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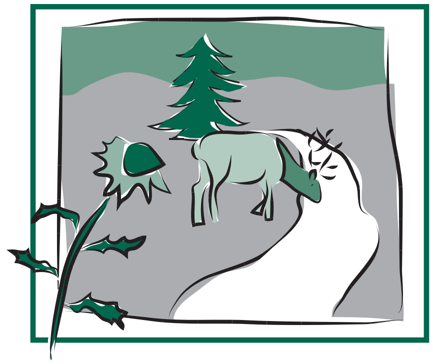

Solar-powered Groundwater Pumping Systems

Fact Sheet No. **6.705** Natural Resources Series | **Water**

by R. Van Pelt, C. Weiner and R. Waskom*

Solar-powered groundwater pumping systems are often considered for use in livestock and other remote watering applications instead of other forms of alternative energy because they are durable, can be mobile, and exhibit long-term economic benefits. Generally, alternative power is considered most feasible when the cost of tapping into the closest public power grid far outweighs the costs of using alternative power. There are several technology alternatives for supplying power, or lift, to groundwater systems including: wind turbines, windmills, generators, and solar arrays. The driving factors for selecting the appropriate technology are regional feasibility, water demand, system efficiencies, and initial and long-term costs. Other factors often include the need for power and water reserves in the form of batteries and livestock tanks.

Feasibility

The selection of solar-powered pumping systems (SPPS) should only follow a thorough look at the feasibility and future prospect of the technology. There are several important steps in this process. Not all of them can be covered here, but the key considerations are mentioned below.

Power Source

The first step is to rule out other sources of power or pumping devices. If the public power grid is reliable and in proximity to the site, preferably less than 1/3 mile, then solar power may be a poor choice. The initial cost of implementing a SPPS can be significantly more than the expense of connecting to the local power grid. The most expensive element of a livestock solar-powered pumping system is usually the photovoltaic modules or panels. Table 1 summarizes the pros and cons associated with different sources of alternative energy for groundwater pumps.

Expectations and Costs

The average daily water consumption for a cow/calf pair in Colorado during the summer is approximately 20 gallons per day. A typical solar-powered system might serve 50 cow/calf pairs. This is a total of 1,000 gallons needed per day. The cost of a system that serves 50 cow/calf pairs can easily reach $10,000. (See Table 4.)

Most economical SPPS will not provide enough water and pressure for the required demand of community indoor plumbing. However, a SPPS is sufficient to meet the indoor plumbing needs of a small building or a remote cabin.

Site Location

The site location plays a major part in the feasibility of a SPPS. Peak sunlight hours (PSH) differ slightly across Colorado. The general rule is that the less PSH available, the more expensive the required photovoltaic (PV) array and pump. System costs increase when more storage is needed to compensate for the limited exposure of the PV array to peak sunlight hours. Most of Colorado has a PSH of between 5.0 and 6.0. Another factor is the climate of the region. Solar-powered systems are not typically designed for extremely cold weather (temperature less than minus 20 degrees C or minus 4 degrees F). However, the systems can be insulated to handle colder temperatures.

The following website shows a PSH map of yearly low peak sunlight hours: www.solar4power.com/map2-global-solar-power.html

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Quick Facts

- Solar-powered pumping systems (SPPS) have been utilized in the United States for over 20 years.
- As photovoltaic (PV) modules become more affordable and the energy efficiency of both the modules and solar-powered pumps increases, SPPS will become a leading technology in remote areas.
- SPPS have proven successful in livestock watering applications throughout the U.S.
- There are some problems involved with SPPS that can be avoided with feasibility analysis and proper installation.

www.ext.colostate.edu

Table 1. Pros and cons of alternative forms of energy for pumps.

	Pros	Cons
Generator	-Moderate initial cost -Easy to install	-High maintenance, expertise required for repair -Short life expectancy (5 years) -Fuel is usually expensive -Long term (10-20 years) annual costs to operate higher than SPSS
Wind Turbine	-Lower initial costs than SPSS -Long life expectancy -Effective at windy sites (avg. wind speed at least 10 mph) -Clean -No fuel needed	-High maintenance needs -Expensive repair -Parts may be difficult to find -Wind can vary seasonally and daily -Lower output in calmer winds
Solar-powered Pumping System (SPSS)	-Easy to install -Can be mounted on trailer to accommodate moving livestock -Reliable long life expectancy (20+ years) -Low maintenance, simple repair if related to solar array -Clean -No fuel needed -Modular system can be closely matched to needs, power easily adaptable to changing demands	-Solar energy can vary seasonally -Higher initial cost -Lower output in cloudy weather

From: "Solar Pumping Systems (SPS) Introductory and Feasibility Guide," Green Empowerment.

System Security

Another important aspect to consider is security. The PV array is one of the most expensive components of the system and it should be protected from theft, vandalism, and livestock. It is strongly recommended that provisions be made to put a small fence around the array. The fence needs to have enough set-back that it does not cast a shadow on the array.

SPPS Components

A solar-powered pumping system has the following minimum components:

1. water well
2. PV array
3. array mounting bracket and rack
4. pump controller
5. electrical ground for controller
6. DC pump with safety ropes, mount, and well seal
7. wiring
8. discharge tubing or piping
9. storage tank
10. tank flotation switch
11. water taps or access points
12. security

The pump should be specifically designed for solar power. It is strongly recommended to purchase the pump controller from the same manufacturer as the pump. Using another manufacturer could cause several unforeseen problems and even invalidate the pump's warranty. If the pump does not contain a built-in check valve, one should be installed to keep the water from flowing back into the well. Very few pumps can handle reverse flow without reducing the life expectancy of the pump. Pumps that are designed to drain during non-operation are meant for extremely cold conditions to keep water from freezing in the lines. The pump should be set no deeper than 2 feet above the bottom of the well to help prevent heavy silt and sand from entering the pump's intake and causing it to seize. The storage tank should be sized to hold at least three days worth of water demand to account for evenings and cloudy days. If the controller is not attached to the array mounting bracket it can be placed in a secure shed or pump house, preferably water tight and dust free.

Well

When installing a new well, it is recommended to contact a licensed water well contractor. If the well is not properly developed prior to installing the solar powered pump it can reduce the life expectancy of the pump. If you are retrofitting a windmill pumping system, the well should be redeveloped before installing a solar powered pump. The goal of redeveloping the well should be to remove biofouling from the sidewalls and sediments from the bottom of the well.

Pump

Pumps designed specifically for solar power utilize direct current (DC) and tend to be very efficient, but they usually cost more than a comparably sized alternating current (AC) pump. Surface mounted pumps can be used for a SPPS but are discouraged because of their limitations when used in deep wells. Based on the specifications from several manufactures, the typical lift abilities for surface pumps designed for solar power are between 10 and 20 feet. Surface pumps also have greater exposure to the climate making them more vulnerable to freezing weather.

Several of the more common submersible solar-powered pump

Sustainability of System

The long-term costs and ability of the SPPS to adapt to changing demands should be implemented into the feasibility of the system. Photovoltaic modules should last 20 to 25 years. This depends on it being maintained (kept clean and securely mounted) and protected from strong winds, lightning and hail storms, and falling objects such as tree branches. The solar pumps should last about 10 years. The other electronics and controls should be designed to last at least 10 years with little electrical maintenance. The overall lifetime of the complete system should be designed and maintained to last 25 years taking into account future demands of the livestock tank. Inspect the system at least once per week checking the pumping rate, operation of controller, condition of PV modules, tanks, wires, and pipes (for leaks/corrosion).

manufacturers are listed in Table 2. This table also indicates general operating parameters for selecting a pump. If using this table, pay particular attention to the footnotes.

The size of the pump will depend on several factors including: available water supply, available power, available storage, total dynamic head (TDH), diameter of well, and water need. Assume that the pump will only be operating during peak sunlight hours. Try to install the most efficient and simplest system that meets the project demands.

It is important to determine the total dynamic head. For a SPPS, total dynamic head can be referred to as the head pressure required to overcome the sum of the static lift of the water, the static height of the livestock tank, and the frictional losses in the pipe network. Use the following calculation to determine the TDH of the pump needed:

TDH = (depth from static water table to top of well + drawdown at sustainable or desired pumping rate + elevation difference from top of well to top of storage tank) x 1.1

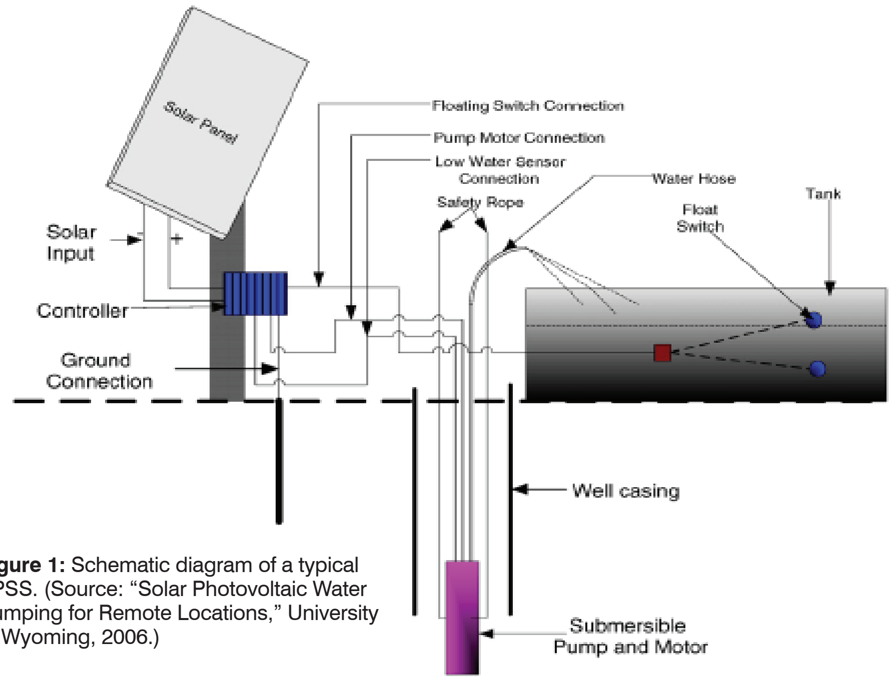

Figure 1: Schematic diagram of a typical SPSS. (Source: "Solar Photovoltaic Water Pumping for Remote Locations," University of Wyoming, 2006.)

An estimate of the required flow rate of the pump can be determined by the following equation:

$$\text{Flow Rate (gpm)} = \frac{\text{demand in gpd}}{\text{PSH per day}} \times \frac{\text{hr}}{60\text{ min}}$$

PSH = Peak Sunlight Hours

Table 2. Manufacturers of submersible solar-powered pumps.

Brand	Model/Series	Diameter (inches)	Power Requirements/Ranges: Voltage Range (volts)	Power (watts)	Max. Current (amps)	Max Lift (feet)	Max Capacity (gpm)	Websites
Divwatt	Solastar-3B	Con-D	34-85 DC	1200	12	656	6.0	www.divwatt.co.za
Fluixnos	Solaflux	3.9	20-70 DC	20-300	~4	492	4.2	www.fluxinos.it
Lorentz	PS150, PS1800 PS200, PS600, PS1200	3.8/3.9 3.9	12-50 DC 24-48 DC	450/1400 1200	~12.5 Con-D	39-197 165-760	21.7-72.0 10-45	www.lorentzpumps.com
Grundfos	16SQF-10, 25SQF-3, 25SQF-6 40SQF-3, 40SQF-5, 60SQF-3, 75SQF-3	3.9	30-300 DC or 90-240 AC	1400	Con-D	50-100	25-75	www.grundfos.com
Grundfos	3SQF-2, 3SQF-3, 6SQF-2, 11SQF-2	2.9	30-300 DC or 90-240 AC	900	Con-D	325-525	3.0-11	www.grundfos.com
Kyocera	SD-Series SC-Series 500 and 1000	3.8-4.6 3.8	12-30 DC 60-120 DC	20-140 140-1000	10 14	100-230 98.4 - 525	2.4-4.5 3.7-43	www.kyocerasolar.com
Solarjack	SDS Series - no longer made SDS Series - no longer made	3.8-4 ~4	12-24 DC 30-180 DC	Con-D 140-2880	Con-D Con-D	Con-D 800	Con-D 50.0	www.goldengenesis.com
Shurflo	9300	3.8	24 DC	155	4.6	230	2.0	www.shurflo.com
Sun Pumps	SDS-Series SCS-Series (1/2 to 2 HP motors)	3.8-4.5 3.9-4.0	12-30 DC 30-180 DC	95-184 320-2070	6 7.1 - 11.5	115-230 30-65	1.3-5.0 4.0-70	www.sunpumps.com
NAPS	SP-Series 400 and 1500	Con-D	[2] 45-90 DC	150-1600	Con-D	43-656	0.64-30.1	www.napssystems.com

NOTES: Not all manufacturers of solar powered pumps are listed. Where possible from Internet resources, all listed specifications are from manufacturers and not the distributors. The operational ranges for most of the pumps listed were based on tests performed with 6kWh/m^2/day of solar irradiance. Lorentz pump specifications were between 5.2 and 7.0 kWh/m^2/day. Actual flow rate depends on perfect sunlight hours at installation site. The listed wattage is based on the performance ranges of the pump, but because of inefficiencies in solar energy conversion it is recommended that the solar modules be sized with a factor of at least 1.25 X the pump demands. Manufacturers only have distributors in certain regions of the world. Before deciding on a solar powered pump make sure your region is served, or it is economical to ship the pump there.

(The desired pumping rate should not be greater than the sustained well yield.)

The next step is to take the well diameter, TDH, and desired flow rate and refer to Table 2, or other manufacturers not listed, to determine what type of pump will fulfill the system needs.

Table 3. Types of PV cells and their efficiency.

Type of Cell	Efficiency Range	Comments
Monocrystalline	14 to 16%	Highest price, affected by temperature
Polycrystalline	12 to 14%	Medium price, affected by temperature
Amorphous Silicon	8 to 9%	Medium to low price, not affected by temperature

Source: Research Institute for Sustainable Energy, Murdoch, Western Australia

Table 4. Estimated cost for 1,000 gal/day SPPS.

Item	Amt	Cost/ Amount* (U.S. $)	Cost (U.S. $)
TDH (ft.)	90	—	—
Pumping Rate (gpm)	3.5	—	—
Pump DC Demand (W)	160	—	—
Peak Sunlight Hours	5.5	—	—
Required PV Array (W)	200	$4	$800
Fixed Mount w/Rack (per module)	1	$75	$75
Grundfos 6 SQF-2 Helical Rotor Pump	1	$1,500	$1,500
Grundfos CU 200 Pump Controller	1	$300	$300
Pump Shut-off Switches & Misc.	1	$500	$500
Wiring (ft.)	100	$1.50	$150
Piping (ft.)	120	$1.25	$150
Installation of SPPS (not including well or storage tank)	1	$1,000	$1,000
Well (ft.)	75	$25	$1,875
Storage Tank for 3 days demand (gal)	3000	$1.50	$4,500
Total cost			**$10,850**

*costs verified September 2007.

PV Array & Photovoltaic Cells

Solar power comes from photovoltaic (PV) cells that convert the sun's energy into usable DC electricity. A module consists of PV cells and an array consists of several modules. PV cells are primarily made from silicon and come in three different types: monocrystalline, polycrystalline (multicrystalline), and amorphous. Figure 2 shows the three types of PV configurations.

The efficiency of the PV module relates to the area of active cells exposed to the sunlight. Monocrystalline are the most efficient, converting approximately 15 percent of the sun's energy to electricity, but they are also the most expensive of the three. Photovoltaic modules have typical warranties of 20 to 25 years, with life expectancies approaching 30 years. Table 3 compares the differences between the three main types of PV cells.

A factor of 1.25 times the pump wattage requirements is often used to determine the preliminary size of the required array. This accounts for the energy losses in the modules and controller. If batteries and a regulator are added into the system, the PV array demand will be higher. The PV array needs to be mounted securely to a tilted rack that is fixed to the ground. If the modules are fixed, the orientation of the tilt is to the south and should be equal to the site latitude. If they are on an adjustable mount, the tilt should be the latitude minus 10 to 15 degrees in the summer and the latitude plus 10 to 15 degrees in the winter.

Pump Controller

The pump controller is a highly specialized item and can vary significantly between manufacturers. A technical term for a pump controller is a 'linear current booster.' The purpose of the pump controller is to regulate and match the flow of DC electricity to the needs of the pump. The pump controller contains the recognition components for the storage tank flotation switch and the low-well switch. The controller should last approximately 10 years.

Additional Components

There can be several additional components to a SPPS that will enhance the performance of the system or add backup energy reserves.

1. **Tank:** If a new livestock tank is being built for the system, it is recommended to design it with a volume sufficient for three days worth of average demand. This is primarily to compensate for nights and cloudy days, especially when other power backup systems are not used. Make sure the internal velocities and pressures are appropriate for the pipe material and desired flow rates.

2. **Trailer Mounting:** A significant advantage of using a solar powered pumping system for livestock watering applications is it can be mobile. The PV array can be mounted on a trailer and set up on-site with the appropriate tilt for the panels. Due to how rough ranch roads tend to be, it is strongly recommended that the PV array be taken off of the rack and secured between layers of high-grade protective padding to keep them from being damaged during transit. If a quality solar-powered pump is purchased it can also be pulled from the old well and secured at the new location along with the PV array. A properly designed mobile

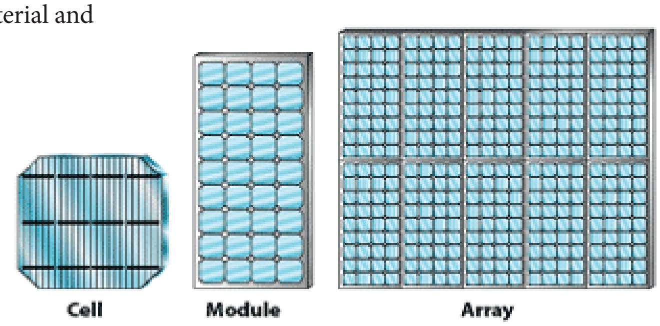

Figure 2: Types of PV modules. (Source: Guide to Solar-Powered Water Pumping Systems in New York State. New York State Energy Research and Development Authority.)

system can provide a substantial cost savings when cattle are moved several times a year to areas in proximity of an accessible well and livestock tank.

3. **Batteries:** Deep-cycle batteries are often used as a power backup. They are recharged during the day through the PV array and drained at night or during cloudy days. The most common battery is lead-acid, which can be trickle charged indefinitely once they reach full charge. The pump controller is usually installed after the batteries. The addition of batteries requires a charge regulator between the batteries and the PV array. The charge regulator needs to monitor the battery voltage to prevent over-charging because the DC solar energy fluctuates throughout the day. It is also recommended to install blocking diodes before the charge regulator. A diode in the system should prevent the PV array from draining the batteries in low light conditions. If adequate water storage is available the batteries are not necessary.

4. **Wind Turbine:** Wind turbines can be a very cost effective backup to solar power in areas with average wind speeds above 10 mph. Usually wind turbines are low maintenance and tend to perform best during the winter and spring.

5. **Generator:** If sufficient water storage is not available, some systems may need a backup generator to run the pump during low sunlight periods. If a generator is used with a DC pump, an inverter is usually required. However, generators are directly compatible with some pumps like the Grundfos SQ Flex pumps. Grundfos recommends an interface controller when using a generator to automatically switch back to solar power when it is available (See Table 2).

6. **Solar Tracking System:** A solar tracking device can be added to the PV array to increase the power yield. Tracking systems are often sold by the manufacturers of PV modules. Trackers are attached to the mounting bracket and control the degree to which the array is tilted towards the sun. They can either be controlled passively (sun's heat exposure) or electronically through part of the converted energy from the PV array. Passive trackers contain liquid (often Freon) that when heated from the sun moves from one cylinder to another causing the rack to tilt more into the sun. Tracking devices have been reported to increase the daily energy yield up to 40 percent at certain latitudes. They can also add approximately 25 percent of additional maintenance costs and increase initial costs by 50%.

7. **Weather Insulation:** Weather proofing and insulation should be added for extremely harsh environments, especially in areas where temperatures reach minus 20 degrees C (minus 4 degrees F).

8. **Low Well Switch:** In low yield wells, where the drawdown of the well exceeds the pumping capacity, the addition of a shutoff switch is needed to keep the pump from running dry. Some pumps advertise they can run dry without damage to the pump, but allowing any pump to continually run dry is a bad idea. Ideally, the pump should shut off when the water level gets within 2 feet of the pump's intake to reduce air intake and turbulence. Some pumps come pre-installed with a safety shut-off switch.

9. **Sand Shroud:** A sand shroud may be needed around the intake zone of the pump. Sand shrouds are recommended for use in wells that have high sediment loads or that were not properly installed. They are particularly recommended in open boreholes which are not screened through the saturated zone of the well. The pump manufacturer can usually provide a compatible sand shroud.

Example SPPS Sizing Calculation

The following example is given based on a Grundfos 6 SQF-2 helical rotor pump and an average sized system for livestock applications. General costs and multiplier values are preliminary estimates taken from the Green Empowerment Feasibility Guide. The listed cost of the pump and controller is a conservative price based on the suggested retail price and the price taken from various online distributors of Grundfos pumps:

Assuming no reserve battery systems and 3 days worth of demand water storage, the SPPS is designed for up to 50 cow/calf pairs at a TDH of 90 feet. The site is located in northeastern Colorado with 4.75 hours a day of peak sunlight.

Calculate estimate of demand: 50 cow/calf pairs x 20 gpd/pair = 1,000 gpd

Calculate preliminary estimate for required flow rate:

$$\text{Flow Rate (gpm)} = \frac{\text{demand in gpd}}{\text{PSH per day}} \times \frac{\text{hr}}{60\text{ min}} = \frac{1{,}000}{4.75} \times \frac{\text{hr}}{60\text{ min}} = 3.51$$

Using Table 2, a Grundfos 6 SQF-2 pump curve matches the flow and head parameters well. At 90 feet of TDH and 3.5 gpm, the pump needs 160 watts of power being delivered directly to the pump. The efficiency losses of energy in the PV modules and other electronics require an array capable of producing approximately 200W or 1.25X the pump requirement. A cost of $4/W for PV module energy output is used which is about the mid cost reported. The pump curve for a Grundfos 6 SQF-2 is shown in Table 4. The total estimated cost of this system is approximately $10,000. Other assumptions and details are also shown in Table 4.

For More Information

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