PRACTICAL ACTION
Technology challenging poverty

technical brief

SOLAR (PHOTOVOLTAIC) WATER PUMPING

Introduction
Water pumping has a long history; so many methods have been developed to pump water. People have used a variety of power sources, namely human energy, animal power, hydro power, wind, solar and fuels such as diesel for small generators. The most common pumps used in remote communities are:

- Hand pumps
- Direct drive diesel driven borehole pumps
- Electric submersible pumps with diesel generator
- Solar submersible pumps

The relative merits of the various pumping methods are laid out in Table 1 below.

	Advantages	Disadvantages
Hand pumps Link	• local manufacture is possible • easy to maintain • low capital cost • no fuel costs	• loss of human productivity • often an inefficient use of boreholes • low flow rates
Animal driven pumps	• more powerful than humans • lower wages than human power • dung may be used for cooking fuel	• animals require feeding all year round • often diverted to other activities at crucial irrigation periods
Hydraulic pumps (e.g. rams) Link	• unattended operation • no fuel costs • easy to maintain • low cost • long life • high reliability	• require specific site conditions • low output
Wind pumps Link	• unattended operation • easy maintenance • long life • suited to local manufacture • no fuel requirements	• water storage is required for low wind periods • high system design and project planning needs • not easy to install
Solar PV	• unattended operation • no fuel costs • low maintenance • easy installation • long life (20 year)	• high capital costs • water storage is required for cloudy periods • repairs often require skilled technicians
Diesel and gasoline pumps	• quick and easy to install • low capital costs • widely used • can be portable	• fuel supplies erratic and expensive • high maintenance costs • short life expectancy • noise and fume pollution

Table 1: Comparison of pumping techniques.

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Applications

Solar pumps are used principally for three applications:

- village water supply
- livestock watering
- irrigation

A solar pump for village water supply is shown schematically in Figure 1. The Village will have a constant water demand although there is need to store water for periods of low insolation (low solar radiation). In environments where rainy seasons occur some of this demand can be met by rainwater harvesting during the rainy season.

Ideally in Sahelian Africa the storage would be 3-5 days of water demand. In practice some installed tanks do not have sufficient capacity and are smaller than a days demand leaving the

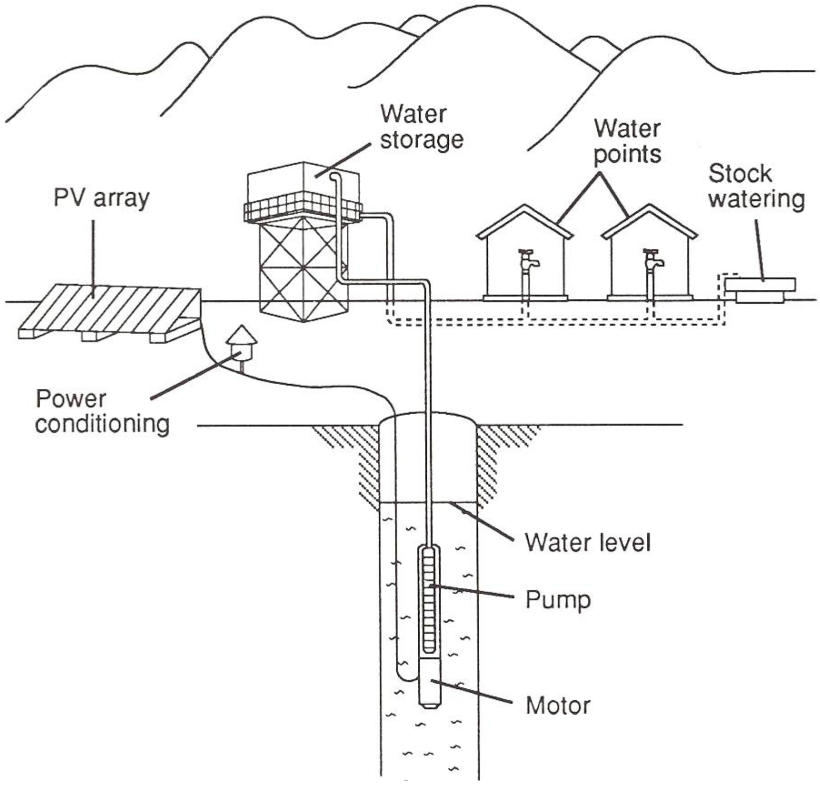

Figure 1: Village water supply. Illustration: Practical Action.

tank empty at the end of the day. This is due to a mismatch between the sizing, pump capacity and the demand profile during the day.

The main applications for solar water pumping are for livestock watering in the USA and Australia. In Africa the systems are used for village water systems and livestock watering. While applications of solar water pumping for irrigation are on the increase especially in India and China.

A solar irrigation system (Figure 2) needs to take account of the fact that demand for irrigation water will vary throughout the year. Peak demand during the irrigation seasons is often more than twice the average demand. This means that solar pumps for irrigation can be under-utilised for most of the year although there can be a reduction in strength of the sun during these times reducing supply side of the equation.

Attention should be paid to the system of water distribution and application to the crops. The system should minimise water losses, without imposing significant additional head on the pumping system and be of low cost.

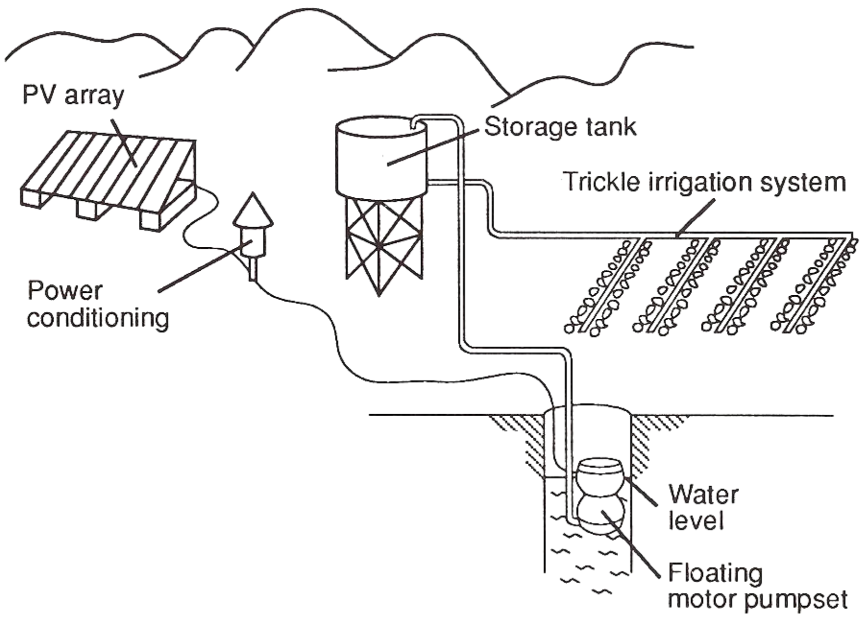

Figure 2: Solar irrigation system. Illustration: Practical Action.

The suitability of major irrigation systems for use with solar pumps is shown in Table 2.

Distribution method	Typical application efficiency	Typical head	Suitability for use With solar pumps
Open Channels	50-60%	0.5-1m	Yes
Sprinkler	70%	10-20m	No
Trickle/drip	85%	1-2m	Yes
Flood	40-50%	0.5m	No

Table 2: Suitability of major irrigation methods for use with solar pumps.

The technology

Photovoltaic pumps are made up of a number of components. There is a photovoltaic array which converts solar energy directly into electricity as DC. The pump will have an electric motor to drive it.. The characteristics of these components need to be matched to get the best performance. The pump motor unit will have its own optimum speed and load depending on the type and size of the pump.

Motor

This can be DC or AC. If an AC motor is used then an inverter is also needed. AC motors are more widely available.

Inverters have become cheap and efficient and solar pumping systems use special electronically controlled variable-frequency inverters which will optimise matching between the panel and the pump. A typical AC system would also need batteries which require maintenance and add to the cost as the system is less efficient and would need a larger array.

The most efficient type of DC motor is a permanent magnet motor. DC motors may have carbon brushes which replacing when they wear out, If a brushed dc motor is used then the equipment will need to be pulled up from the well (approximately every 2 years) to replace brushes.

Brushless designs of DC motors exist where electrical circuits are used instead of commentators and brushes. These are becoming popular in solar pumping systems.

Brushless dc motors would require electronic commutation.

Solar panels
The basic principles of solar photovoltaic panels are explained in the Practical Action Technical Brief *Solar Photovoltaic Energy*.

Some models use a GPS sensor to provide latitude, longitude and time data to enable the controller to calculate the position of the sun and position the solar array.

The pump
Pump options and the system configuration are described below

Submersible pumps
Often with electronic load controllers; the pump will be submerged while the load controller is above ground.

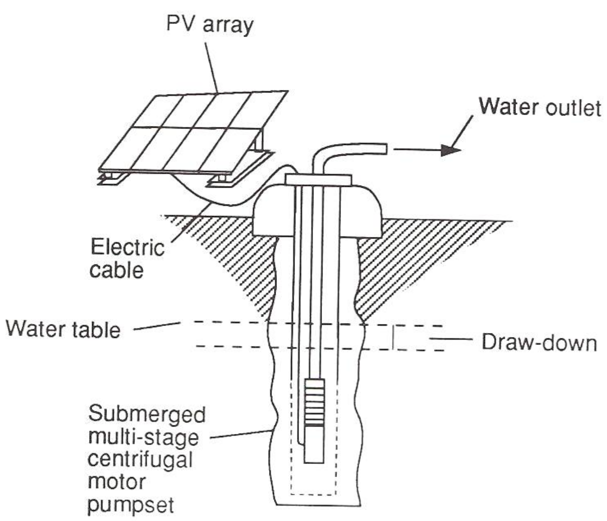

Figure 3: Submerged multistage centrifugal motor pumpset. Illustration: Practical Action.

The advantages of this configuration are that it is easy to install, often with lay-flat flexible pipework and the motor pumpset is submerged away from potential damage.

Multistage centrifugal pumps
The centrifugal pump will start at low torque and can be matched with the solar array without electronic controllers. The pumps are not as efficient as positive displacement pumps using cheap electronic load controllers.

Suitable for smaller heads. Older type set with AC motors operate at heads of 10-25 m.

Positive displacement helical pumps
Helical pumps have the best efficiency and the smallest PV panel for the same specs of water delivery volume pressure and head. They have low rotational speed. The pump is made up of a metal helical rotor which rotates in a rubber casing. Suitable for bigger heads.

A Mono solar pump will slow down when it is cloudy, but because it has no minimum speed (unlike a centrifugal pump) it will keep delivering water.

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Submerged pump with surface mounted motor
The main advantage is the easy access to the motor for maintenance.

The low efficiency from power losses in the shaft bearings and the high cost of installation have been its main disadvantages. In general this configuration is largely being replaced by the submersible motor and pumpset.

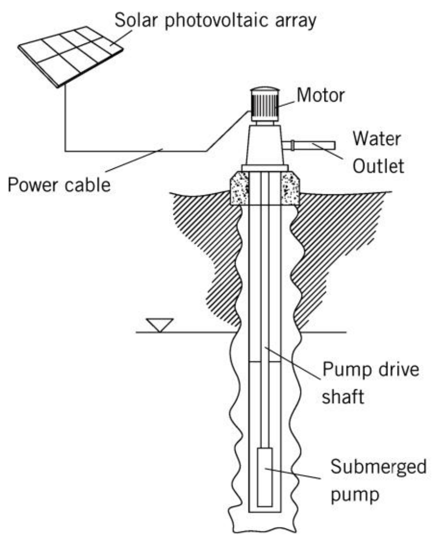

Figure 4: Submerged pump with surface mounted motor.
Illustration: Practical Action / Neil Noble.

Floating motor pump sets
The versatility of the floating unit set makes it ideal for irrigation pumping for canals and open wells. The pumpset is easily portable and there is a negligible chance of the pump running dry.

Most of these types use a single stage submersed centrifugal pump. The most common type has a brushless dc motor. Often the solar array support incorporates a handle or 'wheel barrow' type trolley to enable transportation.

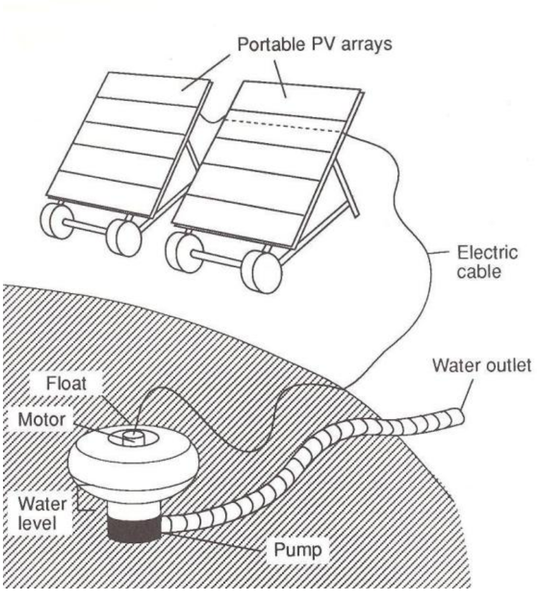

Figure 5: Floating motor pump.
Illustration: Practical Action.

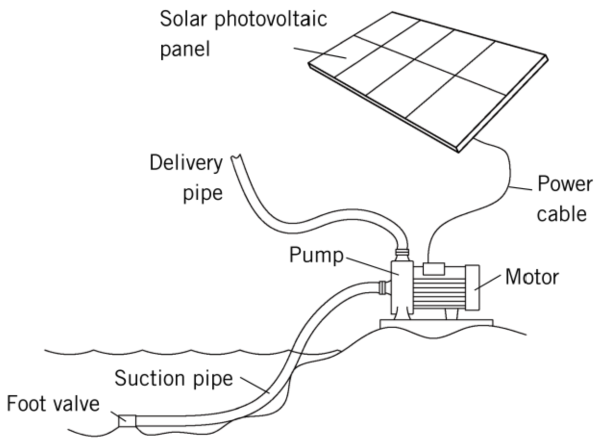

Figure 6: Suction pumpsets.
Illustration: Practical Action / Neil Noble.

Surface suction pumpsets
This type of pumpset is also suitable for low head applications. It is not recommended except where an operator will always be in attendance for maintenance and security of exposed systems.

Although the use of primary chambers and non-return valves can prevent loss of prime, in practice self-start and priming problems are experienced. It is impossible to have suction heads of more than 8 metres.

Less common types of solar powered pumps include solar PV powered reciprocating piston (nodding donkey) pumps and solar thermal pumps or thermosyphones pumps exits but are not commercially used.

Performance

Solar pumps are available to pump from anywhere in the range of up to 200 m head and with outputs of up to 250 m³/day.

Solar pumping technology continues to improve. In the early 1980s the typical solar energy to hydraulic (pumped water) energy efficiency was around 2% with the photovoltaic array being 6-8% efficient and the motor pumpset typically 25% efficient. Today, an efficient solar pump might have an average daily solar energy to hydraulic efficiency of more than 9% but lower efficiencies of 2 - 3% are still common.

It is important to get the most efficient pump available as the difference in cost between the poor pump and a very efficient pump is much less that the additional cost required for a larger PV panel. Accurate sizing of the array is important in keeping costs down.

A good sub-system (that is the motor, pump and any power conditioning) should have an electrical to hydraulic efficiency of around 70% using positive displacement pumps. With diaphragm pumps the efficiency will be around 45% and centrifugal pumps might have an efficiency of 20%.

Procurement

Assessing requirements

The output of a solar pumping system is very dependent on good system design derived from accurate site and demand data. It is therefore essential that accurate assumptions are made regarding water demand/pattern of use and water availability including well yield and expected drawdown.

Domestic water use per capita tends to vary greatly depending on availability. The long-term aim is to provide people with water in sufficient quantities to meet all requirements for drinking, washing and sanitation. WHO guidelines aim for a per capita provision of 40 to 50 litres per day for domestic use only, thus a village of 500 people has a requirement of 20 cubic metres per day. Most villages have a need for combined domestic and livestock watering which will require much greater amounts of water.

Irrigation requirements depend upon crop water requirements, effective groundwater contributions and efficiency of the distribution and field application system.

Irrigation requirements can be determined by consultation with local experts and agronomists or by reference to FAO document: Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, Richard G. Allen, Luis S. Pereira, Dirk Raes, Martin Smith http://www2.webng.com/bahirdarab/Evapotranspiration.pdf

Also see

- *Micro-Irrigation* Practical Action Technical Brief
- *Modern Irrigation Technologies for Smallholders in Developing Countries*
- *Operation and Maintenance of Small Irrigation Schemes*
- *Small-scale Irrigation*

Assessing water availability

Several water source parameters need to be taken into account and where possible measured. These are the depth of the water source below ground level, the height of the storage tank or water outlet point above ground level and seasonal variations in water level. The drawdown or drop in water level after pumping has commenced also needs to be considered for well and borehole supplies. This will depend on the ratio between pumping rate and the rate of refill of the water source, and should be measured and/or provided by those who drill the borehole. In addition, there is usually a seasonal variation in the water level, and a long term trend in the water table level dropping.

The pattern of water use should also be considered in relation to system design and storage requirements. Water supply systems should include sufficient covered water storage to provide for daily water requirements and short periods of cloudy weather. Generally, two to five days water demand is stored.

Sizing solar pumps

The hydraulic energy required (kWh/day)

= volume required (m^3/day) x head (m) x water density x gravity / (3.6×10^6)
= 0.002725 x volume (m^3/day) x head (m)

The solar array power required (kWp) =

$$\frac{\text{Hydraulic energy required (kWh/day)}}{\text{Av. daily solar irradiation (kWh/m}^2\text{/day} \times F \times E)}$$

where F = array mismatch factor = 0.80 on average (a safety factor for real panel performance in hot sun and after 10-20 years)
and E = daily subsystem efficiency = 0.25 - 0.40 typically

Economics

In general photovoltaic pumps are economic compared to diesel pumps up to approximately 3 kWp for village water supply and to around 1 kWp for irrigation.

Links and further reading

- *Solar Water Pumping Guide* (63 pages - 4Mb pdf file) Green Empowerment
  This step-by-step guide was developed to step NGOs through the technical and community feasibility, initial design and budgeting aspects of solar water pumping projects. You can download the document below.
- *Solar Energy for Rural Communities: The Case of Namibia*
  Yaron, Gil; Forbes, Tani and Jansson, Sven, Practical Action Publishing
- *Solar Water Pumping: A Handbook* Jeff Kenna and Bill Gillett, Practical Action Publishing
- *Water Lifting Devices: A Handbook Third Edition*
  Peter Fraenkel and Jeremy Thake, Practical Action Publishing
- *Practical Guide to Solar Photovoltaic Systems for Technicians: Sizing, installation and maintenance* Louineau, Jean-Paul, Practical Action Publishing
- *Electricity Services in Remote Rural Communities: The Small Enterprise Model*
  Sanchez Teodoro, Practical Action Publishing
- *A Cost and Reliability Comparison Between Solar and Diesel Powered Pumps*
  Solar Electric Light Fund (SELF), 2008
- *Theft prevention measures for PV systems* Emcon Consulting Group, Namibia

Useful addresses

Green Empowerment
140 SW Yamhill
Portland, Oregon 97204
USA
Tel: (503) 284-5774
Fax: (503) 460-0450
E-mail: info@greenempowerment.org
Web: www.greenempowerment.org

Lifewater International
2840 Main Street, Morro Bay, CA 93442
Mailing address: PO Box 3131, San Luis Obispo, CA 93403, USA
Tel: +1 805 772 0600, +1 888 543 3426
Fax: +1 805 772 0606
E-mail: info@lifewater.org
Web: http://www.lifewater.org/

Suppliers

The most suitable suppler will depend on the part of the world in which the pump is to installed. Information on equipment suppliers can be found on the following websites.

- http://energy.sourceguides.com/
- http://www.ecobusinesslinks.com/solar_energy_solar_power_panels.htm

Below is a sample list of suppliers and does not imply endorsement by Practical Action.

True Energy Group
Pendre Enterprise Park
Tywyn Gwynedd Wales
LL36 9LW
United Kingdom
Tel: +44 (0) 1654 712 713
Fax: +44 (0) 1654 710 641
http://www.trueenergy.com/
Professional renewable energy products and solutions suppliers. International experience on solar water pumping.

African Energy
237 S. Miller Lane, P.O. Box 664, Saint David, Arizona
USA, 85630
Tel: 1 520 720 9475
Fax: 1 520 720 9527
E-mail: info@africaenergy.com
Web: http://www.africanenergy.com
African Energy is a specialized distributor of solar electric and power back-up equipment focusing exclusively on the African market, including solar water pumping systems.

Tata BP Solar India Ltd
78, Electronics City
Hosur Road
Bangalore 560 100
India
Tel: 6660 1300, 4070 2000, 4070 3000
Fax: 080-2852 0116
E-mail: tatabp@tatabp.com
Web: http://www.tatabpsolar.com/#
A wide range of solar products including solar water pumping.

Tenesol
Z.A.C. de la Tour, 12-14 allée du Levant
69890 La Tour de Salvagny, France
Tel: +33 (0)4 78 48 88 50
Fax: +33 (0)4 78 19 44 83
E-mail: standard@tenesol.com
Web: http://www.tenesol.com/en/

Mono Pumps (Australia) Pty. Limited,
338-348 Lower Dandenong Road,
Mordialloc 3195,
Victoria,
Australia
Web:
http://www.monopumps.com.au/en-au/solar-products
Solar powered water pumping equipment with helical pump.

Davis & Shirtliff Limited
Industrial Area, Dundori Road,
P.O. Box: 41762-00100,
Nairobi, Kenya.
Tel: +254 020 6968 000 / 020-558335
E-mail: sales@dayliff.com
Web: http://www.dayliff.com/
Solar water pumping equipment suppliers

Grundfos International A/S
Poul Due Jensens Vej
7,Bjerroingbo, DK-8850 Denmark
Tel: +45 86 68 1400
Fax: +45 86 68 0468
Web: www.grundfos.com
Solar and wind powered water pumping hybrids – SQFlex.

Solar Water Pumping was revamped in 2010 based on information provided by Michel Maupoux, of Green Empowerment, who has installed solar water pumps in Nicaragua and the Philippines. Last updated May 2012.

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