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 with a minimum of effort. These have utilised a variety of power sources, namely human energy, animal power, hydro power, wind, solar and fossil fuels for small generators. The relative merits of these are laid out in Table 1 below.

	Advantages	Disadvantages
Hand pumps	• local manufacture is possible • easy to maintain • low capital cost • no fuel costs	• loss of human productivity • often an inefficient use of boreholes • only low flow rates are achievable
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)	• unattended operation • easy to maintain • low cost • long life • high reliability	• require specific site conditions • low output
Wind pumps	• 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 • low maintenance • easy installation • long life	• 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.With village water supply, a constant water demand throughout the year occurs, although there is need to store water for periods of low insolation (low solar radiation). Typically in Sahelian Africa the storage would be 3-5 days of water demand. In environments where rainy seasons occur, rainwater harvesting can offset the reduced output of the solar pump during this period. The majority of the 6000 or more solar pumping systems installed to date are for village water supply or livestock watering.

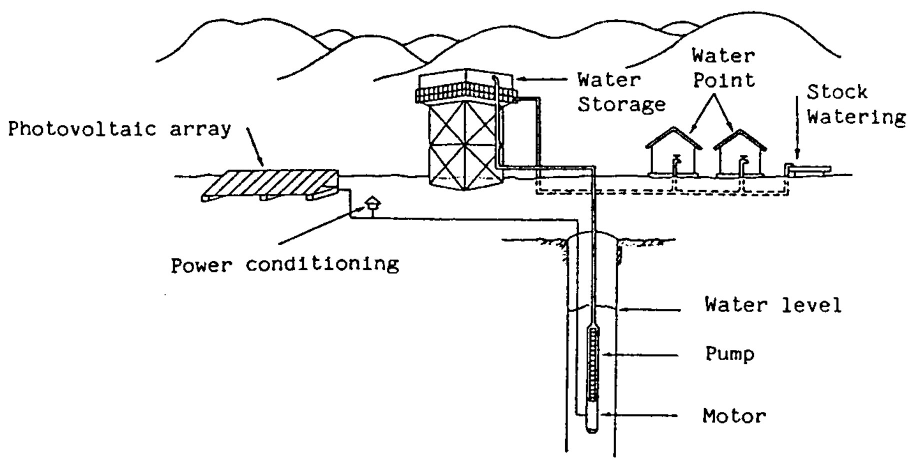

Figure 1: Village water supply

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 are under-utilised for most of the year. 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.

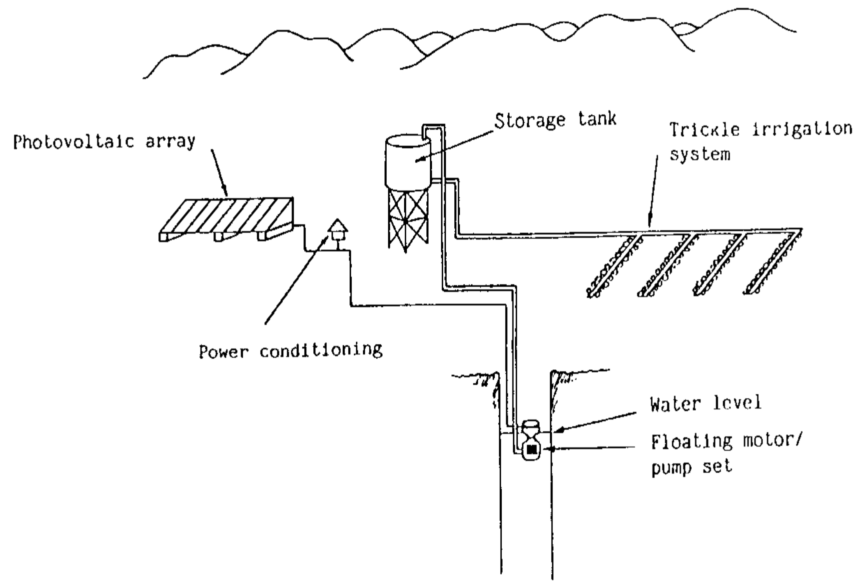

Figure 2: Solar irrigation system

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

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The technology

Systems are broadly configured into 5 types as described below:

Submerged multistage centrifugal motor pumpset - Figure 3

This type is probably the most common type of solar pump used for village water supply. 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.

Either ac or dc motors can be incorporated into the pumpset although an inverter would be needed for ac systems. 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 dc motors would require electronic commutation. The most commonly employed system consists of an ac pump and inverter with a photovoltaic array of less than 1500Wp.

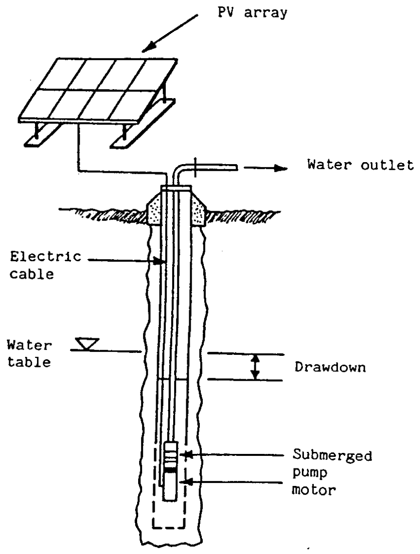

Figure 3: Submerged multistage centrifugal motor pumpset

Submerged pump with surface mounted motor - Figure 4

This configuration was widely installed with turbine pumps in the Sahelian West Africa during the 1970s. It gives easy access to the motor for brush changing and other maintenance.

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

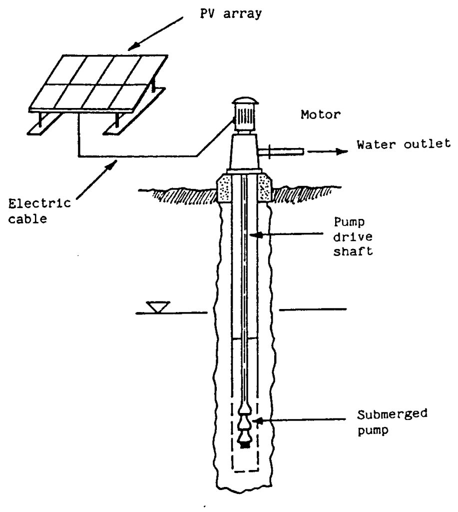

Figure 4: Submerged pump with surface mounted motor

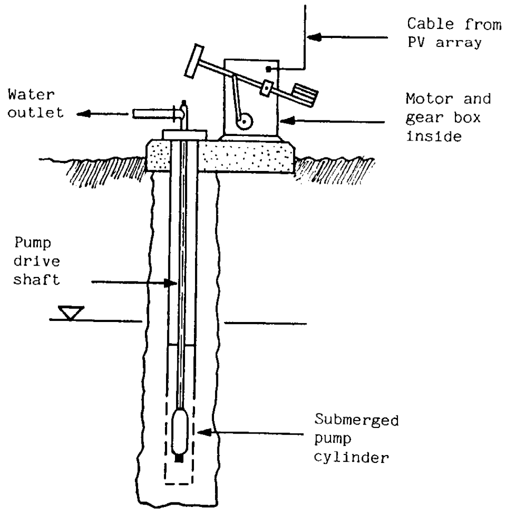

Figure 6: Reciprocating positive displacement pump

Reciprocating positive displacement pump - Figure 5

The reciprocating positive displacement pump (often known as the jack or nodding donkey) is very suitable for high head, low flow applications.

The output is proportional to the speed of the pump. At high heads the frictional forces are low compared to the hydrostatic forces often making positive displacement pumps more efficient than centrifugal pumps for this situation.

Reciprocating positive displacement pumps create a cyclic load on the motor which, for efficient operation, needs to be balanced. Hence, the above ground components of the solar pump are often heavy and robust, and power controllers for impedance matching often used.

Floating motor pump sets - Figure 6

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.

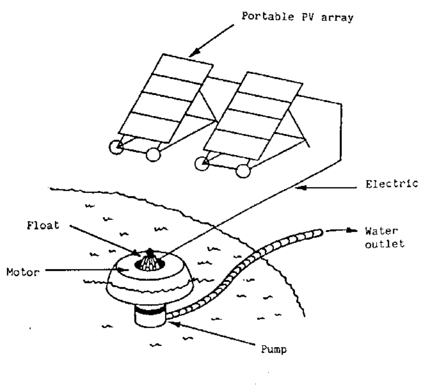

Figure 5: Floating motor pump

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

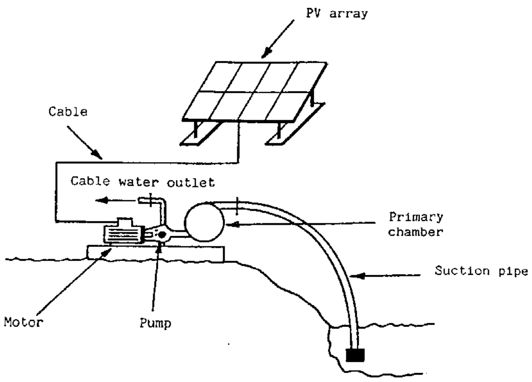

Figure 7: Suction pumpsets

Surface suction pumpsets - Figure 7

This type of pumpset is not recommended except where an operator will always be in attendance. 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 impractical to have suction heads of more than 8 metres.

Performance

The performances of some commercially available products are shown in Figure 8. Solar pumps are available to pump from anywhere in the range of up to 200m head and with outputs of up to 250m³/day.

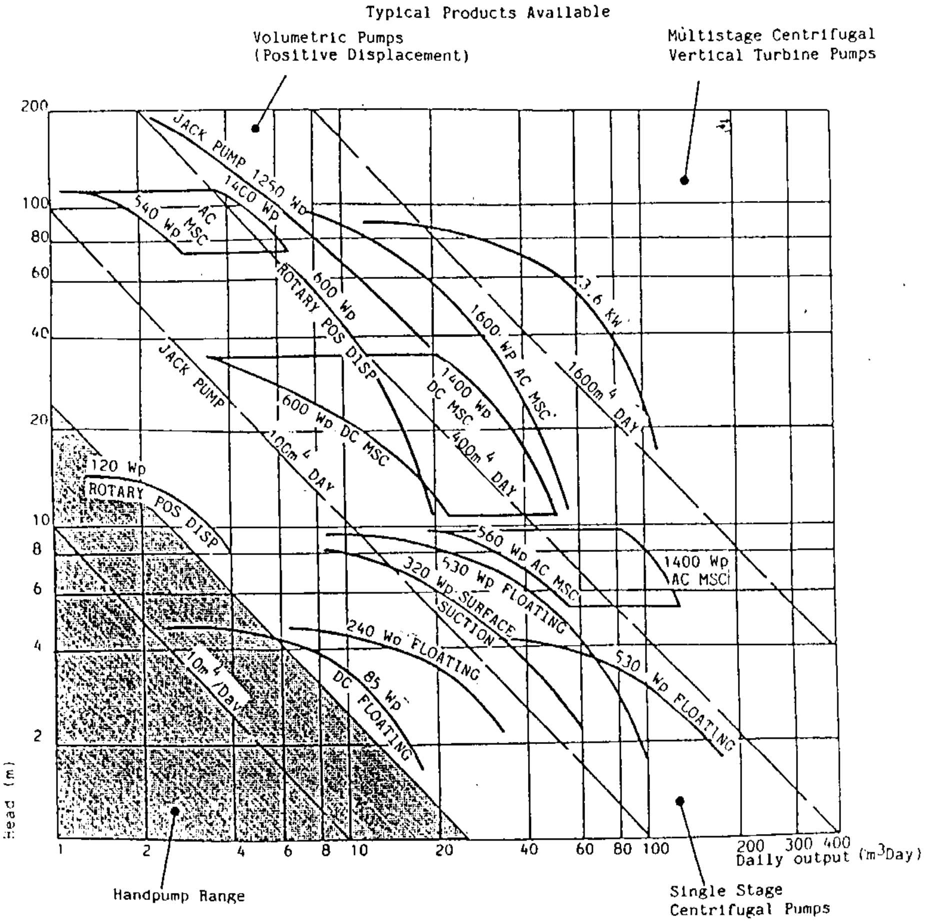

Figure 8 Pump performance

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 has an average daily solar energy to hydraulic efficiency of more than 4%. Photovoltaic modules of the monocrystalline type now have efficiencies in excess of 12% and more efficient motor and pumpsets are available. A good sub-system (that is the motor, pump and any power conditioning) should have an average daily energy throughput efficiency of 30-40%.

Costs

A photovoltaic pumping system to pump 25m³/day through 20m head requires a solar array of approximately 800Wp in the Sahelian regions. Such a pump would cost approximately $6,000 FOB. Other example costs are shown in Table 3.

A range of prices is to be expected, since the total system comprises the cost of modules, pump, motor, pipework, wiring, control system, array support structure and packaging. Systems with larger array sizes generally have a lower cost/Wp. The cost of the motor pumpset varies according to application and duties; a low lift suction pump may cost less than $800 whereas a submersible borehole pumpset costs $1500 or more.

Motor pump/ Configuration	Output (m^3.day) @ 5kWhm/cu.m/ day insolation	Head (m)	Solar Array (Wp)	System Price US$ FOB
Submerged borehole motor pump	40 25	20 20	1200 800	7000-8000 6000-7000
Surface motor/ submerged pump	60	7	840	5000-6000
Reciprocating positive displacement pump	6	100	1200	7500-9000
Floating motor/pumpset	100 10	3 3	530 85	4000 2000
Surface suction pump	40	4	350	3000

Table 3: Photovoltaic pumping system specifications

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. Present short-term goals aim for a per capita provision of 40 litres per day, 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.

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 'Cropwater requirements' (J Dorrenbos, WO Pruitt - FAO, Rome, Italy - 1977).

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.

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 (m³/day) x head (m) x water density x gravity / (3.6 x 10^6)
= 0.002725 x volume (m³/day) x head (m)

The solar array power required (kWp) =

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

where F = array mismatch factor = 0.85 on average
and E = daily subsystem efficiency = 0.25 - 0.40 typically

Economics

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

References

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Jeff Kenna and Bill Gillett: Solar Water Pumping. A handbook.
IT Publications, 1985.

U.R.S. Rentch: Solar Photovoltaics for Irrigation Water Pumping.
SKAT, St. Gallen, 1982.

Groundwater: Waterlines, Vol.20, No.2, October 2001, ITDG Publishing

Useful addresses

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Suppliers of photovoltaic pumps

Note: This is a selective list of suppliers and does not imply endorsement by Practical Action.

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Fax: +1 319 588 0720
Web: www.aymcdonald.com

BP Solar,
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Fax: +44 1932 762686
Web: www.bpsolar.com

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