Solar Water Pumping Systems for Remote Villages

Green Empowerment

Nov. 2010

Clean Water Distribution Options

Technology	Advantages	Constraints, comments
Gravity Fed or Ramp Pump	-Low cost -Simple to install and use -Easy maintenance -No fuel needed – 24 x 7 operation	**Gravity:** Needs a clean spring above located above the town **Ram Pump**:- Need appropriate site (falling water at a lower level, to be moved to a higher elevation) -Draws from stream water or spring
Diesel Generator	-Moderate initial cost -Easy to install	-Frequent maintenance., expertise required -Short life -Fuel often expensive, supply intermittent -Noise, dirt, fumes -Lifetime (20 yr.) costs higher than SPS
Human Pumping	-Very Low cost -No fuel needed -Low maintenance	- Very time and labor consuming - Limited in depth & flow (power required)
Wind Turbine	-Lower initial costs than SPS -Long life -Effective at windy sites -Clean -No fuel needed	-High maintenance needs -Expensive repair -Parts difficult to find -Wind can vary seasonally -Lower output in calmer winds
Solar Pumping System (SPS)	-Easy to install -Reliable long life -Low Maintenance, simple repair -No fuel needed -Clean -Modular system, can be expanded	Solar energy can vary seasonally Highest initial cost Lower output in cloudy weather

Components of a Solar Pumping System

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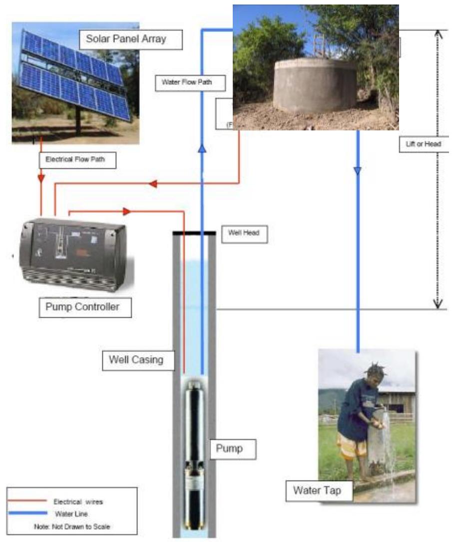
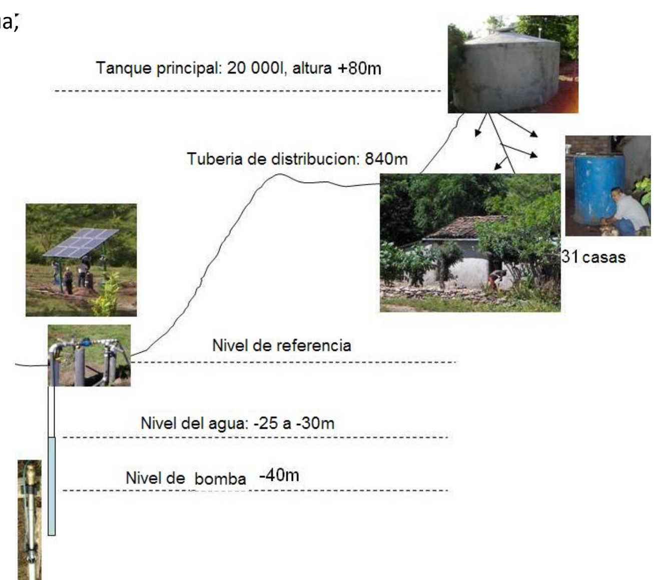


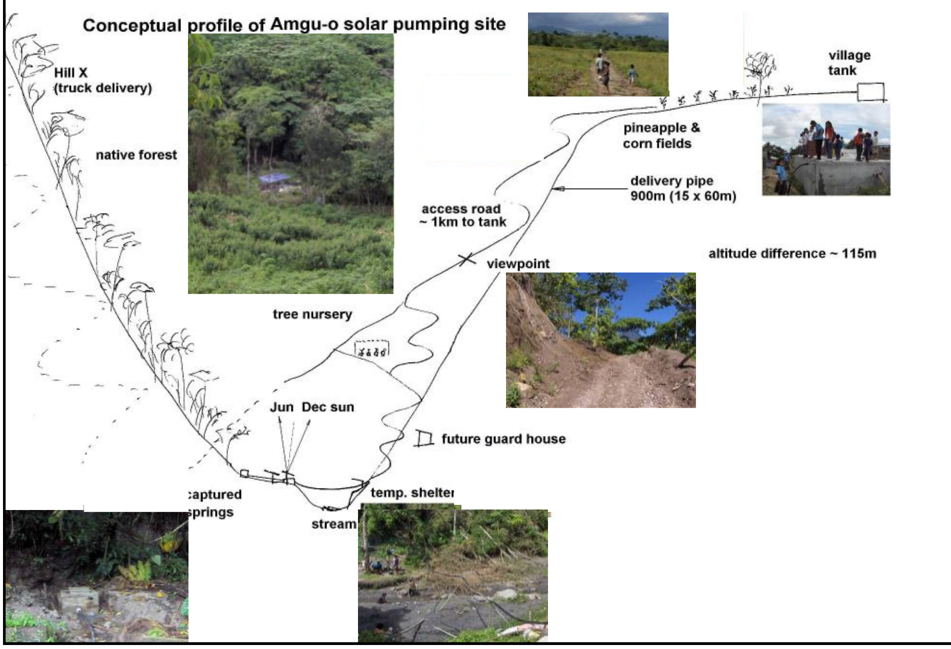
- PV panels
- Controller
- Cables, switches, etc.
- Pump & motor
- Water Tank
- Water pipes
- Faucets, etc.

Well & Casing Example

Bramadero, Nicaragua;
200 people



Spring capture example



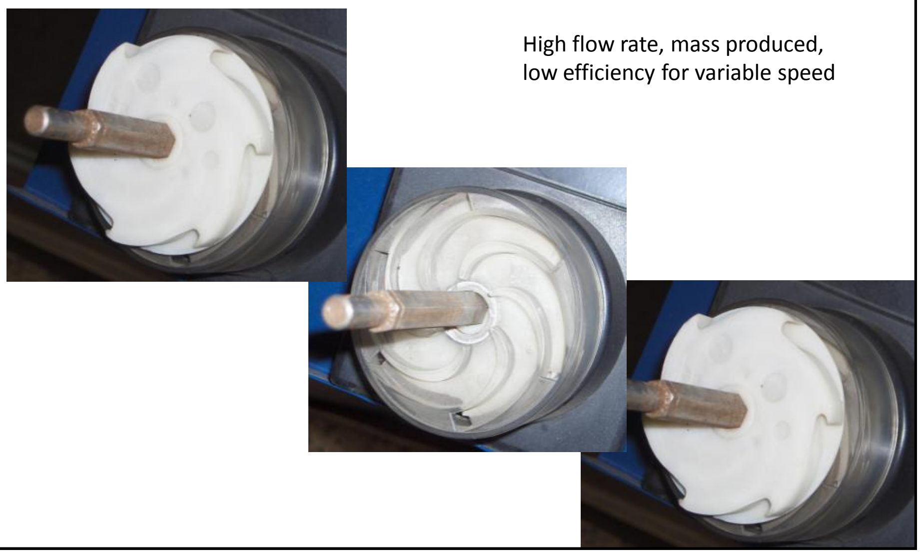
Types of water pumps

Surface vs. submersible

- If water level is < 20ft / 6m from ground surface, the atmospheric pressure can push water up to the pump. The pump has enough “suction”
- If the water level is deeper, i.e. in a well, the pump has to be submerged in the water.
- Submersible pumps are designed to fit in a standard bore casing, i.e. 4” o 6”

DVD: Windy Dankoff

Multistage Submersible centrifugal pump



High flow rate, mass produced,
low efficiency for variable speed

Submersible helical pump

high efficiency, high pressure
limited flow rate

Pumping System Sizing Principle

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The power required to move water is expressed as :

Power (W) = Flow rate (m^3/s) x Head (m) x Constant

To select a pump, we need to determine:

- How high the water needs to be pumped
- How much water is needed per day
- How fast the water needs to be pumped, i.e. the nominal flow rate of the pump (per minute or second) and whether it is compatible with the well/ spring capability

- For solar: available solar energy (PSH/ kWh/m2)
- For ram: available surface flow rate + possible drop

1: Water Demand

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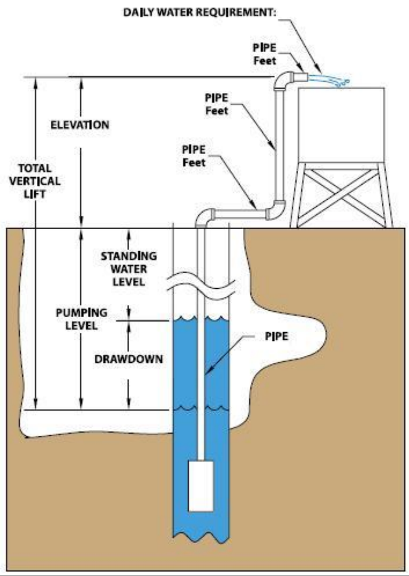
Users	Guideline gal/day	Quantity	Total gal/day	m^3/day
People	**10**	**500**	**5000**	19
Dairy cow	23			
Horse	13			
Pig	4.5			
Sheep / Goat	1.5			
Chickens	.04			

Notes:
1) a proper population survey is needed to see what the water will be used for, if it is a straight replacement for current uses, or if new uses are expected.
2) small plants & trees, and animals may be provided gray water.

1,000 gal = 3.8 m^3

2: Lift and Head



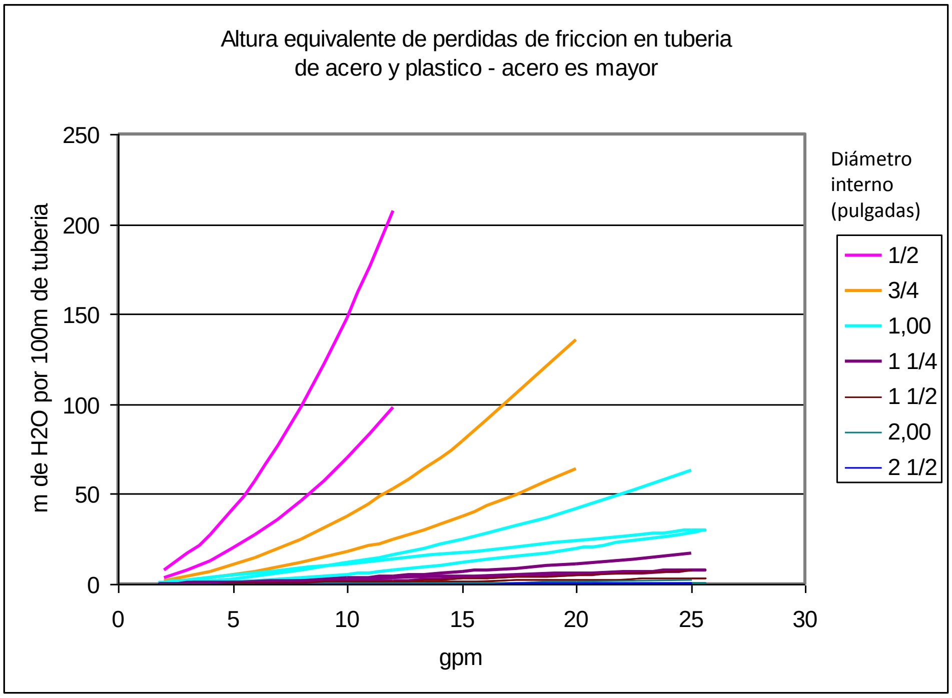
- Lift: The water needs to be elevated from its dynamic level in the well or spring to the point of delivery into the tank
- Head: in addition, there is a resistance due to friction in the pipes, fittings, etc. This is usually converted in "equivalent length of pipe"
- The total of Lift and friction head is the Total Dynamic Head (TDH)
- Field measurement techniques are beyond the scope of this workshop but very important

Estimating Lift and Head

- Vertical Lift components:
  - Elevation difference
  - + static water level depth in well
    - + seasonal adjustments
    - + long term depletion of the water table?
  - + drawdown: when the pumps pulls water, the level drops – measured while pumping at different rate

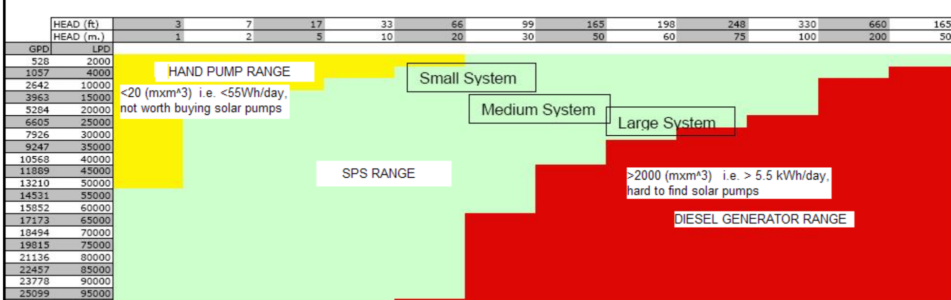
  Total Vertical Lift: TVL = Elevation + water level + drawdown
- Friction Head: computed from tables or software, depending on pipe size and material.
  - For short distances, simple pipes, can estimate or design for 4-7% of TVL. For long distances, select pipes to obtain friction ~2% of pipe length.
- TDH = TVL + friction head
- Example – Potreritos:

  Elevation up to tank = 30m
  static level + drawdown = 20m
  seasonal safety margin = 5m
  Total vertical lift = 55m
  assuming 7% friction losses, TDH = 55m +(55x7%) = 58.85m ~200ft



Are you within Solar Pumping range?

- Rule of thumb:
  multiply head (m) x daily volume (m³). ("hydraulic duty")
- If the result is >2000, it will be difficult to find a system with such high performance
- If the result is <20, it's not worth it. A hand pump works.



3: Solar Resource (PSH)

Resource assessment

Solar tracking mode	Fixed
Slope °	12.0
Azimuth °	0.0
Show data	

Bluefields, Nicaragua

http://www.retscreen.net/

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d
January	4.29	4.65
February	4.96	5.24
March	5.47	5.58
April	5.81	5.70
May	5.06	4.85
June	4.04	3.86
July	3.71	3.57
August	4.02	3.93
September	4.38	4.39
October	4.15	4.29
November	3.95	4.22
December	3.93	4.27
Annual	**4.48**	**4.54**

Annual solar radiation - horizontal	MWh/m²	1.63
Annual solar radiation - tilted	MWh/m²	1.66

Depending on climate & local access to water during rainy season, use either best, worse, or average PSH

15

4: 1st Pass Solar Pump Sizing

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Flow rate:

Using peak sun power, the pump needs to be able to pump the total daily demand within PSH hours

Example - Potreritos:

500 people x 12gal/day = 6,000 gal/day (~23 m³)

Local average PSH = 4.5 = 270 min

Nominal pump flow rate = 6,000/ 270 = 22.2 gpm (84.4 l/min)

We need a pump able to pump 22gpm with a TDH of 200ft

Note: whenever the solar power is lower than 1000 kW/m², the pump will deliver a lesser flow rate than nominal, with a lesser efficiency

Losses and Efficiency

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1. Electro-Mechanical pump efficiency
   - Not all the electrical power ends up moving water
   - Depends on the type of pump (positive displacement vs. centrifugal) and the model
   - Boosted by the use of an MPPT controller, but still varies during the day
   - Recommended to use 30-40% for feasibility study, but may go up to 45-70% depending on equipment used.

2. PV+ electrical circuit efficiency
   - Common practice to assume 80% of Wp is usable by pump

5: Solar Array Sizing (SI)

- *Hydraulic* Power (W) = Pressure (Pa) * Flow rate (m^3/s)
  = [Head (m) *9.81 m/s^2 *1000kg/m^3] * [flow (l/s) / 1000]

  Hydraulic Power (W) = TDH (m) * flow (l/s) *9.81

- Electrical Power needed by the pump:

  Electrical Power (W) = $\frac{\text{TDH (m) * flow (l/s) *9.81}}{\text{pump efficiency (\%)}}$ can vary 30% - 60%!

- Nominal PV Power (Wp) = *Electrical* Power / 80% (includes temp & age derating)

E.g. – Potreritos:
59m * 1.54 l/s * 9.81 = 893W hyd
/ 30% = 2977W elec /80% = 3722 Wp
/ 45% = 1985W elec /80% = 2481 Wp

Installed Potreritos Array: 2.7kWp

18

5: Solar Array Sizing (common units)

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5.1 Electrical power needed by the pump:

- In metric units:
  Power (W) = $\frac{\text{Flow (l/min) x Head (m) x .163}}{\text{pump efficiency (\%)}}$
- In English units
  Power (W) = $\frac{\text{Flow (gpm) x Head (ft) x .188}}{\text{pump efficiency (\%)}}$
- Example – Potreritos (cont'd):
  20gpm x 200ft x .188
  if /30% = 2,507 W
  if /42% = 1,790 W

5.2 Assuming only 80% of Array power is usable, we need:

if pump eff. = 30%, 2,507W/80% = 3,133Wp
if 42%, 1,790W/80% = 2,238Wp

this value needs to be rounded up to an integer number of panels, depending on the panels available

Example & Variability

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	A	B	G	H	I	J	K	L
1	**Solar Pumping sizing spreadsheet**			**Site:**	**example**			
2								
3	conversion factors/constants:			known (site) parameters ; input				
4	1gal = ... liters	3.81		recommended preliminary values				
5	1gal = ... m^3	0.00381						
6	1 ft= ... m	0.305		**GE SPS 2004 manual formulas**				
7	water density*gravity (SI)	9,810						
8	1hp = ...W	736		English units		metric units (SI)		
9	Population				500		500	
10	need/day /person			Gal	12	liters	45.6	
11	Daily need			Gal (per day)	6000	m^3 (/day)	22.8	
12	Total static water head			ft	180	m	55	
13	Head losses due to friction (5-10%)	7%			7%		7%	
14	Dynamic head			ft	194	m	59	
16	Perfect Solar Hours (PSH @ 1kW/m^2)				5		5	
17	computed (nominal) flow rate for PSH			gpm	20	l^3/min	76	
18	computed (nominal) flow rate for PSH					l/s	1.2667	
20	selected pump nominal (design) flow rate			gpm	20	lpm	76	
21	nominal (design) dynamic head			ft	194	m	59	
22	constant factor (gravity/(seconds/h))			0.188		0.163		
23								
25	pump average efficiency	30%			30%		42%	
26	**Pump design Watts**				**2,430**		**1,744**	
28	electrical loss factor from PV nominal	20%			20%		20%	
29	Electrical efficiency							
30	**PV Design Watts**				**3,038**		**2,180**	
31	**Selected PV kWp**						**2,200**	

Switch to SolarPumpSystemDesign-class.xls for demo

Group exercises

Water pumping workshop		Problem descriptions					
Site description:							
Country	Philippines	Philippines	Haiti	Nicaragua	Nicaragua	Ecuador	Tanzania
Location	Mindanao	Herminal (Negros island)	TerreBlanche	Potreritos	Bramadero /San Geronimo	Nantip (Amazons)	Ngelenge (~Songea)
latitude	~6 deg N	10d N	19 deg 35' 37" N				10.4 S
longitude		120 d E	72 deg 38' 30" W	SW region			35.4 E
Population - households	90	55					
Population - people	+100 external students during the day	330	school - 500 students + clinic - 50 patients	500	600	120	2000
Daily water volume target	14 to 28m3/day	10m3	tbd			4000 l	5-10 gal/dia/p
Water source:	springs	spring	well in courtyard			spring	
Water level in well (m)	n/a	n/a	60	25	30		
drawdown	n/a	n/a	included	3m	5m		17
flow rate	1 - 1.3lps	129l/min	52gpm max		9gpm max	52 l/min	45 gpm
Elevation difference to tank (m)	118m	41m	as needed	50m	23m	9	32
distance to tank (m)	900m	200m	tbd			300	500
Comments/notes	rain water harvesting in village		2-story clinic			village is next to large river, terrain is flat	
Solar Data							
PSH min (hrs = kWh/m2/day)	4	4	4.5	4.6	4.6	4	4
PSH avg	5	5	5.5	5.1	5.1		
Feasibility Study calculations							

Solar Pump - Vendor Role

- Most of the SPS comes from one vendor:
- Each pump has a specific controller designed for it by the same vendor
- Many vendors also sell PV panels
- Each vendor uses a proprietary software to forecast their system performance for every month of the year, and quote accordingly.
- Most vendors also sell many accessories: support structures, safety rope, water-resistant cables, underwater connection kits, etc.
- Balance of system (BOS) can be procured locally: wires, pipes
- Support structures often made locally as well.

Request for Quote: what to ask

- Provide basic characteristics: depth, drawdown, maxi flow rate, lift (TDH estimate), target daily flow, geographical location.
- Ask for performance forecast for the site (simulation)
- Be ready to adjust description as field info may be adjusted
- Request itemized quote from local & overseas vendors and see what could be procured locally and at what cost.
- Enquire about shipment duration & cost alternatives

Separately, from local resource:
Find out about possible import taxes, brokerage fees, etc.

Demo: software

http://www.monopumps.com.au/en-au/downloads-amp-tools-0
http://net.grundfos.com/Appl/WebCAPS/

Manufacturers

- Evaluate finding a local distributor, vs. importing
- Specific models & brands change / form alliances

Conergy (Dankoff)	USA	www.conergy.us	Dankoff's "slow pump" + Grundfos
Grundfos	Denmark	www.grundfos.com	Most sold in the world
Lorentz	Germany + China	www.lorentz.de	Helicoidal, variable quality reputation
Mono	Australia	http://www.monopumps.com.au/en-au/solar-products	Helicoidal, good quality, high pressure, few local distributors
Shurflo	USA	http://www.shurflo.com/pages/new_industrial/Industrial/solar/solar_home.html	Limited depth, common for small systems
SunPumps	USA	http://www.sunpumps.com/	Various own models + Grundfos

Sample Budget - Equipment

Potreritos Equipment bill	
PV panels 2866Wp	**$12,072**
Pumps (large + small)	$1,753
controllers (large + small)	$534
submersible cable (300ft)	$330
lightning arrestors (6)	$216
Float switch (4)	$176
30Amp/600VDC disconnect	$145
Misc parts	$695
TOTAL US	**$15,921**
+ Shipment + taxes	
+ locally procured parts	
Grand total	**$22,080**

2005 price!

Sample Budget – Project

Final Project Design **(GE)**	**$ 6,500**
Procurement of Solar Pump Equipment	**$22,080**
Construction of Water Tank and Distribution Lines **(Enacal)**	**$14,800**
Community Labor and Donated Materials	**$ 1,140**
Project Related Community Development Work—Community Water Board, Training, Reforestation and Patio Gardens	**$11,356**
Project Follow Up and Evaluation	**$ 1,930**
Total Cost	**$57,806**

References

Green Empowerment

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Village Distribution Example