Guide to Solar-Powered Water Pumping Systems in New York State

NYSERDA
New York State
Energy Research and
Development Authority

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Introduction

The purpose of this guide is to provide New York State farmers and landowners with information on planning and installing solar-powered water pumping systems. Because every location has different needs and resources, this guide provides the general principles required to make an informed decision on whether or not a solar pump is right for your operation.

Currently, solar water pumps are used in the western United States as well as in many other countries or regions with abundant sunlight. Solar pumps have proven to be a cost-effective and dependable method for providing water in situations where water resources are spread over long distances, power lines are few or non-existent, and fuel and maintenance costs are considerable. Historically, solar water pumps have not been widely used in New York State, in part due to the perception that solar does not work in New York. However, demonstration units that have been operating over the past few years have proven that solar pumps work at capacity when needed most: during warm, sunny days. This is particularly important for animal grazing operations.

While there are several possible methods for supplying water to remote pastures, such as wind, gas/diesel pumps, and ram pumps, solar-powered water pumps may offer the best option in terms of long-term cost and reduced labor. In the relatively rare instances with favorable topography and spring or pond location, ram pumps or gravity feed may be better options. In flat areas where the water is supplied by a remote well and where there is limited access to the power grid, solar pumps appear to be the best option.

Solar/Photovoltaic Power

Solar or photovoltaic (PV) cells are made of semiconducting materials that can convert sunlight directly into electricity. When sunlight strikes the cells, it dislodges and liberates electrons within the material which then move to produce a direct electrical current (DC).[1] This is done without any moving parts.

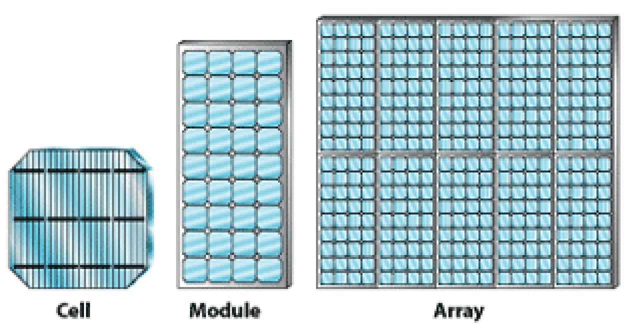


Figure 1. Diagram that shows how individual cells make up a module. An array consists of sets of modules (from the National Renewable Energy Laboratory, Golden, CO).

[1] For a more thorough explanation of solar power, please visit the National Renewable Energy Laboratory website http://www.nrel.gov/clean_energy/solar.html

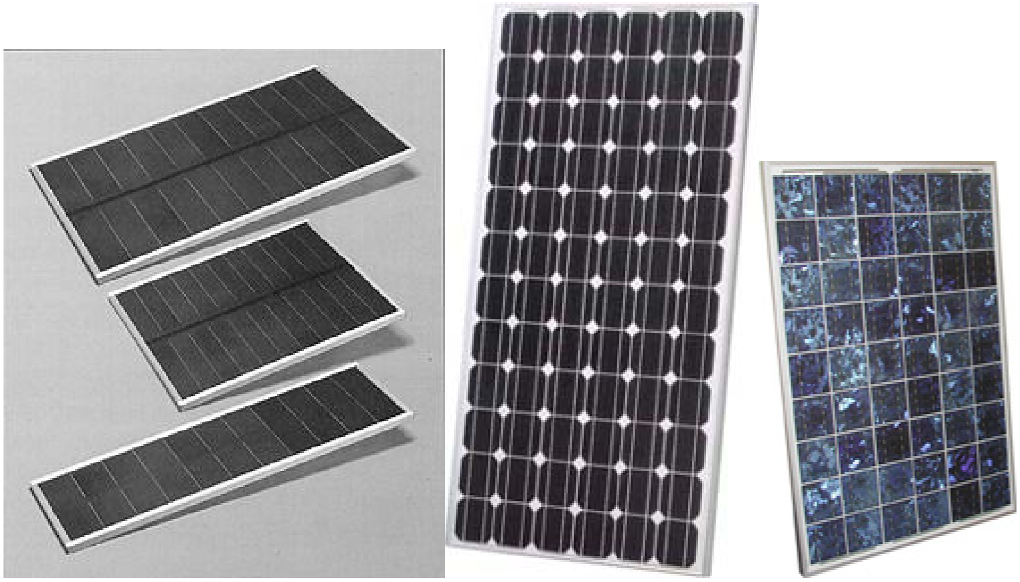
PV cells are combined to make *modules* that are encased in glass or clear plastic. Modules can be aggregated together to make an *array* that is sized to the specific application (Figure 1). Most commercial PV cells are made from silicon, and come in three general types: monocrystalline, multicrystalline, and amorphous (Figure 2). Single crystal or monocrystalline cells are made using silicon wafers cut from a single, cylindrical crystal of silicon. This type of PV cell is the most efficient, with approximately 15% efficiency (defined as the fraction of the sun's energy that is converted to electrical power), but is also one of the most expensive to produce. They are identifiable as having individual cells shaped like circles or rectangles.

Multicrystalline or polycrystalline silicon cells are made by casting molten silicon into ingots, which crystallize into a solid block of intergrown crystals. The size of the crystals is determined mostly by the rate at which the ingot is cooled, with larger grains made by slower cooling. Cells are then cut from the ingot. Multicrystalline cells are less expensive to produce than monocrystalline ones, due to the simpler manufacturing process and lower purity requirements for the starting material. However, they are slightly less efficient, with average efficiencies of around 12%.

Amorphous silicon PV cells are made from a thin layer of noncrystalline silicon placed on a rigid or flexible substrate. They are relatively easy to manufacture and are less expensive than monocrystalline and polycrystalline PV, but are less efficient with efficiencies of around 6%. Their low cost makes them the best choice where high efficiency and space are not important.

Photovoltaic modules have been around for more than 50 years and have been mass-produced since 1979. Due to improvements in manufacturing technology and economies of scale, the cost of PV has fallen by 90% since the early 1970s. PV modules are now readily available in a wide range of sizes from several well established companies. The reliability of PV is such that 20- to 25-year power warranties are typical, with life expectancies beyond 30 years.

PV arrays are installed so that they maximize the amount of direct exposure to the sun. That usually means placement in an area clear of shading from buildings and trees, in a southward direction, and at an angle equal to the latitude of the location. If the PV array is used seasonally, as with most water pumping systems in the northeastern US, then a solar tracker may be used to tilt the PV array as the sun moves across the sky. This increases daily energy gain by as much as 40% at New York latitudes. With more hours of peak sun, a smaller pump and power system may be used, thus reducing overall cost. Tracking works best in clear sunny weather. It is less effective in cloudy climates and on short winter days, and should not be used in windy areas.



a b c

Figure 2. Examples of the types of commercially available PV modules: a) amorphous (courtesy of Unisolar); b) monocrystalline (courtesy of Sharp); and polycrystalline (courtesy of Matrix).

Solar Water Pumps

Electric water pumps that are plugged into an outlet using alternating current (AC) are generally not built to operate very efficiently because there is no limitation to the amount of power available. Solar water pumps are designed to use the direct current (DC) provided by a PV array, although some newer versions use a variable frequency AC motor and a three-phase AC pump controller that enables them to be powered directly by the solar modules. Because PV is expensive and its power production can be variable, solar pumps need to be as efficient as possible; that is, they need to maximize the gallons of water pumped per watt of electricity used.[2] They must also be able to pump during low light (low power) conditions. In order to meet these demands, pump manufacturers needed to change their water pump designs.

Most conventional AC pumps use a centrifugal impeller that “throws” the water into motion. A multi-stage centrifugal pump has a series of stacked impellers and chambers. When operating at low power, the amount of water pumped by centrifugal pumps drops dramatically. This makes centrifugal pumps somewhat limited in solar applications, though efficient centrifugal pumps are available. Many designers of solar water pumps took the approach of using positive displacement pumps, which bring water into a chamber and then force it out using a piston or helical screw. These types generally pump more slowly than other types of pumps, but have good performance under low power conditions, and can achieve high lift.

Both submersible and surface solar pumps are available. A submersible pump remains underwater, such as in a well (Figure 3). A surface pump (Figure 4) is mounted at water

[2] For more information, see *Solar Water Pumping: A Practical Introduction* by Windy Dankoff at http://www.dankoffsolar.com

level either adjacent to the water source or, in the case of a floating pump (Figure 5), on top of the water. Surface pumps are less expensive than submersible pumps, but they are not well suited for suction and can only draw water from about 20 vertical feet. Surface pumps are excellent for pushing water long distances.

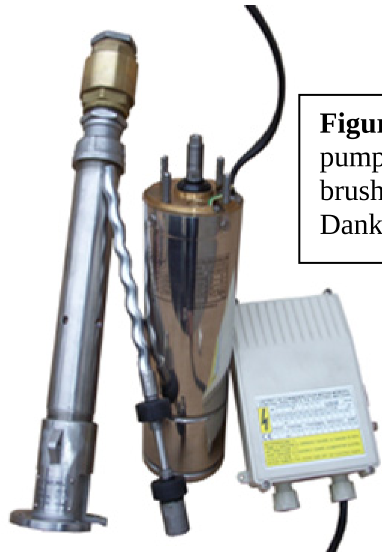


Figure 3. Photo of a submersible pump that uses a helical rotor and brushless motor (courtesy of Dankoff Solar, Inc.)

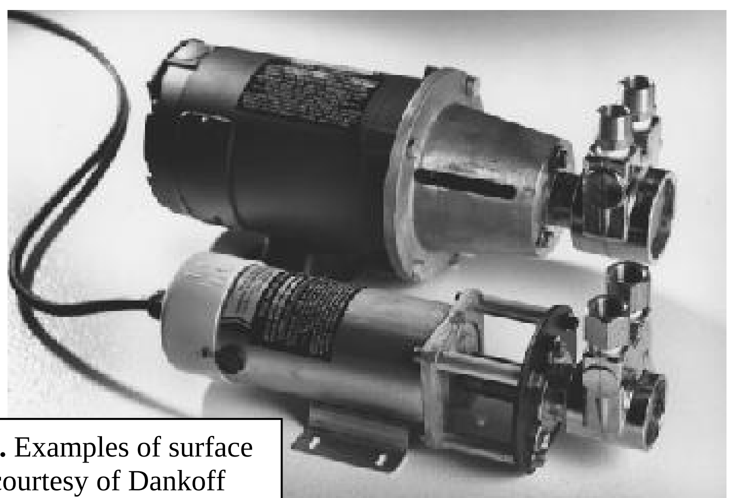


Figure 4. Examples of surface pumps (courtesy of Dankoff Solar, Inc.).

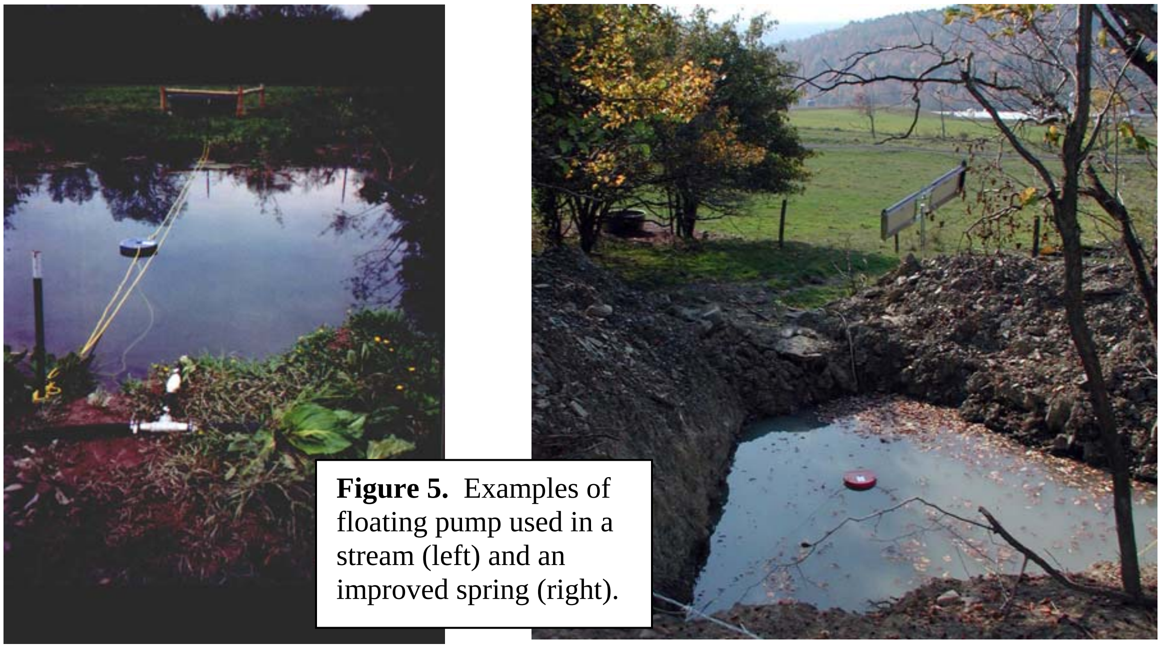


Figure 5. Examples of floating pump used in a stream (left) and an improved spring (right).

Solar pumps are available in a wide range of types and sizes. The pump that is right for an application is determined after carefully calculating your needs (see System Sizing, below). The smallest solar pumps require less than 150 watts and can pump at 1.5 gallons per minute. Over ten sunny hours in August, such a system can pump up to 900 gallons. For example, one brand of submersible pump, with 300 watts of PV, can produce over 1100 gallons per day from a 150-foot-deep drilled well. The equivalent ¾ HP 240 VAC pump would require 2000 watts of PV, an inverter and batteries to do the same amount of work.

Comparison to Other Watering Systems

There are other options for pumping water in remote applications. These and their advantages and disadvantages are listed in Table 1.

Table 1. Comparison of Solar and Other Remote Watering Systems

Pump Type	Advantages	Disadvantages
Solar	• Low maintenance • No fuel costs or spills • Easy to install • Simple and reliable • Unattended operation • System can be made to be mobile	• Potentially high initial cost • Lower output in cloudy weather • Must have good sun exposure between 9 AM and 3 PM
Diesel (or gas) power systems	• Moderate capital costs • Can be portable • Extensive experience available • Easy to install	• Needs maintenance and replacement • Maintenance often inadequate, reducing life • Fuel often expensive and supply intermittent • Noise, dirt and fume problem • Site visits necessary

Windmill	• Potentially long-lasting • Works well in windy site	• High maintenance and costly repair • Difficult to find parts • Seasonal disadvantages • Need special tools for installation • Labor intensive • No wind, no power
Gravity	• Very low cost • Low maintenance • No fuel costs or spills • Easy to install • Simple and reliable	• Practical in only few places
Ram	• Very low cost • Low maintenance • No fuel costs or spills • Easy to install • Simple and reliable	• Requires moving water for operation
Hauling	• Lowest initial cost • Excellent mobility	• Very labor intensive

The key to PV's success is the low labor and maintenance costs relative to the other options. The long-term economics make PV pumps superior to most other remote watering options, except where gravity feed is available. One study completed by the Bureau of Land Management at Battle Mountain, Nevada compared solar water pumping systems to generator systems. For one 3.8 gpm system with a 275 foot design head, the PV system cost only 64% as much over 20 years as the generator system did over only 10 years. This remote solar site also used only 14% as many labor hours. A Sandia National Laboratories study[3] noted that photovoltaic pumping systems in remote locations would often be cost effective compared to generators, even with five times the initial capital cost. Inexpensive diesel or gas generators have low initial costs but require consistent maintenance and have a design life of approximately 1500 hours. Small to medium sized solar pumping systems often cost less initially than a durable slow speed engine driven generator.

Uses for Solar Water Pumps in New York

Solar pumps are very cost-effective for remote applications, particularly where utility interconnect costs more than $5000. That is usually about one-third to one-half mile from the grid. Specific applications include:

- Off-grid homes and cabins;
- Livestock watering: pond and stream protection, rotational or prescribed grazing, and remote pasturing;
- Aquaculture: aeration, circulation, and de-icing;
- Irrigation: best for small scale applications.

[3] Stokes et al., 1993

Solar pumps are used globally where there is no power and water sources are scattered, such as cattle ranches or village water systems. In temperate regions, the water pumps can be used year-round. Because the northeastern U.S. is subject to frigid weather, the use of solar pumps for providing water for grazing livestock in New York is generally seasonal. In grazing operations, a solar pump can be used to fill a central tank that is located at a high point of the property. The water can then be distributed by gravity feed to a network of pipes to individual stock tanks. Solar pumping can also be used for small-scale irrigation, though this has not yet been implemented. It is possible that water systems set up for watering grazing livestock could be oversized to provide emergency pasture irrigation during drought. During the winter, PV arrays and submersible pumps can remain outside, though surface pumps should be stored for the season.

Figure 6. A 240 W array with pump controller and passive tracker for submersible pump in Ithaca.

Description of System Sizing and Installation

A typical solar water-pumping system that is installed for a grazing operation includes the PV array, the controller, the pump, and accessories (Figure 6). The size of the array and the pump will be determined by several factors. In this section, the methodology used to determine the size of the system is described along with the general procedures used during installation. The goal is to give the reader an understanding of the process.

You may decide to design and install your own system, but it is suggested that you contact an experienced installer to assist you.

System Sizing and Components

Determine Watering Needs

The first step is to determine the amount of water that you will need. If your needs vary during the season, be conservative and use the highest amount that you expect to use. The guidelines below can be used to approximate water usage.

Application	**Approximate Usage**
Household	50 gallons per day, per person (average)
Cattle and Horses	10-15 gallons per day, per head
Dairy Cows	20-30 gallons per day
Sheep and goats	2 gallons per day
Small Animals	¼ gallon per day, per 25lb body weight
Poultry	6-12 gallons per day, per 100 birds
Young Trees	15 gallons per day in dry weather

Determine Water Source

The configuration of the watering system will be defined largely by the type of water source and its location relative to the places you want to provide water. The water source will either be subsurface (well) or surface (pond, stream, or spring). Wells are preferable because of the improved water quality and consistency. However, wells are expensive to drill, particularly where water tables are deep. Surface water sources may vary seasonably, such that the amount and quality of the water is low during the summer when it is needed most.

For wells, the following need to be determined:

- static water level;
- seasonal depth variations;
- recovery rate; and
- water quality.

The well driller should give you this information for a new well. For most wells, water quality is not an issue if not used for human consumption.

For surface water sources, the following need to be determined:

- seasonal variations; and
- water quality, including presence of silt, organic debris, etc.

The water delivery system should be mapped out to determine the location of the water source and the desired points of distribution. The map should have height contours so that you can calculate the height differences. Figure 7 shows an example of a farm that can use a low lying pond as the source combined with a storage tank placed on a hill. The water can then be gravity fed through the distribution pipes to individual paddocks. A water resource manager can assist you with planning a water distribution system.

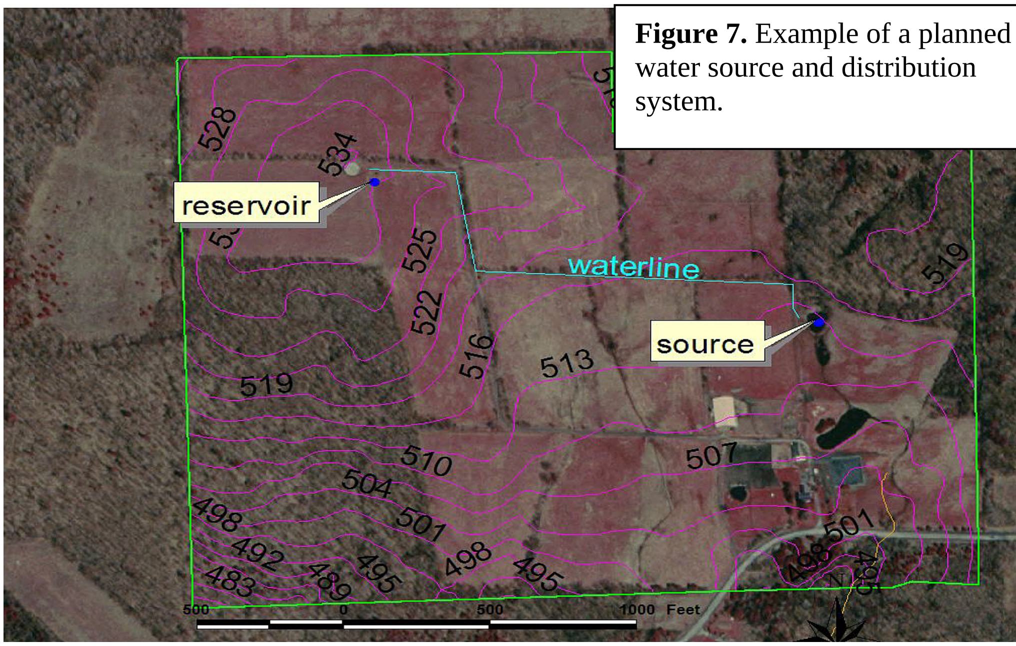


Figure 7. Example of a planned water source and distribution system.

Suitability of the Site for Solar

The site of the water source must then be evaluated for suitability for the installation of the solar-powered water pumping system. The following are specific issues that must be addressed:

- the solar panels require a south facing location with no significant shading;
- locations must be found for the water pump (surface), controllers, storage tank and other system components;
- the solar array should be as close to the pump as possible to minimize wire size and installation cost;
- if batteries are to be used, they must be in a reasonably dry/temperature-controlled location with proper venting; and
- if year-round water is required, freeze proofing issues must be addressed. A heated area is preferred for water storage and pressure tanks. It is not economical to use PV to run a resistance heater in the winter.

Assuming that you can place the array in a location that can receive full sun, you then need to estimate the regional solar potential using published data or maps for your region[4]. These sources will tell you what *full sun hours* per day your area receives. The average for most of New York State is 2.5 hours in the winter, 5.5 hours in the summer, and 4 hours for the year. Multiply the array wattage by this number to get a rough estimate of daily power available at the site.

Determine Total Dynamic Head

Once you have determined the amount of water that is needed, the characteristics of the water source, and an idea of the distances (both vertical and horizontal) that the water will be pumped, you can determine the size pump that you need and the amount of power needed from the PV array. You need to calculate the value of the *total dynamic head* (TDH), which is the sum of the static lift of the water, the static height of the storage tank, and the losses from friction.

The static lift is measured from the solar array to the low water level in the well, pond, or stream. The static height of the storage tank is measured from the array to the top of the tank. Using a topographical map or an altimeter, you can estimate this last value.

Friction losses are the resistance of water flow due to the inside surface of the pipe. In general, the smaller the pipe and the higher the pumping rate, the higher the resistance. Friction losses are expressed in terms of equivalent height and are determined by the pumping rate and the size of the pipe. In order to calculate the pumping rate of the pump in gallons per minute (gpm), the following equation can be used:

$$\text{GPM} = \frac{\text{gallons per day}}{\text{peak sun hours per day}}\, x\, \frac{\text{hour}}{60\ \text{minutes}}$$

For instance, if you require 1500 gallons per day as calculated at the beginning, and you have determined that the site has 5 peak sun hours per day during the grazing season, you need a pumping rate of 5 gpm. A friction loss table (see Appendix 2) uses the pumping rate and the inside diameter of the pipe to give a friction loss in terms of vertical feet for every hundred feet of pipe. To take the example further, if you are using 300 feet of ¾ inch pipe at 5 gpm, you would need to add 5.78 x 3 = 17.34 feet to the sum of the static lift and height.

Determine Pump Size and PV Array

Now that you know the total lift in terms of TDH and the desired pumping rate in gpm, you refer to the charts provided by the manufacturer to determine the specific pump and

[4] For example, http://www.nrel.gov/gis/solar_maps.html

the size of the PV array (see Figure 8). The PV array will be specified in terms of wattage and voltage. It is standard procedure to increase the specified wattage by 25% (multiply by 1.25) to compensate for power losses due to high heat, dust, aging, etc. The cost of just the PV panels without any government incentives is estimated at $6 to $8 per watt including a stationary array mount, or $5 to $6 without the mount.

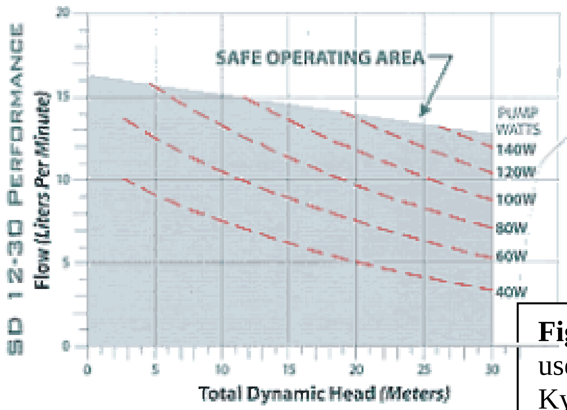


Figure 8. An example of a graph used to size a pump (from Kyocera Solar)

Passive Trackers

A passive tracker for the PV array may be used to increase the power output by keeping the array pointed at the sun throughout the day[5]. The tracker does this by using canisters of liquid on each end of the tracker that are connected to each other by a tube. When the sun heats one canister, it drives the liquid to the canister on the other side, causing the rack to tilt. This goes on throughout the day, keeping the rack pointed directly at the sun. Compared to a stationary rack, a tracker can increase power output 25-50%.

A tracker can reduce the number of PV panels required. An additional benefit is a potential reduction in pump stalling due to low light conditions during early morning and late afternoon at low sun angles. This is of particular importance for systems that use a centrifugal pump, where water yield drops exponentially with a drop in power. Trackers work best in the summer months.

Trackers are not for every application. The “wings” of the tracker can catch wind, so they should not be used in high wind areas. In some situations, it may be just as economical to increase the size of the array and not use a tracker.

Pump and Charge Controllers

The pump controller is an electronic linear current booster that acts as an interface between the PV array and the water pump. It operates very much like an automatic transmission, providing optimum power to the pump despite wide variations in energy production from the sun. It is particularly helpful in starting the pump in low light conditions. A charge controller is installed when batteries are used in the system. Its purpose is to keep the batteries from overcharging or becoming completely discharged.

[5] For more information, see Solar Tracking for Solar Water Pumps by Windy Dankoff

Most controllers are configured to allow the use of a float switch for full tank pump shutoff and some offer basic diagnostic LED displays (Figure 9).

Figure 9. A charge controller attached to the array for a system with batteries. For a system without batteries, only a pump controller would be installed.

Tank Storage

All solar water pumping systems use some type of water storage. The idea is to store water rather than store electricity in batteries, thereby reducing the cost and complexity of the system. A general rule of thumb is to size the tank to hold at least three days worth of water.

The most common method of water storage is a food-grade plastic tank (Figure 10) which is often placed at a high point on the property for gravity feed to different fields or paddocks used in seasonal grazing or drip irrigation applications. A float switch is installed inside the tank to control the pump according to water level (Figure 11). A wire is run along with the distribution pipe from the switch to the pump controller.

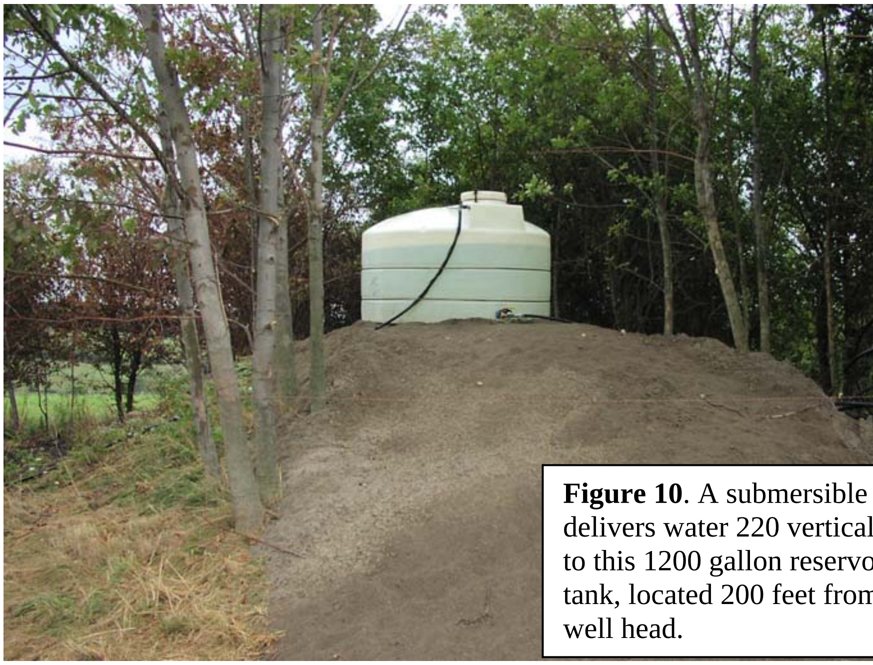


Figure 10. A submersible pump delivers water 220 vertical feet to this 1200 gallon reservoir tank, located 200 feet from the well head.

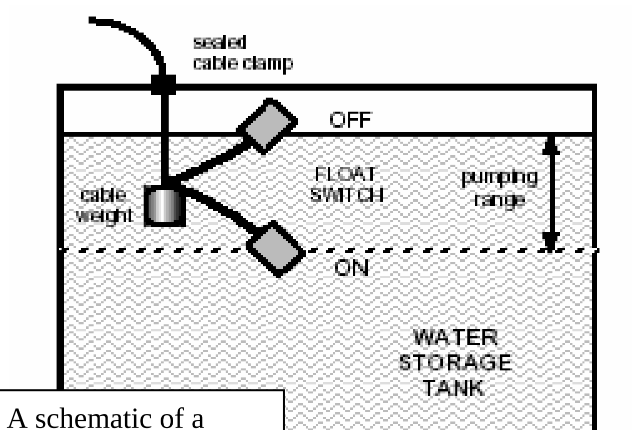


Figure 11. A schematic of a storage tank using a float switch.

Pressurized Water Systems

In some applications, a pressurized water system may be required. A properly sized solar pump may be used in a pressurized water system much the same as a standard AC powered pump (Figure 12). If full-time water is needed, the pressure tank can be oversized to provide sufficient water through the night. Storage batteries may also be used to provide a continuous power source. The solar array is used for battery charging purposes, recharging each day what was used during the night. A charge controller and low voltage disconnect are needed in this type of system.

Figure 12. PV powered booster pump assembly in a mobile unit.

Does Solar Water Pumping Work in New York?

More than a dozen solar water-pumping systems have been installed in upstate New York since 2001 by Four Winds Renewable Energy. With funding from the NYS Department of Agriculture and Markets, two systems were installed at the Alfred State College Tech Farm in order to test the long-term performance of solar water pumps used in seasonal grazing. The systems are a submersible pump placed in a 225 ft. well (90 ft. static water level) in a heifer pasture and a floating pump placed on a developed spring in a pasture used for grazing beef cattle. On clear days, the pumping rate was consistently 1.8-1.9 gpm, the maximum that the pump is rated for, over the course of the day (excluding sunrise and sunset). This was measured between 9 AM and 5 PM on summer days, with lower rates during the dawn and dusk hours. On partly cloudy days, the midday pumping rate was 0.9 to 1.3 gpm when clouds obscured the sun. During severe cloud cover, such as rainy days, the pump would not operate (but is not needed). The highest values (1000-1120 gpd) were seen during clear summer days.

In 2002, Four Winds Renewable Energy installed seven more systems in Steuben, Tioga and Tompkins County. More installations are scheduled through the "Solar-Powered Livestock Watering Project" sponsored by the Finger Lakes RC&D and funded by NYSERDA. All nine existing systems are doing well, meeting or exceeding projected daily water production.

Conclusions

Solar water pumps can provide simple and low labor watering options for farms that require water in remote areas. Several general points to keep in mind about solar water pumping include:

- Water storage in metal or plastic tanks is used instead of power storage in a battery. This reduces costs and makes the system simpler. A float switch turns the pump off when the tank is full.

- An electronic pump controller is used to smooth out the current to the pump. It acts like an automatic transmission in the sense that it helps the pump to start and to operate in low light conditions.

- As with the turtle and the hare, slow and steady wins the race. Many solar pumps are made to pump slowly over the course of the day, which allows water to be pushed over considerable distances and vertical rises. Slow pumps can use small-diameter piping, reducing the installed cost. Slow pumps require less power and allow the use of limited water resources, such as a slowly recharged well.

- To reduce the cost of a system, water conservation must be practiced. PV modules are expensive, and reducing water use in any manner will save on the installed cost.

- Solar pumps are generally most competitive in smaller systems where combustion engines are least economical.

- Solar pump systems are low maintenance. With automatic shutoff from a float valve, they require only occasional inspection.

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Appendix 1

Glossary of Solar Water Pumping Terms[6]

Booster Pump - A surface pump used to increase pressure in a water line, or to pull from a storage tank and pressurize a water system. See Surface Pump.

Casing - Plastic or steel tube that is permanently inserted in the well after drilling. Its size is specified according to its inside diameter.

Cable Splice - A joint in electrical cable. A submersible splice is made using special materials available in kit form.

Centrifugal Pump - A pumping mechanism that spins water by means of an "impeller." Water is pushed out by centrifugal force. See also Multi-Stage.

Check Valve - A valve that allows water to flow one way but not the other.

DC Motor, Brush-Type - The traditional DC motor, in which small carbon blocks called "brushes" conduct current into the spinning portion of the motor. They are used in DC surface pumps and also in some DC submersible pumps. Brushes naturally wear down after years of use, and may be easily replaced.

DC Motor, Brushless - High-technology motor used in centrifugal-type DC submersibles. The motor is filled with oil, to keep water out. An electronic system is used to precisely alternate the current, causing the motor to spin.

DC Motor, Permanent Magnet - All DC solar pumps use this type of motor in some form. Being a variable speed motor by nature, reduced voltage (in low sun) produces proportionally reduced speed, and causes no harm to the motor. Contrast: Induction Motor.

Diaphragm Pump - A type of pump in which water is drawn in and forced out of one or more chambers, by a flexible diaphragm. Check valves let water into and out of each chamber.

Driller's Log - The written form on which well characteristics are recorded by the well driller. In most states, drillers are required to register all water wells and to send a copy of the log to a state office. This supplies hydrological data and well performance test results to the public and to the well owner.

Drawdown - Lowering of level of water in a well due to pumping.

Drop Pipe - The pipe that carries water from a pump in a well up to the surface.

Foot Valve - A check valve placed in the water source below a surface pump. It prevents water from flowing back down the pipe and "losing prime." See Check Valve and Priming.

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[6] Courtesy of Dankoff Solar Products, Copyright ©2002 by Dankoff Solar Products, Inc.

Friction Loss - The loss of pressure due to flow of water in pipe. This is determined by 3 factors: pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. It is expressed in PSI or Feet (equivalent additional feet of pumping).

Gravity Flow - The use of gravity to produce pressure and water flow. A storage tank is elevated above the point of use, so that water will flow with no further pumping required. A booster pump may be used to increase pressure. 2.31 Vertical Feet = 1 PSI. See pressure.

Head - See Vertical Lift and Total Dynamic Head. In water distribution, synonym: vertical drop.

Impeller - See Centrifugal Pump.

Induction Motor (AC) - The type of electric motor used in conventional AC water pumps. It requires a high surge of current to start and a stable voltage supply, making it relatively expensive to run from by solar power. See Inverter.

Jet Pump - A surface-mounted centrifugal pump that uses an "ejector" (venturi) device to augment its suction capacity. In a "deep well jet pump" the ejector is down in the well to assist the pump in overcoming the limitations of suction. (Some water is diverted back down the well, causing an increase in energy use.)

Linear Current Booster (LCB) - An electronic device which varies the voltage and current of a PV array to match the needs of an array-direct pump, especially a positive displacement pump. It allows the pump to start and to run under low sun conditions without stalling. Electrical analogy: variable transformer. Mechanical analogy: automatic transmission. Also called pump controller. See Pump Controller.

Multi-Stage Centrifugal - A centrifugal pump with more than one impeller and chamber, stacked in a sequence to produce higher pressure. Conventional AC deep well submersible pumps and higher power solar submersibles work this way.

Open Discharge - The filling of a water vessel that is not sealed to hold pressure. Examples: storage (holding) tank, pond, flood irrigation. Contrast: Pressure Tank.

Perforations - Slits cut into the well casing to allow groundwater to enter. May be located at more than one level, to coincide with water-bearing strata in the earth.

Pitless Adapter - A special pipe fitting that fits on a well casing, below ground. It allows the pipe to pass horizontally through the casing so that no pipe is exposed above ground where it could freeze. The pump may be installed and removed without further need to dig around the casing. This is done by using a 1-inch threaded pipe as a handle.

Positive Displacement Pump - Any mechanism that seals water in a chamber, then forces it out by reducing the volume of the chamber. Examples: piston (including jack), diaphragm, rotary vane. Used for low volume and high lift. Contrast with Centrifugal. Synonyms: volumetric pump, force pump.

Pressure - The amount of force applied by water that is either forced by a pump, or by the gravity. Measured in pounds per square inch (PSI). PSI = vertical lift (or drop) in Feet / 2.31.

Pressure Switch - An electrical switch actuated by the pressure in a pressure tank. When the pressure drops to a low set-point (cut-in) it turns a pump on. At a high point (cut-out) it turns the pump off.

Pressure Tank - A fully enclosed tank with an air space inside. As water is forced in, the air compresses. The stored water may be released after the pump has stopped. Most pressure tanks contain a rubber bladder to capture the air. If so, synonym: captive air tank.

Pressure Tank Precharge - The pressure of compressed air stored in a captive air pressure tank. A reading should be taken with an air pressure gauge (tire gauge) with water pressure at zero. The air pressure is then adjusted to about 3 PSI lower than the cut-in pressure (see Pressure Switch). If precharge is not set properly, the tank will not work to full capacity, and the pump will cycle on and off more frequently.

Priming - The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source. A self-priming pump is able to draw some air suction in order to prime itself, at least in theory. See Foot Valve.

Pulsation Damper - A device that absorbs and releases pulsations in flow produced by a piston or diaphragm pump. It consists of a chamber with air trapped within it.

Pump Controller - An electronic device that controls or process power to an array-direct pump. It may perform any of the following functions: stopping and starting the pump; protection from overload; power conversion or power matching (see Linear Current Booster).

Pump Jack - A deep well piston pump. The piston and cylinder is submerged in the well water and actuated by a rod inside the drop pipe, powered by a motor at the surface. This is an old-fashioned system that is still used for extremely deep wells, including solar pumps as deep as 1000 feet.

Recovery Rate - Rate at which groundwater refills the casing after the level is drawn down. This is the term used to specify the production rate of the well.

Safety Rope - Plastic rope used to secure the pump in case of pipe breakage.

Sealed Piston Pump - See positive displacement pump. This is a type of pump recently developed for solar submersibles. The pistons have a very short stroke, allowing the use of flexible gaskets to seal water out of an oil-filled mechanism.

Self-Priming Pump - See Priming.

Static Water Level - Depth to the water surface in a well under static conditions (not being pumped). May be subject to seasonal changes or lowering due to depletion.

Submergence - Applied to submersible pumps: Distance beneath the static water level, at which a pump is set. Synonym: immersion level.

Submersible Cable - Electrical cable designed for in-well submersion. Conductor sizing is specified in millimeters, or (in USA) by American Wire Gauge (AWG) in which a higher number indicates smaller wire. It is connected to a pump by a cable splice.

Submersible Pump - A motor/pump combination designed to be placed entirely below the water surface.

Suction Lift - Applied to surface pumps: Vertical distance from the surface of the water in the source, to a pump located above surface pump located above. This distance is limited by physics to around 20 feet at sea level (subtract 1 ft. per 1000 ft. altitude) and should be minimized for best results.

Surface Pump - A pump that is not submersible. It must be placed no more than about 20 ft. above the surface of the water in the well. See Priming. (Exception: see Jet Pump.)

Total Dynamic Head - vertical lift + friction loss in piping (see Friction Loss).

Vane Pump - (Rotary Vane) A positive displacement mechanism used in low volume high lift surface pumps and booster pumps. Durable and efficient, but requires cleanly filtered water due to its mechanical precision.

Vertical Lift - The vertical distance that water is pumped. This determines the pressure that the pump pushes against. Total vertical lift = vertical lift from surface of water source up to the discharge in the tank + (in a pressure system) discharge pressure. Synonym: static head. Note: Horizontal distance does NOT add to the vertical lift, except in terms of pipe friction loss. NOR does the volume (weight) of water contained in pipe or tank. Submergence of the pump does NOT add to the vertical lift in the case of a centrifugal type pump. In the case of a positive displacement pump, it may add to the lift somewhat.

Well Seal - Top plate of well casing that provides a sanitary seal and support for the drop pipe and pump. Alternative: See Pitless Adapter.

Wellhead - Top of the well, at ground level.

Appendix 2

Water Pipe Sizing Chart

Water Pipe Sizing Chart

Friction Loss in Plastic Pipe with Standard Inside Diameter (SIDR)

THIS CHART APPLIES ONLY TO: PVC pipe, Schedule 40 (160 PSI) and to PE (polyethylene) pipe with SIDR designation (most common 100 PSI black pipe)

HEAD LOSS in VERTICAL FEET per HUNDRED FEET of pipe or VERTICAL METERS per HUNDRED METERS of pipe

Nominal Pipe Diameter (Inches)

FLOW RATE		1/2 *	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6
GPM	*LPM*	*.662*	*.82*	*1.05*	*1.38*	*1.61*	*2.07*	*2.47*	*3.07*	*4.03*	*5.05*	*6.06*
									actual Inside Diameter (inches)			
1	*3.8*	1.13	0.14	0.05	0.02	.	.	.	.	.	.	.
2	*7.6*	4.16	0.35	0.14	0.05	0.02	.	.	.	.	.	.
3	*11*	8.55	2.19	0.32	0.09	0.05	.	.	.			
4	*15*	14.8	3.70	0.53	0.16	0.09	0.02	.	.			
5	*19*	22.2	5.78	0.81	0.25	0.12	0.04	.	.			
6	*23*	31.0	7.85	1.00	0.35	0.18	0.07	0.02	.			
7	*27*	.	10.6	1.52	0.46	0.23	0.08	0.03	.			
8	*30*	.	13.4	1.94	0.58	0.30	0.09	0.05	.	.	.	.
9	*34*	.	16.9	2.43	0.72	0.37	0.12	0.06	.	.	.	.
10	*38*	.	20.3	2.93	0.88	0.46	0.16	0.07	0.02	.	.	.
11	*42*	.	24.3	3.51	1.04	0.53	0.18	0.08	0.03	.	.	.
12	*46*	.	28.6	4.11	1.22	0.65	0.21	0.09	0.04	.	.	.
14	*53*	.	.	5.47	1.64	0.85	0.28	0.12	0.05	.	.	.
16	*61*	.	.	7.02	2.10	1.09	0.37	0.14	0.06	.	.	.
18	*68*	.	.	8.73	2.61	1.34	0.46	0.18	0.07	.	.	.
20	*76*	.	.	10.6	3.16	1.64	0.55	0.21	0.08	0.02	.	.
22	*83*	.	.	13.3	3.79	1.96	0.67	0.25	0.09	0.03	.	.
24	*91*	.	.	14.9	4.44	2.31	0.79	0.30	0.11	0.04	.	.
26	*99*	.	.	.	5.15	2.66	0.90	0.35	0.14	0.05	.	.
28	*106*	.	.	.	5.91	3.05	1.04	0.42	0.16	0.05	.	.
30	*114*	.	.	.	6.72	3.46	1.18	0.46	0.18	0.06	.	.
35	*133*	↑	.	.	8.94	4.62	1.57	0.62	0.23	0.07	.	.
40	*152*		.	.	11.0	5.91	1.99	0.79	0.30	0.09	0.02	.
45	*171*		.	.	14.2	7.37	2.49	0.97	0.37	0.12	0.04	.
50	*190*		.	.	17.3	8.96	3.03	1.20	0.46	0.14	0.05	.
55	*208*		.	.	.	10.7	3.60	1.43	0.55	0.16	0.06	.
60	*227*		.	.	.	12.5	4.23	1.66	0.65	0.18	0.07	0.02
65	*246*			.	.	14.5	4.90	1.94	0.74	0.22	0.08	0.03
70	*265*			.	.	16.7	5.64	2.22	0.85	0.25	0.09	0.04
75	*284*				.	19.0	6.40	2.52	0.97	0.28	0.10	0.05
80	*303*				.	.	7.21	2.84	1.09	0.32	0.12	0.06
85	*322*				.	.	8.06	3.19	1.22	0.37	0.13	0.07
90	*341*				.	.	8.96	3.53	1.36	0.39	0.14	0.08
95	*360*			.	.	.	9.91	3.90	1.50	0.44	0.16	0.09
100	*379*	.	.	.	.	.	10.9	4.30	1.66	0.49	0.18	0.12
150	*569*	.	.	.	.	.	23.1	9.10	3.51	1.04	0.37	0.16
200	*758*	.	.	.	.	.	.	15.5	5.98	1.76	0.62	0.28

NOTE: Shaded values are at velocities over 5 feet per second and should be selected with caution.

* NOTE: 1/2" data applies to PE pipe only. PVC has smaller ID of .612"

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