is the vertical distance that the water travels on its pumping journey.

For a submersible pump (Figure 54a), the static head is the height difference between the pump and the water destination. This is equal to:

\[
\text{Static head (submersible)} = \text{drawdown level} + \text{static water level} + \text{lift from surface}
\]

For a surface pump (Figure 54b), the static head is the height difference between the top of the water source and the water destination. This is equal to:

\[
\text{Static head (surface)} = \text{suction lift} + \text{lift from surface}
\]

![Figure 54: a) The static head of a submersible pump; b) the static head of a surface pump.](image)

1.16.2 Calculating the dynamic head

Ascertaining the dynamic head of a pumping system involves complex calculations. Pump Industry Australia has produced a textbook on the ins and outs of pipe friction. Examples of dynamic head calculations are included in Appendix F: Calculating dynamic head (page IX).
Several websites can help you to calculate a pumping system’s TDH: among them is [www.pumpworld.com/totaldynamic-head-calculator.htm](http://www.pumpworld.com/totaldynamic-head-calculator.htm). In general, dynamic head friction losses are affected most by pipe diameter; a larger pipe diameter can reduce the dynamic head significantly, especially in a pumping system with high flow rates. Next are the friction losses due to changes in water direction, obstructions or changes in the pipe diameter. Therefore, pipe fittings such as elbows, filters and valves should be used only where necessary to avoid pointless increases in the system’s dynamic head. Friction losses due to the length of the pipe are generally minimal in comparison.

Most pump manufacturers and suppliers can provide tools with which you can calculate or estimate the dynamic head of your proposed system based on standard piping options.

### 1.16.3 Selecting the water pipes

The diameter and material of the water pipes you choose will affect the dynamic head of the system. Larger-diameter and/or better quality pipes will reduce the dynamic head (*Figure 55*); installing piping of a suitable diameter and quality will minimise system losses and could reduce the size of the pump required (although a larger-diameter and/or better-quality pipe will increase the cost of the system).

Selecting the most appropriate water pipes entails balancing the additional costs incurred against the benefits of increased system efficiency.

*Figure 55*: Using a larger-diameter pipe will reduce the dynamic head but increase the system cost.
Example: Tamworth dairy farm

The total dynamic head (TDH) is to be calculated for the dairy farm in Tamworth. Here, water is to be moved from a river to a stock dam. The following information was calculated in earlier examples:

- Static water level = 1m
- Length of piping required between river and pump = 3m
- Length of piping required between pump and stock dam = 100m
- Vertical lift between ground level and stock dam = 10m
- Daily flow rate = 65m³/day
- Maximum hourly flow rate = 14.4m³/hr (June)

The static head is equal to the static water level plus the vertical lift, giving 11m. The dynamic head is too complicated to calculate manually, so [www.pumpworld.com/total-dynamic-head-calculator.htm](http://www.pumpworld.com/total-dynamic-head-calculator.htm) was used to calculate the TDH (i.e. static head + dynamic head) for this site.

For the dynamic head calculation, pipe size must be known. Selecting an appropriate pipe size involves some trial and error. Finding the right size is a balance between a pipe wide enough to ensure that the dynamic head is not excessive but not so wide that the pipe price is unreasonable. In this example, the TDH was calculated for a range of pipe sizes and the most appropriate size of pipe was then selected.

<table>
<thead>
<tr>
<th>Pipe size</th>
<th>Total dynamic head (TDH) (static head + dynamic head)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32mm</td>
<td>82.1m</td>
</tr>
<tr>
<td>40mm</td>
<td>35.0m</td>
</tr>
<tr>
<td>50mm</td>
<td>19.1m</td>
</tr>
<tr>
<td>63mm</td>
<td>13.6m</td>
</tr>
<tr>
<td>75mm</td>
<td>12.1m</td>
</tr>
</tbody>
</table>

A 63mm pipe gives a total dynamic head of 13.6m (11m of static head and 2.6m of dynamic head). This appears to be a reasonable dynamic head compared to the static head, so a 63mm pipe will be selected.
1.17 Step 5: Select the pump/array

To complete the solar pumping system design, the pump and array need to be selected. The previous sections lay out the principles in refining your requirements. This will give you confidence and a basis on which to compare the offerings of different pump installers/manufacturers. While the manufacturer should be able to provide a suitable pump/array package, it is still useful to be able to estimate head and flow requirements and to understand the general principles of selecting the pump and array size.

Following these sections is a brief overview of solar-powered pump-sizing software tools supplied by leading pump suppliers.

1.17.1 Pump selection

You should select a pump that is capable of the required flow and head. Solar pump manufacturers generally present their pump selection information in one of two ways.

1. **Pump performance curves**: The pump performance curves below list flow rate on the vertical axis, power on the horizontal axis; each line represents a different total dynamic head (TDH). For a particular TDH, the

<table>
<thead>
<tr>
<th>Pipe size</th>
<th>Total dynamic head (TDH) (static head + dynamic head)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25mm</td>
<td>73.2m</td>
</tr>
<tr>
<td>32mm</td>
<td>64.0m</td>
</tr>
<tr>
<td>40mm</td>
<td>61.3m</td>
</tr>
<tr>
<td>50mm</td>
<td>60.5m</td>
</tr>
</tbody>
</table>

Example: Griffith small orange farm

The total dynamic head (TDH) is to be calculated for the small farm in Griffith. The water is to be moved from a bore to a water tank. The following information was calculated in earlier examples.

- Static water level = 15m
- Drawdown of pump (height between turned-on pump and total of water level) = 5m
- Length of piping between pump and stock dam = 300m
- Vertical lift between ground level and stock dam = 40m
- Maximum daily flow rate = 12.6m³/day (February)
- Maximum hourly flow rate = 1.7m³/hr (February)

The static head is equal to the static water level plus the drawdown plus the vertical lift, giving 60m. The dynamic head is too complicated to calculate manually, so [www.pumpworld.com/total-dynamic-head-calculator.htm](http://www.pumpworld.com/total-dynamic-head-calculator.htm) was used to make these calculations.

For the dynamic head calculation, the proposed pipe size must be known. Selecting a suitable pipe size requires one that is wide enough to ensure that the dynamic head is not excessive but not so wide that the pipe price is unreasonable. Thus, the TDH was calculated for multiple pipe sizes before the size deemed most appropriate was selected.

A 32mm pipe gives a total dynamic head of 64.0m (60m of static head and 4m of dynamic head). This appears to be a reasonable dynamic head compared to the static head. As the pipe in this system is quite long, using a narrower pipe could reduce the cost of the system significantly. Therefore, a 32mm pipe will be selected.
possible flow rates of each pump can be determined. The power required to achieve each flow/head combination is found on the horizontal axis (Figure 56).

![Figure 56: Pump performance curves for two pumps; a) SQF 1.2-2 and b) SQF 5A-6.](image)

### Example

Using Figure 56a and Figure 56b, which pump is most suitable for a system with the following parameters?

- a) Total dynamic head = 60m, required flow rate = 1 m³/hr
- b) Total dynamic head = 30m, required flow rate = 2 m³/hr
- c) Total dynamic head = 10m, required flow rate = 8 m³/hr

### Answers

- a) SQF 1.2-2 (Figure 56a): This is the only pump that can reach a head of 60m. The power required for this head and flow combination would be ~300W.
- b) SQF 5A-6 (Figure 56b): Even though both pumps can reach a head of 30m, only the SQD 5A-6 can pump the required flow rate at this head. The power required for this head-and-flow combination would be ~470W.
- c) SQF 5A-6 (Figure 56c): This is the only pump that can reach a flow rate of 8m³/hr. The power required for this head-and-flow combination would be ~1,000W.

2. **Pump/array performance tables** (Table 19): These tables usually have solar energy listed at the top, head on the left and the flow rate for each combination. For a solar array of a particular size, the possible head heights of each pump can be determined. The maximum flow rate for each combination can then be ascertained. The pink, green and purple boxes show three different sizes of pump.
Table 19: Pump/array performance table for a candidate Submersible Pump, based on a 6.5kW/hr average performance.

<table>
<thead>
<tr>
<th>Head (m)</th>
<th>200W array</th>
<th>400W array</th>
<th>600W array</th>
<th>800W array</th>
<th>1,200W array</th>
<th>1,600W array</th>
<th>1,800W array</th>
<th>2,400W array</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>28</td>
<td>71</td>
<td>107</td>
<td>113</td>
<td>116</td>
<td>117</td>
<td>118</td>
<td>120</td>
</tr>
<tr>
<td>10</td>
<td>24</td>
<td>64</td>
<td>93</td>
<td>104</td>
<td>113</td>
<td>115</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>15</td>
<td>21</td>
<td>54</td>
<td>79</td>
<td>95</td>
<td>108</td>
<td>113</td>
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<td>34</td>
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</tr>
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<td>40</td>
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<td>102</td>
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<td>45</td>
<td>8</td>
<td>20</td>
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<td>41</td>
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<td>50</td>
<td>8</td>
<td>18</td>
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<td>35</td>
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<td>68</td>
<td>72</td>
</tr>
<tr>
<td>55</td>
<td>7</td>
<td>17</td>
<td>26</td>
<td>33</td>
<td>51</td>
<td>62</td>
<td>65</td>
<td>70</td>
</tr>
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It is important to note the assumptions many manufacturers make when providing sizing information. For example, Mono solar pump brochures show their pumps’ performance at a 6.5kW/hr performance level. This correlates to a day with 6.5 PSH of solar radiation, which would be a clear summer day. It will not deliver the listed performance on an average winter day. Mono’s solar pump sizing program allows you to input more detail, however, and can be used to find a solar pump that will also deliver the required flow rate on an average winter day.

The type of solar-powered pump that is suitable depends on the application. Various types of pumps are explained in Sections 6.3 and 6.4, along with their suitability for different applications (as summarised in Table 20):
### Table 20: Summary of the suitability of different pump technologies and installations for various applications.

<table>
<thead>
<tr>
<th>Pump types</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump technology</td>
<td></td>
</tr>
<tr>
<td>Centrifugal</td>
<td>Centrifugal pumps tend to be more suitable for applications requiring large flows and small heads; however, centrifugal pumps are available for a range of flow/head combinations.</td>
</tr>
<tr>
<td>Helical rotor</td>
<td>Helical rotor pumps best suit applications requiring low flows and high heads. However, helical rotor pumps are available for a range of flow/head combinations.</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Diaphragm pumps are best suited for applications where the fluid being pumped is viscous or where the flow rate must be controlled within a precise range. With the exception of fertiliser injection, it is uncommon for diaphragm pumps to be used for irrigation purposes.</td>
</tr>
<tr>
<td>Pump installation</td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>Surface pumps have a suction lift limit that must be adhered to. This limit is set by the manufacturer but will not exceed 25ft (7.62m). Surface pumps require a solid installation site close to the water source with suitable protection from the elements.</td>
</tr>
<tr>
<td>Submersible – floating</td>
<td>Floating pumps are floated on the surface of the water source so that suction lift limit is not relevant. They require mooring to the bank and suitable protection from the elements.</td>
</tr>
<tr>
<td>Submersible – bore</td>
<td>Bore pumps are especially designed for bores. A particular pump may only be suitable for a bore of a specific size.</td>
</tr>
</tbody>
</table>

### 1.18 Selecting the solar array

Matching a solar array to pumping needs involves complex calculations; it is not as simple as selecting an array with the power requirements to supply your pump, for the following reasons:

- The power rating of solar modules is given according to standard test conditions (see ‘Datasheet values: ratings of a PV module’, page 13) This is generally higher than what will be delivered in real world conditions. A good rule of thumb is that modules will operate at about 75 percent of their rated power, at most, due to losses.
- The variability of solar radiation levels means that the power output of the array will vary throughout the day. This is particularly the case when you’re running a centrifugal pump, which can have significantly different efficiencies when operating at different power levels.
- The array must be configured to match not only the power requirements but the voltage and current requirements of the motor pump.
- The power requirements of the pumps may or may not include the efficiency of the motors. This efficiency is usually around 80 percent.
- If you are considering a grid connected solution or generating power for other on farm uses, you need to factor in total farm electricity needs, pattern of use, and optimisation of tarrifs.

It is advisable to work with a solar provider who has extensive experience with pumping systems, working with irrigation engineers and with the optimisation of farm electricity supply.
Various types of modules are available, and are addressed in more detail in ‘Composition and types of solar modules’ (page 15). If given a choice of modules, remember that ‘higher efficiency’ relates to the size of the module, not to its power output. Paying extra for high-efficiency modules may not be worth your while, especially if installation space is not restricted.

When selecting solar modules or a package, it is important to check that the modules you’re considering are approved by the Clean Energy Council and meet all relevant standards. There are two lists of approved modules: those approved for use on buildings; and those approved for use for ground-mounted systems. Most solar pumps use ground-mounted systems. For detailed information about this form of approved module, go to www.solaraccreditation.com.au/products/modules/modules-for-ground-mounted-systems.html.

1.18.1 Example: Solar pump sizing software
In Australia, the leading solar-pump companies offer sizing software that can be used to ascertain the most appropriate solar pump package for your location and applications, based on information you provide. We recommend that you search for available software packages. A query for the terms ‘solar pump sizing software’ or ‘solar pump calculator’ should produce useful results.

Mono Pumps sizing software: CASS
The Mono Pumps sizing software is known as computer-aided solar simulation, or CASS, downloadable from www.solarcass.com. It contains the company’s four main solar pumping products, any of which might be used for farm-scale pumping. The products are the Sun-Sub (a bore pump), Sun-Ray SRX Floating, Sun-Ray SRX Surface and SB3 (for small bores). You select the Australian city closest to your farm’s location and inputs the site parameters. The software then calculates average daily and hourly flows for each month of the year and suggests appropriate Mono products to suit your requirements.
Example in CASS: Tamworth dairy farm

The requirements for the dairy farm in Tamworth have been inputted into the CASS software for the Sun-Ray SRX Surface Pump (Figure 57).

Notes:

- A stationary array type was selected even though the farm owner plans to use a manually tilting array. This is because the other options listed by CASS are a one-axis and a two-axis tracking array, either of which would have a significantly higher output.
- For this farm, ‘Flow Req Type’ must be selected as ‘worst’ as the pump it plans to use is required to move the required flow even in the months of lowest solar radiation, June and July.

After you select ‘Calculate’, the software determines the array size and pump type that would be needed to deliver the required daily flow to your applications. For this example, a 1,600W array with the listed MPPT, pump and motor will supply the minimum of 65m³/day on an average day each month of the year (Figure 58).
The software can also calculate an hourly flow rate for an average day of each month (Figure 59).

Figure 58: Output of CASS.

Figure 59: Hourly flow rate for a) June; and b) January.
Grundfos sizing software: WebCAPS

The Grundfos sizing software is called WebCAPS and can be found at [http://net.grundfos.com/Appl/WebCAPS](http://net.grundfos.com/Appl/WebCAPS). It works only for the company’s bore-pump products, the SQF range, although the site gives you the option of selecting surface pumps. Simply choose the Australian city that is closest to your location and input the requested site parameters; the software then suggests the most appropriate Grundfos pump for your needs along with some alternative options.

Example: Griffith small orange farm

The requirements for the small farm in Griffith have been inputted into WebCAPS (Figure 60).

![Figure 60: Inputs into WebCAPS.](image)

Notes:

- Convert units of measurement into Australian (metric) data using the settings button at the top right-hand side of the page. Australia’s power supply frequency is 50Hz; it uses SI units rather than US units.
- Pipe system friction losses may need to be inputted manually. The total dynamic head calculator given in Section 6.2.2 can be used to check these.
- ‘Peak month’ is the month in which you anticipate having the highest water usage.
- ‘Solar modules’ must be selected (with, the numbers representing the modules’ wattage and the letters the type of module). In this instance, 250W polycrystalline modules were selected, as these would be suitable for most farm pump systems. Lower wattage modules were chosen, as these would be well suited to a small pumping system.
- ‘Control box options’ fall into two main categories: CU units, for regular solar pumps, and IO units for solar pumps with additional generator connections.
- An inverter needs to be selected only for a large system.
- The ‘pump material’ and ‘outlet’ boxes can be left blank.

After the user selects the ‘Start Sizing’ button (at the bottom right-hand corner of the web page), Grundfos recommendations are supplied (Figure 61).
Figure 61: Grundfos recommendations.

The text in the box on the right-hand side of this figure can be summarised as follows:

- Pump: SQF 2.5-2N
- Array: 4 x SW 250 polycrystalline modules
- Controller: CU 200

More information about the output of this configuration can be found by clicking ‘Alternatives’. This provides some alternative options and indicates the estimated pumping performance of the configuration over four months: January, April, July and October (Figure 62).

Figure 62: Alternative options given by the Grundfos sizing tool.

The complexity of sizing a solar array is highlighted by comparing the array size recommended by the Grundfos sizing tool with the power requirements gleaned from the pump curve. Grundfos’s sizing tool recommends a 1,000W array (4 x 250W) coupled with the pump SQF 2.5-2N. The pump curve for this pump is shown in Figure 63. Using a flow rate of 1.7m³/hr and a head of 64m with the pump curve, you get an estimated pump power requirement of approximately 600W; however, Grundfos’s sizing tool takes into account the fact that available solar power varies throughout the day and includes system losses to arrive at an array size of 1,000W.
Figure 63: Grundfos pump curve for SQF 2.5-2N.
SECTION 4: SYSTEM INSTALLATION AND COMMISSIONING

Solar PV systems must be installed safely by a licensed electrician in accordance with the manufacturer’s instructions. We recommend using an accredited solar installer with an established track record and good after sales service. We also suggest involving your regular electricity service provider in the process and, if the system is for irrigation, your regular irrigation engineer.

1.19 Site safety
The key to site safety is knowing the potential hazards of your site and managing these effectively. Hazards typically associated with solar PV-powered water-pumping systems can be divided into two categories: electrical and non-electrical hazards.

1.19.1 Electrical hazards
Working with electricity is hazardous. Working with electricity and water in the same system requires increased care during, and after, installation. Below are some key guidelines for working with solar electricity in Australia:

- According to Australian Standard S3000, electrical work on any sections of a solar PV system that have voltages greater than 120V DC or 50Vrms AC must be performed by a licensed electrician.
- Solar modules will produce electricity whenever sunlight hits them and attempting to cover them (such as with blankets) to stop them generating is not a safe practice.
- Solar PV module connectors should be the same make and model as each other; using imitation or ‘compatible’ connectors is against Australia standards (AS5033) and can be dangerous.
- All wiring should be considered live and treated as live. The voltage and current values of each wire should be measured, and exposed wire ends should be terminated appropriately to prevent anyone from coming into contact with them.

1.19.2 Non-electrical hazards
There are several non-electrical hazards to keep in mind when installing a solar PV pumping system. Often, solar pumps are installed in exposed, remote areas, so it is especially important to avoid injuries. Never work on a solar pumping system alone. Some common non-electrical hazards include:

- **Sun exposure:** Solar systems are installed in exposed locations with limited shading so anyone installing such a system is at risk of exposure to sunburn and potentially, heat stroke. The risk of heat stroke can be reduced by wearing a hat, cool clothing and high-SPF sunscreen, taking regular breaks and drinking plenty of water.
- **Slips and trips:** Worksite with rough or slippery terrain can increase the risk of slips and trips for people carrying equipment.
- **Strains:** Solar pumping systems include components that are bulky and heavy, so it is important that anyone involved uses appropriate lifting methods. In some cases, lifting aids may be required to assist with moving heavy equipment.
- **Cuts and burns:** Components of a solar pumping system (module frames, bolts, nuts, etc) can have sharp edges and may get very hot on sunny days. Gloves should be worn when handling this equipment to prevent cuts and burns.
- **Animals:** Often solar pumps are installed in rural areas frequented by snakes, spiders and other insects. Care should be taken when opening equipment. System installers should have ready access to first-aid, including treatment for bites from venomous and toxic species common to the area.
1.20 Installing the array and electrical wiring

The electrical components of a solar pumping system should be installed according to Australian standards and the manufacturer’s instructions.

Many solar pumping system packages include solar modules with interconnecting cables/connectors set up for ‘plug and play’. These modules should be installed and connected according to the manufacturer’s instructions. If system components – say, pumping equipment and solar modules – are to be provided by different suppliers, suitable advice should be sought from the solar pump manufacturer or from a qualified solar installer regarding the installation and electrical connection of the new solar PV system to DC pumping equipment.

The solar array and the mounting system should be installed according to the manufacturer’s instructions. Correctly fixing the solar modules to the mounting frame is particularly important. The manufacturer’s instructions will dictate the allowable clamping points to the solar modules and recommended installation methods. Unless the solar array and framing are installed according to the manufacturer’s instructions and to suit the prevailing conditions, the structural loadings of this equipment will be compromised.

The wiring between the array, system controller and electric motor should be installed according to Australian standards and the manufacturer’s instructions. This includes selecting the correct wire sizing and protection devices: using undersized cable, for instance, would result in higher electrical losses. The electrical schematics of a DC-configured and an AC-configured solar pumping system are shown in Figure 64 and Figure 65, respectively.

**Note:** Some of the components specified in the electrical schematics may be combined into one device. It is important to check that all components are contained in the system – or, if not, that suitable reasons for this are given by the supplier prior to installation.

![Figure 64: Schematic of a DC-configured solar pumping system.](image_url)
Australian standards covering the installation of and safety requirements for solar PV arrays are as follows:

**Both DC and AC systems**

- ‘Earthing PV Array’: Clause 4.4.2.1 and Appendix B2 AS/NZS5033:2012 and Section 4 AS/NZS 4509.1
- ‘Electrical Equipment – Sizing and Selection’: Section 4 AS/NZS5033:2012 and Section 3 AS/NZS4509.1
- ‘DC Cable Sizing’: Section 3 AS/NZS4509.1, Section 3 AS/NZS5033:2012, AS/NZS3000 and AS/NZS3008
- ‘Battery Current Protection’: Section 3 AS/NZS4509.1 and Clause 3.3.3 AS/NZS5033:2012
- ‘Optional Battery Storage’: Section 7 AS/NZS4509.1
- ‘Sizing of Protection Devices’: Section 3 AS/NZS5033:2012 and AS/NZS4509.1
- ‘System Commissioning’: Section 10 AS/NZS4509.1

**Only DC systems**

- ‘DC Cable Sizing and Connection to Loads’: Section 4 AS/NZS 4509.1, Section 3 AS/NZS5033:2012, AS/NZS3008 AS/NZS3000

**Only AC systems**

- ‘Multi-mode Inverter Compliance’: Clause 2.1 and Section 4 AS/NZ4509.1
- ‘Optional Generator’: Section 6 AS/NZS4509.1
- ‘AC Electrical Cable’: Section 3 and 4 AS/NZS4509.1, AS/NZS3008 and AS/NZS3000
1.21 Installing pumps and piping

Typically, a solar pumping system requires installation of electrical, mechanical and structural equipment. Contracting an experienced company or its personnel is generally the best way to ensure the successful installation and long-term operation of the system.

If you opt to install pumping system components independently, it is important that you or whoever you contract follows the manufacturer’s instructions in full. It is advisable that before you begin the installation, you set out the relevant guides and equipment in the correct chronology, as detailed by the pump manufacturer’s installation instructions.

The pump and motor should be mounted firmly on a suitable base, with attention given to alignment of the pump and motor on this foundation, and to the alignment of the pump and the motor (if these are not already aligned).

Piping should be installed so that it is supported and anchored independently. The piping should not put any weight on the pump attachment.

1.22 System commissioning

System commissioning occurs once the system’s components have been installed. A general guide to system commissioning is as follows:

1. **Check electrical connections**: Check that the physical cabling is securely fastened and then check the electrical system for continuity.
2. **Check water connections**: Examine the pipes and the connections between these pipes and the pump, to ensure that they are secure and supported.
3. **Check pump**: Check that the pump and motor alignment are correct; check the pump lubricants; and inspect any seals.
4. **Prime pump (if required)**: Some pumps will need to be primed initially; this usually involves filling the casing with water.
5. **Turn on array**: Check the output voltage and current of the array.
6. **Turn on the control systems**: Check the system readings against the manufacturer’s specifications.
7. **Turn on the pump**: Following the manufacturer’s instructions, start the pump. Monitor its pressure and water flow to confirm that the system is operating correctly.
8. **Observe pump operation**: Check for leaks and monitor system readings while the pump is in operation.
SECTION 5: MAINTENANCE

Solar generation systems require little maintenance. There are some procedures that might be required, however; these may include:

- **Solar module cleaning**: The solar modules should have been installed with a minimum tilt of 10° to allow for self-cleaning with rain; however, modules may benefit from a guide clean if there’s been no decent rain for a while or if dirt is accumulating at their edges, as dirt reduces modules’ output. Clean solar modules using water and a non-abrasive cleaning material, and avoid getting water near any of the electrical components. Before cleaning, ensure the solar PV system is shut down. And always ensure the manufacturer’s cleaning instructions are followed.

- **Cabling check**: The cabling should be checked for any loose connections or damage. Remember that a solar array generates electricity whenever light is hitting it, so cabling in solar arrays should always be treated as if it is live. Before checking the cabling, the solar system should be shut down.

- **Mounting system check**: Check that the mounting system is stable and mechanically secure.

- **Vegetation maintenance**: Any vegetation around the solar array should be maintained to ensure that it does not shade the array. Some grazing animals, such as sheep, may be suitable for keeping grass levels below the array (Figure 66). It must be ensured that the grazing animals will not attempt to bite any connecting wires or equipment. Leads must be kept out of reach. More information on vegetation and animal management can be found in the report ‘Agricultural Good Practice Guidance for Solar Farms’ published by the UK consultancy group BRE (Building Research Establishment).

1.23 Pump maintenance

Regular servicing and maintenance of pumps, is essential to ensure that the system performs as required for its designed lifetime. Pump manufacturers may advertise their products as ‘low maintenance’ or ‘no maintenance.’ Regardless, the system owner can perform certain maintenance actions to ensure the pumping system is working optimally.

- **Listen to the water pipes**: Listen to the flow of water through the pipes at an accessible point in the system. Sounds of uncharacteristic rushing water could mean increased flow or pressure in the system due to blockages.
• **Listen to the pump and motor:** Rattling or rumbling in the system that does not normally occur could indicate a damaged pump or motor. If you detect such sounds in your system, contact the manufacturer immediately.

• **Check the float switch:** Regularly check the system’s float switch to ensure it is working as per the manufacturer’s documentation.

• **Other manufacturer maintenance requirements:** You should have been provided with an operation and maintenance guide for the pumping system. Always read the installation guide.

The manufacturer may allow the system owner to replace certain parts without voiding the warranty. Be sure to read the operation and maintenance guides for the system before making such replacements.
SECTION 6: SYSTEM ECONOMICS

In this section, we include a summary of the key criteria that should be used to guide your decision-making process and the comparative influence each is likely to have on your final decision. Understanding the various pricing aspects that make up the cost of a solar pumping system may assist you in minimising the operational costs of the system and help further your understanding of the long-term cost viability of the various systems available.

Note that the economic criteria given here are defined only in relation to agricultural pumping applications. The following information and definitions are general in nature and should not be taken as financial advice. For advice regarding the accounting and tax implications of implementing a solar power solution, you should consult a professional financial advisor.

1.24 Life cycle cost: an introduction

The life cycle cost (LCC) of any equipment or system is the total ‘lifetime’ cost of purchasing, installing, operating, maintaining and disposing of that equipment. Figure 67 summarises the typical life cycle cost for a medium-sized diesel-powered pumping system.

![Figure 67: Typical breakdown of life cycle costs for a medium-sized diesel-powered pumping system (Source: Office of Industrial Technologies Energy Efficiency and RE – US Department of Energy).](image)

Why do I need to consider the life cycle cost (LCC) when all I want to do is purchase a pumping system?

The LCC of a solar-powered pumping system can be compared to those of pump-powering alternatives — diesel pumps, for instance. Making such comparisons can help you find the most economical system for your needs.

Typically, solar pumping systems have higher up-front costs than similarly sized diesel-fuelled or grid-powered pumping systems, but minimal operating costs. There are no fuel costs and maintenance costs are low. A diesel pump, in contrast, incurs continuous operational expenses, including ongoing and increasing fuel costs, additional labour and higher maintenance costs. The LCC of a proposed solar pumping system and alternative systems will provide you with a good indication as to which type of system will be the most cost-effective choice.

The LCC can also be used to choose between different solar pump packages. A more expensive solar package may be more durable than a cheaper package, requiring less maintenance and fewer replacement costs in the future, which may make the more expensive system more economical over the long term.

The LCC can be used to determine the ‘breakeven’ point of different technologies. An example of this — a comparison between a solar pumping system and a diesel pumping system — is shown in Figure 68. The diesel pump is the cheaper option until the breakeven point, at around three years. After this time, the solar pump becomes progressively cheaper to run than the diesel one.
To calculate an accurate LCC, a number of financial factors should be considered. They include:

- present energy/fuel prices,
- the expected annual energy price increase (inflation) during the pumping system’s life,
- the discount rate (inflation) of purchasing equipment,
- the interest rate,
- expected equipment life (calculation period), and
- ongoing costs (maintenance, down time, environmental, disposal, labour, etc).

1.25 Pumping cost breakdown
The costs of a pumping system can be divided into capital costs (up-front costs) and operating costs (ongoing costs).

1.25.1 Capital costs
The capital costs of a pumping system comprise any up-front costs. These include the costs of:

- design
- equipment,
- installation and commissioning,
- purchasing land to accommodate the pumping system,
- grid connection (if applicable), and
- financing/legal work.

Typically, the capital costs of a solar pumping system are high in comparison to those of fuel-powered pumping systems, due to the cost of solar modules, electrical wiring and associated installation services. By comparison, diesel pumps are generally cheaper to purchase and install.

On the upside, the cost of solar modules has decreased significantly over the past 10 years, as shown in Figure 69, making them more competitive in price. A solar pumping system can have a lower capital cost based on the fact that it provides a localised power-generation source. Just compare the cost of a solar pumping system with that of having
to power a pump from the electricity grid in locations where connection to the grid may require installing kilometres of poles and wires from the nearest grid supply point to the pump location!

Figure 69: Trends in typical solar module prices ($/watt) in Australia 1993-2013 (current AUD) (Source: APVI National Survey Report of PV Power Applications in Australia 2013).

Rebates may be available to reduce the up-front cost of a solar-powered pumping system. An overview of rebates available at date of publication is included in Appendix G. Note: available rebates are subject to change.

1.25.2 Operating costs
The operating costs of a pumping system include any ongoing costs incurred over the life of the system, including:

- **energy costs** – the cost of the fuel/electricity required to run the pump, such as diesel fuel. The unit cost of electricity or fuel usually increases over time, so this needs to be taken into consideration over the life of the system (Figure 70). Solar pumps have no ongoing energy costs.

- **maintenance costs** – the costs of regularly checking and servicing the entire pumping system. Servicing may involve lubricating moving parts, checking oil and water levels, checking pipes and cables, observing the operation of the pump and cleaning (including costs of the tools and materials required for maintenance, oil, water, et cetera). A solar pumping system requires far less ongoing maintenance than a diesel-based one.

- **replacement costs** – the cost of replacing parts of the system due to wear, including those of replacing minor components such as seals and bearings as well as major components such as the motor, pump, inverter, and batteries (if applicable).

- **personnel costs** – the cost of time spent monitoring and operating the pump, and associated costs that may include time spent refuelling, starting up, shutting down and maintaining the pumping system as well as the time and fuel spent travelling to and from the pump – for example, to carry diesel fuel to the site, and in refuelling. Many farmers don’t put a monetary value on their time but this should be included in an economic analysis.

- **safety costs** – costs associated with the risk of storing fuel and operating dangerous equipment. These may not apply directly in all circumstances, but any safety risks arising from the use of a diesel pumping system should be considered, and could also result in higher insurance premiums.
other costs such as measurement & verification (M&V) – If the project is generating any certificates or carbon credits under federal or state programs, there may be costs associated with the measurement and verification of outcomes.

1.26 A comparison between solar and diesel pumping
While solar has higher associated capital costs, diesel pumping has significantly higher operating costs over the life of the system.

It is not possible to provide specific figures for these cost comparisons because each possible pumping installation will have its own installation, logistics and pumping requirements and thus, will incur differing costs. The figures shown give an indication of the varying scale of costs between the two pumping scenarios over the estimated life of the solar pumping system, i.e. 20 years.

Typically, solar is superior to diesel for stock and domestic applications when all costs are considered. Table 21 breaks down the factors to be considered when comparing solar pumping and diesel pumping systems.
Table 21: Small system - indicative, cumulative cost allocations for solar pumping and diesel pumping systems. In this example, it can be seen that solar power solution is beneficial

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Solar pumping system</th>
<th>Diesel pumping system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Equipment costs&lt;br&gt;Equipment includes array, array mounting, system controllers, electric motor/pump, wiring, piping</td>
<td>Equipment limited to a generator (where applicable), motor/pump and piping</td>
</tr>
<tr>
<td>Installation costs</td>
<td>Installation includes both pump and piping installation, and array and wiring installation</td>
<td>Installation limited to a generator (where applicable), pump and piping installation</td>
</tr>
<tr>
<td>Operating costs</td>
<td>Energy/fuel costs&lt;br&gt;None</td>
<td>Energy costs depend on the size of the pump, how often the pump is used and system efficiencies. Projected price increases should be included. These can represent up to 85% of the lifetime costs of a diesel pump</td>
</tr>
<tr>
<td></td>
<td>Ongoing maintenance&lt;br&gt;Maintenance costs are limited to the array (minimal), the pump and the electric motor</td>
<td>Scheduled maintenance of the generator/diesel motor, including refuelling, oil changes, checking pressures, cleaning air filters, lubricating parts; pump maintenance also required</td>
</tr>
<tr>
<td></td>
<td>Equipment replacement&lt;br&gt;Solar modules offer a 20- to 25-year performance guarantee to 80-85% output. Solar pumps and controllers offer a warranty ranging from 12 to 24 months, with an expected operating life of five years</td>
<td>Diesel generator would be expected to need replacement every 20,000 hours, on average, between 5,000-50,000 hours, depending on the quality of the engine and how well it has been maintained (AC pumps carry a warranty of 12-24 months)</td>
</tr>
<tr>
<td>Personnel costs</td>
<td>Limited site visits are required as maintenance is minimal</td>
<td>Site visits are required for refuelling, starting up/shutting down the generator, and for more extensive maintenance</td>
</tr>
<tr>
<td>Safety risks</td>
<td>Limited safety risks with the operation of a solar pump</td>
<td>Safety risks associated with fuel storage and transport; fire risk at pump</td>
</tr>
</tbody>
</table>

Indicative modelling of these cumulative costs places solar well ahead of diesel equivalent (see Figure 71)

Figure 71: Diesel vs solar - indicative cost comparison for stock and domestic pumping

Estimated combined investment costs (time, money, etc.)

<table>
<thead>
<tr>
<th>Solar water pump</th>
<th>Diesel water pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
</tr>
<tr>
<td>Replacement</td>
<td></td>
</tr>
<tr>
<td>Personnel</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
</tr>
</tbody>
</table>

Modelling cumulative costs for large systems is far more complex given the wide range of variables likely to be involved.

If pumping is both highly irregular and high volume the business case for solar is likely to depend on there being other uses for electricity on farm, ability to reduce tariffs on mains electricity, or ability to export and sell excess electricity off season.
## APPENDIX A: GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC electricity</strong></td>
<td>AC stands for alternating current; it is a form of electricity in which the current’s direction changes at a set frequency. AC electricity is compatible with the grid and with most household appliances</td>
</tr>
<tr>
<td><strong>Air mass</strong></td>
<td>The volume of air, defined by its temperature and water vapour content</td>
</tr>
<tr>
<td><strong>Array</strong></td>
<td>See ‘Solar array’</td>
</tr>
<tr>
<td><strong>Centrifugal pump</strong></td>
<td>A pump that utilises rotating impellers to move water</td>
</tr>
<tr>
<td><strong>Circuit breaker</strong></td>
<td>An electrical protection device that can open an electrical circuit under fault conditions, such as when there is too much current. A circuit breaker that closes the circuit again can be guidedly reset</td>
</tr>
<tr>
<td><strong>Clean Energy Council</strong></td>
<td>An industry association representing Australia’s clean energy sector</td>
</tr>
<tr>
<td><strong>Solar controller</strong></td>
<td>A device that converts power generated by the solar array in a certain voltage/current configuration to a voltage/current configuration that can be utilised more efficiently by the pump</td>
</tr>
<tr>
<td><strong>Conversion efficiency</strong></td>
<td>The proportion of energy in sunlight that is converted by a PV module into electrical energy, expressed as a percentage (also known as the efficiency of the module)</td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td>The rate of flow of an electric charge, where current is measured in amps</td>
</tr>
<tr>
<td><strong>DC electricity</strong></td>
<td>DC stands for direct current and is a form of electricity in which the direction of the current does not change as is produced by solar PV modules</td>
</tr>
<tr>
<td><strong>Diaphragm pump</strong></td>
<td>A positive displacement pump in which a diaphragm moves up and down to draw water into a one-way valve and then push it out again through a one-way valve</td>
</tr>
<tr>
<td><strong>Drawdown</strong></td>
<td>The distance or depth by which the standing water level lowers when water is pumped from a bore</td>
</tr>
<tr>
<td><strong>Earthing</strong></td>
<td>An electrical safety concept that prevents people from being electrocuted by providing a low-resistance path along which electricity can flow harmlessly to the ground if there is a fault</td>
</tr>
<tr>
<td><strong>Electricity grid</strong></td>
<td>The electricity distribution network: the poles and wires that deliver electricity from power plants to households (also known as the ‘grid’ or the ‘power grid’)</td>
</tr>
<tr>
<td><strong>Energy efficiency</strong></td>
<td>Using either passive or active practices to reduce the amount of energy used</td>
</tr>
<tr>
<td><strong>Equinox</strong></td>
<td>The time of year when the sun is at its average altitude and the lengths of day and night are equal. There are two equinoxes each year: one in March and one in September</td>
</tr>
<tr>
<td><strong>Flow rate</strong></td>
<td>Volume of water provided per second, minute, hour or day</td>
</tr>
<tr>
<td><strong>Friction loss</strong></td>
<td>Pressure loss due to the resistance to water flow in a pipe</td>
</tr>
<tr>
<td><strong>Fuse</strong></td>
<td>An electrical protection device that opens a circuit under fault conditions, i.e. when there is too much current. A fuse opens the circuit by melting and so must be replaced in order to re-close the circuit</td>
</tr>
<tr>
<td><strong>Grid</strong></td>
<td>See ‘electricity grid’</td>
</tr>
<tr>
<td><strong>Ground mounting</strong></td>
<td>A mounting method for solar PV modules</td>
</tr>
<tr>
<td><strong>Inflation</strong></td>
<td>The rate at which the value of money decreases over time</td>
</tr>
<tr>
<td><strong>Inverter</strong></td>
<td>A unit that converts DC electricity to AC electricity</td>
</tr>
<tr>
<td><strong>Irradiance</strong></td>
<td>The total amount of solar radiation available shown as power per unit area, measured in W/m²</td>
</tr>
<tr>
<td><strong>Solar radiation</strong></td>
<td>The total amount of solar radiation energy available per unit area over a specified period of time; the sum of irradiance over a time period, often measured in kWh/m²/yr or MJ/m²/day</td>
</tr>
<tr>
<td><strong>Kilowatt (kW)</strong></td>
<td>A unit of measurement of power equivalent to 1,000 watts</td>
</tr>
<tr>
<td><strong>Kilowatt-hour (kWh)</strong></td>
<td>A unit of measurement of energy (power over time) equivalent to 1,000 watt-hours</td>
</tr>
<tr>
<td><strong>Kilopascals (kPa)</strong></td>
<td>A unit used to measure pressure</td>
</tr>
<tr>
<td><strong>Latitude</strong></td>
<td>The geographic coordinate that specifies the north-south position of a point on the earth’s surface</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Linear current booster</td>
<td>A type of solar controller that can increase the amount of current supplied by a solar array to match pump requirements without increasing the power output</td>
</tr>
<tr>
<td>Litres per minute (LPM)</td>
<td>A unit used to measure the rate of water flow</td>
</tr>
<tr>
<td>Magnetic north</td>
<td>The direction in which a compass will point (solar modules should be aligned with true north, not magnetic north)</td>
</tr>
<tr>
<td>Maximum power point tracker (MPPT)</td>
<td>An electronic device that alters the electrical operation of solar PV modules so that they produce the maximum power possible at any given time</td>
</tr>
<tr>
<td>Module</td>
<td>See ‘Solar module’</td>
</tr>
<tr>
<td>Monocrystalline cell</td>
<td>A PV cell sliced from a single crystal of silicon, typically the most efficient and most expensive type of PV technology. It has a smooth, monochromatic appearance and is square, often with the edges missing</td>
</tr>
<tr>
<td>Mounting system</td>
<td>Hardware that secures the solar PV modules to a rooftop or the ground</td>
</tr>
<tr>
<td>Multicrystalline cell</td>
<td>A PV cell sliced from an ingot of silicon. Typically lower in efficiency and cheaper than monocrystalline, it has an opal-like appearance in sunlight</td>
</tr>
<tr>
<td>Multimode inverter</td>
<td>An inverter that is able to operate when it is connected to the grid as well as when it is disconnected from the grid</td>
</tr>
<tr>
<td>Overcurrent protection</td>
<td>A device that disconnects the system in the event of excessive levels of current</td>
</tr>
<tr>
<td>Parallel wiring</td>
<td>A system of wiring for solar modules or batteries that increases the current of a given array. Parallel wiring is ‘+’ to ‘+’ (positive to positive) and ‘-’ to ‘-’ (negative to negative)</td>
</tr>
<tr>
<td>Peak sun hours (PSH)</td>
<td>The number of PSH for the day indicates the amount of solar radiation received that day in an area of one square metre, equivalent to the number of hours for which power at 1kW/m² is received</td>
</tr>
<tr>
<td>Photovoltaic (PV)</td>
<td>A type of solar power in which electricity is generated from light (also referred to as solar electric or solar power)</td>
</tr>
<tr>
<td>Pole mount</td>
<td>A mounting method in which a solar array is affixed to a stationary pole-top</td>
</tr>
<tr>
<td>Polycrystalline cell</td>
<td>See 'multicrystalline cell'</td>
</tr>
<tr>
<td>Present value</td>
<td>The present-day value of money spent in the future, accounting for interest earned and inflation</td>
</tr>
<tr>
<td>PSI</td>
<td>Pounds per square inch, a unit of measurement for pressure</td>
</tr>
<tr>
<td>PV array</td>
<td>See ‘Solar array’</td>
</tr>
<tr>
<td>PV cell</td>
<td>See ‘Solar cell’</td>
</tr>
<tr>
<td>PV module</td>
<td>See ‘Solar module’</td>
</tr>
<tr>
<td>PV system</td>
<td>The solar modules and all associated equipment required to make it work</td>
</tr>
<tr>
<td>Rated power</td>
<td>The amount of power a module is able to produce under standard test conditions</td>
</tr>
<tr>
<td>Series wiring</td>
<td>A system of wiring for solar modules or batteries that increases voltage. Series wiring is ‘+’ to ‘-’ (positive to negative)</td>
</tr>
<tr>
<td>Solar altitude</td>
<td>The angle between the sun and the horizon (always between 0° and 90°)</td>
</tr>
<tr>
<td>Solar azimuth</td>
<td>The angle between north and the point on the compass at which the sun is positioned on a horizontal plane. The azimuth angle varies as the sun moves from east to west across the sky throughout the day. In general, azimuth is measured clockwise from 0° (true north) to 359°</td>
</tr>
<tr>
<td>Solar array</td>
<td>Solar modules, electrically connected</td>
</tr>
<tr>
<td>Solar cell</td>
<td>A single photovoltaic device</td>
</tr>
<tr>
<td>Solar module</td>
<td>A collection of solar cells that are connected, physically and electrically, held together by a frame and covered by a protective surface such as glass</td>
</tr>
<tr>
<td>Solar noon</td>
<td>The point of time in a day where the sun is at its highest point in the sky. This does not regularly correspond to midday, due to variations in time zones and the tilt of the rotational axis of the earth</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Energy from the sun See ‘Irradiance’.</td>
</tr>
<tr>
<td><strong>Solar resource</strong></td>
<td>The amount of sunlight available to a solar system, which is affected by the location, tilt and orientation of solar modules as well as by any shading they experience at the site</td>
</tr>
<tr>
<td><strong>Solstice</strong></td>
<td>The times of year when the sun’s altitude is at an extreme: the summer solstice occurs when the sun at solar noon is at its highest; the winter solstice, when the sun at solar noon is at its lowest. In the Southern Hemisphere, the winter solstice occurs in June and the summer solstice occurs in December</td>
</tr>
<tr>
<td><strong>Standard test conditions (STC)</strong></td>
<td>Operating conditions, where the cell temperature is 25°C, irradiance is 1,000W/m² and air mass is 1.5. Ratings of a solar module on a datasheet are generally based on ratings achieved under STC. This is not to be confused with Small-scale Technology Certificates which are also portrayed with the initials 'STC'. Small-scale Technology Certificates are a type of Renewable Energy Certificate (REC) as part of Australia’s Renewable Energy Target (RET).</td>
</tr>
<tr>
<td><strong>Standing water level</strong></td>
<td>The distance from the top of the water level to ground level when no water is being pumped</td>
</tr>
<tr>
<td><strong>System grounding</strong></td>
<td>See ‘Earthing’</td>
</tr>
<tr>
<td><strong>Thin-film cell</strong></td>
<td>A PV cell made by depositing thin semiconductor layers onto a surface (the least efficient but cheapest PV cell technology)</td>
</tr>
<tr>
<td><strong>True north</strong></td>
<td>The direction of the North Pole (from whence all measurements should be taken)</td>
</tr>
<tr>
<td><strong>Vertical lift</strong></td>
<td>The vertical distance from the ground to the output of the pumping system</td>
</tr>
<tr>
<td><strong>Voltage or volts</strong></td>
<td>Voltage is the amount of electrical pressure, which causes electricity to flow in the power line. If electricity were water, voltage would be the measure of pressure at the tap</td>
</tr>
<tr>
<td><strong>Watt (W)</strong></td>
<td>A unit of measurement of power (volts x amps = watts)</td>
</tr>
<tr>
<td><strong>Watt-hour (Wh)</strong></td>
<td>A unit of measurement of energy (power over time)</td>
</tr>
<tr>
<td><strong>Watt-peak</strong></td>
<td>The unit of measurement for the rated power of a PV module</td>
</tr>
<tr>
<td><strong>Yield</strong></td>
<td>The amount of energy generated by a PV system over a period of time</td>
</tr>
</tbody>
</table>
APPENDIX B: UNITS OF MEASUREMENT

ELECTRICAL

W (watt)
A measurement of electrical power.

kW (kilowatt)
A measurement of electrical power. 1kW = 1,000W.

kWh (kilowatt hour)
A measurement of electrical energy. One kWh is the amount of energy equivalent to one kilowatt of power used or generated over one hour. 1kWh = 1,000Wh.

Solar radiation

kW/m² (kilowatt per metre squared)
A measurement of solar radiation power. One kW/m² is equivalent to one kW of solar radiation power received on a square metre. 1kW/m² = 1,000W/m².

kWh/m²/day (kilowatt hour per metre squared per day)
A measurement of solar radiation energy, i.e. power over time. One kWh/m²/day is equivalent to one kWh of solar radiation energy received on a square metre over a day. 1kWh/m²/day = 1,000Wh/m²/day.

kWh/m²/year (kilowatt hour per metre squared per year)
A measurement of solar radiation energy, i.e. power over time. One kWh/m²/year is equivalent to one kWh of solar radiation energy received on a square metre over a year. 1kWh/m²/year = 1,000Wh/m²/year.

PSH (peak sun hours)
A measurement of solar radiation energy. Peak sun hours refers to the number of hours at maximum solar radiation levels (1kW/m²) that would give the equivalent daily solar radiation energy. It represents the area under the solar radiation curve; 1 PSH is equal to 1kWh/m²/day.

MJ (megajoules)
A measurement of energy. One kWh of energy is equal to 3.6MJ and one kWh/m² is equal to 3.6MJ/m².

WATER VOLUME

L (litre)
A metric measurement of water volume. It is the amount of water contained in one cubic decimetre (i.e. a cube 10cm x 10cm x 10cm).

kL (megalitre)
A metric measurements of water volume. It is the amount of water contained in one cubic metre and is equivalent to 1,000L.

ML (megalitre)
A metric measurements of water volume. It is equivalent to 1,000,000L.

m³ (metre cubed)
A metric measurements of water volume. It is the amount of water contained in one cubic metre and is equivalent to 1,000L or 1kL.
APPENDIX C: SOLAR PUMP DESIGN CHECKLIST

The design of a solar pump entails some complex calculations. This guide aims to explain the key principles of solar pumping design so that if you are considering buying a solar pump package, you have the overview you need make informed decisions about suitable solar pump suppliers and packages.

The main information that you, the potential system owner, will need to provide to a solar pump supplier relates to the application and the proposed site.

The following checklist refers to the process of designing a solar pumping system, and may assist you in choosing a suitable solar pump package.

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Determine application for water pump</td>
<td></td>
</tr>
<tr>
<td>2. Calculate daily water requirements and monthly/seasonal variations</td>
<td></td>
</tr>
<tr>
<td>3. Gather historical solar resource data</td>
<td></td>
</tr>
<tr>
<td>4. Assess site for equipment layout:</td>
<td></td>
</tr>
<tr>
<td>• location of water source</td>
<td></td>
</tr>
<tr>
<td>• location of water pump</td>
<td></td>
</tr>
<tr>
<td>• location of solar array</td>
<td></td>
</tr>
<tr>
<td>• location of water delivery point</td>
<td></td>
</tr>
<tr>
<td>• pipe routes</td>
<td></td>
</tr>
<tr>
<td>• cable routes</td>
<td></td>
</tr>
<tr>
<td>5. Gather information about the water resource:</td>
<td></td>
</tr>
<tr>
<td>• type of water source</td>
<td></td>
</tr>
<tr>
<td>• static water level</td>
<td></td>
</tr>
<tr>
<td>• water source depth</td>
<td></td>
</tr>
<tr>
<td>• recovery rate</td>
<td></td>
</tr>
<tr>
<td>• topography</td>
<td></td>
</tr>
<tr>
<td>• water quality</td>
<td></td>
</tr>
<tr>
<td>• seasonal variations</td>
<td></td>
</tr>
<tr>
<td>• water losses</td>
<td></td>
</tr>
<tr>
<td>6. Gather information about the water delivery point:</td>
<td></td>
</tr>
<tr>
<td>• where the water is going</td>
<td></td>
</tr>
<tr>
<td>• capacity of water storage (where relevant)</td>
<td></td>
</tr>
<tr>
<td>• distance from solar pump</td>
<td></td>
</tr>
<tr>
<td>• Vertical lift from solar pump</td>
<td></td>
</tr>
<tr>
<td>7. Select array tilt and calculate solar radiation levels</td>
<td></td>
</tr>
<tr>
<td>8. Calculate flow rates:</td>
<td></td>
</tr>
<tr>
<td>• daily flow rate</td>
<td></td>
</tr>
<tr>
<td>• hourly flow rate</td>
<td></td>
</tr>
<tr>
<td>9. Calculate total dynamic head.</td>
<td></td>
</tr>
<tr>
<td>10. Find all suitable pump/array packages.</td>
<td></td>
</tr>
<tr>
<td>11. Undertake an economic analysis.</td>
<td></td>
</tr>
<tr>
<td>12. Assess alternate/complementary power supplies, e.g. diesel generator</td>
<td></td>
</tr>
<tr>
<td>13. Select pump/array packages</td>
<td></td>
</tr>
</tbody>
</table>
# APPENDIX D: OFFICE OF WATER – WATER NEEDS FOR A RURAL PROPERTY

<table>
<thead>
<tr>
<th>STOCK WATER</th>
<th>Description</th>
<th>1. Consumption rate (m³/ head)</th>
<th>2. Your stock numbers</th>
<th>1. x 2. = Sub total m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>Lactating, Dairy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry dairy, Beef</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feedlot</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calves</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheep</td>
<td>Type of pasture being grazed</td>
<td>Quality of drinking water (Total dissolved salts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated</td>
<td>Soft water</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low salt</td>
<td>0 to 2000 parts per million</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low salt</td>
<td>2000 to 5000 ppm</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low salt</td>
<td>5000 to 10000 ppm</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High salt</td>
<td>0 to 6000 ppm</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Lambs</td>
<td>(adopt half the sheep rate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goats</td>
<td></td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horses</td>
<td>Working</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grazing</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pigs</td>
<td>Sow</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pig (allow 10 per sow)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry</td>
<td>Table bird to 10 weeks</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Layers</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Turkey</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Wildlife</td>
<td>3.6 – 4.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## DOMESTIC WATER

<table>
<thead>
<tr>
<th>Description</th>
<th>m³/person or area</th>
<th>Persons/Area</th>
<th>Sub total m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household House – without septic</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House – with septic</td>
<td>64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Septic only</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House Garden For each 1000 m² or 0.1 ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Coastal / Tablelands</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Slopes</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Plains</td>
<td>600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Western</td>
<td>800</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## FARMING

<table>
<thead>
<tr>
<th>Description</th>
<th>m³/ unit</th>
<th>Number of units</th>
<th>Sub total m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy For each m² of wash down area</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piggery For each sow – includes sow &amp; progeny, drinking &amp; wash down</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dip Based on 2 events per year: - Plunge per 100 head</td>
<td>0.8 – 1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Spray per 100 head</td>
<td>0.6 – 2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop spraying Based on 2 events per year: - Herbicide/ insecticide per ha of crop</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firefighting Based on a single event: - Buildings per m²</td>
<td>0.125</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Grass per m²</td>
<td>0.075</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Net Annual Water Requirement**

m³

Note: This table provides an estimate of your net annual water requirement and is not recommended for designing farm reticulation schemes which are based on peak daily requirements.

**What is this as a volume?** To covert net annual water requirement into a volume (ie megalitres) use the following equation:

\[
\text{m³} \div 1000 = \text{Megalitres (ML)}
\]

One megalitre is a million litres or 1,000 kilolitres of water.
APPENDIX E: FINDING IRRADIATION DATA ON THE BUREAU OF METEOROLOGY (BOM) WEBSITE

Part of the information required before you can size a solar pumping system accurately is the amount of solar radiation available at the proposed pump site. One of the best sources of this information is the Australian Government’s Bureau of Meteorology (BoM), which hosts a large number of weather stations throughout NSW.

To find the solar radiation data for a particular site in NSW, head to www.bom.gov.au. Navigate to the ‘Climate and Past Weather’ page and then to the ‘Weather & climate data’ link. On this page, click the ‘Select using Map’ tab.

From this point, navigate to the nearest weather station to the proposed pump location (use the dropdown menu to choose the ‘Monthly solar exposure’ data set; then select the appropriate weather station).
Once you have selected the closest weather station to the proposed pump site, click the ‘Monthly solar exposure data’ link in the bubble that pops up (highlighted here in red) to access a table displaying the relevant data.

Make sure that the units of measurement are in kWh/m\(^2\) and not in MJ/m\(^2\).

The data that will be most useful is in the ‘Summary statistics for all years’ table, below the main table for the page. In this table, the top row contains mean monthly values. These are the solar radiation values you’ll need for the solar pumping design.
APPENDIX F: CALCULATING DYNAMIC HEAD

Calculations of a pumping system’s dynamic head are made up of two components: pipe friction loss and friction head loss.

\[ \text{Dynamic head} = \text{pipe friction loss} + \text{friction head loss} \]

PIPE FRICTION LOSSES

Pipe friction losses represent the resistance of a pipe to water flowing through it. The following equation can be used to calculate pipe friction losses, assuming a steady laminar flow (a streamlined flow with no turbulence).

\[ h_L = f \times \frac{L}{D} \frac{V_{avg}^2}{2g} \]

where:

- L = the total length of the pipe in metres (not just the vertical height, but the length of pipe),
- D = the internal diameter of the pipe in metres,
- \( V_{avg}^2 \) = the average velocity of the water within the pipe in m/s,
- g = the force of gravity, which is equal to 9.81m/s\(^2\), and
- f = the friction factor for laminar flow (see equation below).

The equation for calculating friction flow, below, is for a circular pipe in a laminar flow condition:

\[ f = \frac{64}{Re} = \frac{64\mu}{\rho DV_{avg}} \]

where:

- \( \mu \) = the dynamic viscosity of water (temperature-dependent),
- \( \rho \) = the density of water (temperature-dependent),
- D = the wetted diameter of the pipe (that is, the diameter of those sections of the internal pipe that touch water), and
- \( V_{avg} \) = The average velocity of the water.

FRICITION HEAD LOSS

The friction head loss represents the losses that occur due to bends in any of the pipe or valves in the system as well as those that occur as a result of the size of the valves or pipes. The following equation is used to calculate the friction head loss:

\[ h_f = \frac{KV^2}{2g} \]

where:

- K = the resistance coefficient (this depends on the type of valve or the degree of bend in a system),
- V = the velocity of water, and
- g = the force of gravity, which is equal to 9.81m/s\(^2\).
APPENDIX G: SOLAR PV SYSTEM REBATES IN AUSTRALIA

Solar PV system rebates reduce the up-front cost of a solar-powered pumping system. Most solar PV system rebates originate with government bodies, state and federal, although financial incentives for installing an off-grid solar system from electricity distributors.

The current rebate relevant to solar PV-powered pumps available in Australia (as of August 2014) comes in the form of small-scale technology certificates (STCs).

What are STCs?

STCs are part of an Australian Government scheme to support small-scale renewable energy the Small-scale Renewable Energy Scheme (SRES). This scheme is part of the government’s Renewable Energy Target (RET), another federal government program to source 20 percent of Australia’s electricity supply from renewable energy.

An STC is an electronic certificate that represents the power-generation potential of a small renewable-energy generator, such as a solar PV pumping system. An eligible system will receive one STC for each 1MWh of renewable energy it generates over a period of 15 years. The amount of generation is estimated based on the size of the solar PV system and the postcode location of the system. The Australian Government’s Clean Energy Regulator (CER) manages the STCs and provides a STC calculator on its website at www.rec-registry.gov.au/sguCalculatorInit.shtml

How are STCs created

STCs are created when an eligible system is installed and an application is made to the CER. By default, the STCs are owned by the owner of the system, but are typically assigned to the system installer, retailer or STC agent in return for an upfront discount on the system. The STCs are then sold into a market where they are purchased by carbon emitting generators and energy retailers to fulfil their obligations to the SRES.

What is needed to be eligible for STCs?

To be eligible for STCs, a solar PV system must be:

- new,
- made up of components approved by the Clean Energy Council (www.solaraccreditation.com.au),
- installed correctly by a Clean Energy Council accredited installer, and
- comply with all local, state and federal government requirements.

Example:

A 1kW system is to be installed in Bingara, NSW, postcode 2404. The CER STC calculator determines that this system would create 20 STCs. This means that the system would be expected to produce approximately 20MWh of energy over a 15-year period.

A 2kW system installed in Bingara will create 41 STCs. This means that the system is expected to produce approximately 41MWh of energy – double the amount of the 1kW system – over a 15-year period.