Selecting a Solar Water Pumping System

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Introduction

- Design and selection of the correct solar water pumping system mainly requires knowledge of the actual site including:
  - Solar irradiation;
  - Daily water requirement; and
  - The total dynamic head.

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Total Dynamic Head

The total dynamic head is calculated based on:

- the vertical height (static head) that the water must be pumped
- and the effective head caused by
  - Friction losses at the pipe
  - Friction losses at the fittings
  - Velocity head at the beginning and end of pump.

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Pump Selection

- The solar water pump manufacture will provide information on the solar water pumping system performance for various heads and solar irradiation.
- Information needed from the designer includes:
  - The solar irradiation for the site;
  - The volume of water required daily;
  - The static head;
  - The length of pipe required;

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Pump Selection

- Calculate the total dynamic head for the site by:
  - Selecting the appropriate type of pipe and its diameter;
  - Calculating the total frictional losses (friction head) for the type, size and length of pipe used;
  - Calculate the total dynamic head for the site; and
- Using the manufacturers data sheets or software to select the most appropriate solar water pumping system.

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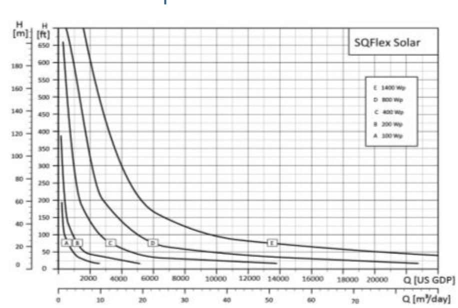
Pump datasheet extract



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Type of water pump systems

- Three types of solar water pumping systems are available including:
  - Borehole/well (submersible) pumps;
  - Surface pumps; and
  - Floating pumps.

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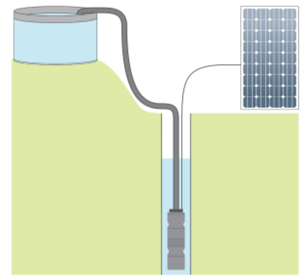
Borehole/Well Pump (Submersible Pump)



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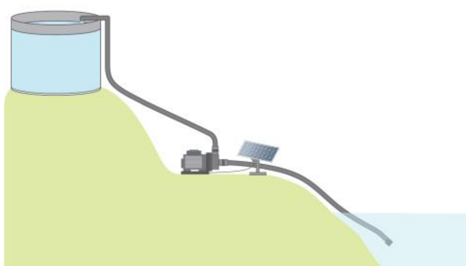
Surface Pump



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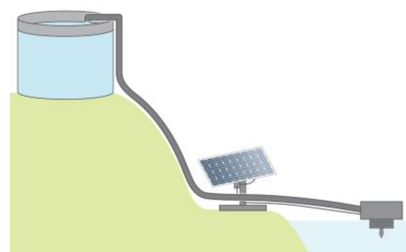
Floating Pump



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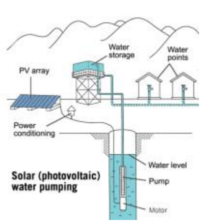
Designing and Selecting a Solar Water Pumping System-Summary

- The steps in designing and selecting solar water pumping system are summarised as follows:
- During a site visit:
  - Determine the water source and select the appropriate pump (borehole or surface pump)
  - Determine the daily water requirement
  - Verify the long term water resource availability
  - Determine location of storage tank, solar array, pump, and pipe runs



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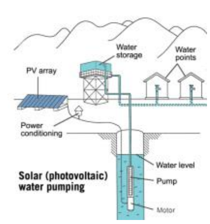
Designing and Selecting a Solar Water Pumping System-Summary 2

- During site visit (continued)
  - Measure pipe run length
  - Measure the static head for the site. Take measurements for:
    - pipe inlet to pump and
    - pump to pipe outlet
  - Measure the total distance from the water source to the final location of the water.



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Designing and Selecting a Solar Water Pumping System – Summary 3

- Determine the solar irradiation for the selected site on an annual and a monthly basis.
- Select the size and type of the water pipe to be used
- Make an estimate of the expected dynamic head and select a possible solar water pumping system.
- Choose a type of pump consistent with the quality of the water being pumped and the overall characteristics of the site
- Use the estimated maximum flow rate of the selected pump and calculate the frictional losses to determine the dynamic head.
- Check the that the selected solar water pumping system can meet the calculated total dynamic head

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Worked Example 1– Calculating the daily water requirement

- Assume the required water requirements for a village is estimated at 11.89 US gallons (45 litres) per person.
- There are 200 people in the village. The required daily volume of water required is: 11.89 x 200 = 2378 US gallons (approx. 9000 litres or 9 m^3).
- Note there is a difference between a US gallon and an imperial gallon - there are 3.785 litres in a US gallon and 4.54 litres in an imperial gallon

- *However, though this might be the required water volume, the designer must verify that the source (or system) can provide that volume of water consistently. This will be mostly dependent on the water resource though in some cases the solar resource may be a factor.*

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Monthly Water Requirement

- Sometimes the actual water requirements may vary by the month.
- The daily water requirements for each month can recorded as shown in the table below.

Daily flow rate that is required each month

Month	Required average daily flow rate each Month.	Month	Required average daily flow rate each Month.
January	______ US Gallons/Day	July	______ US Gallons/Day
February	______ US Gallons/Day	August	______ US Gallons/Day
March	______ US Gallons/Day	September	______ US Gallons/Day
April	______ US Gallons/Day	October	______ US Gallons/Day
May	______ US Gallons/Day	November	______ US Gallons/Day
June	______ US Gallons/Day	December	______ US Gallons/Day

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MEASURING STATIC HEAD

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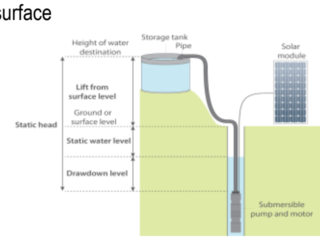
Calculating Static Head- Borehole/Well Pump

- This can be specified as:
- Static head = Drawdown level + Static water level + Lift from surface



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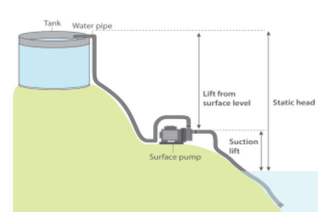
Calculating Static Head- Surface Pump

- Static head = Suction lift + Lift from the pump location on the land surface



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Measuring the distance

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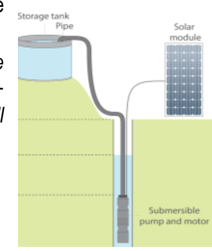
Borehole/Well Pump

- The total length of water pipe required is:
- *Distance from top of submersible pump to top of borehole/well + distance between borehole/well and the outlet at the storage tank.*



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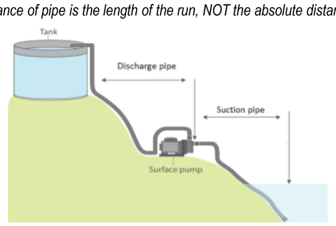
Surface Pump

For the surface pump there will be two water pipes:

- The suction water pipe; and
- The discharge water pipe.

The lengths of both of these pipes need to be determined individually.

Note: the distance of pipe is the length of the run, NOT the absolute distance between structures.



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Solar Irradiation

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Solar Irradiation

- Typically obtained from national meteorological or agricultural departments.
- In the case of some islands, (e.g. Nauru and PNG) the United States Department of Energy Atmospheric Radiation Measurement (ARM) program
- Data can be downloaded from [Global Solar Atlas](http://globalsolaratlas.info/) - http://globalsolaratlas.info/.
- One other source for solar irradiation (energy) data is the NASA website: https://power.larc.nasa.gov/data-access-viewer/ .
- *Note: NASA data has, in some instances, had higher irradiation figures than that recorded by ground collection data in some countries.*

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Array Orientation and Tilt

- For maximum solar input at latitudes higher than 10 degrees, the fixed ground mounted array frame should be orientated towards the equator for better yield
  - Northern hemisphere – face South,
  - Southern Hemisphere – face North
- For latitudes less than 10 degrees the orientation is not an issue.
- Tracking systems can produce up to 130% more energy than stationary systems

Suva Comparison of Peak Sunlight Hours (kWh/m²/day) at horizontal, tilt equal to latitude, and tilt = lat. + 15

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt	6.29	6.2	5.54	4.67	4.05	3.72	3.89	4.44	5.08	6.04	6.32	6.38	5.21
18° Tilt	6.27	5.88	5.55	4.99	4.61	4.38	4.51	4.88	5.21	5.83	6.1	6.41	5.38
33° Tilt	5.95	5.4	5.33	5.03	4.84	4.7	4.8	5	5.1	5.43	5.71	6.13	5.28

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Selecting the water pipe

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Water Pipes

- Water pipe can be supplied as metal pipes, PVC pipes (hard plastic pipes) or polyethylene pipes (commonly known as poly pipe).
- Because of its flexibility poly pipe is often used with solar water pumping systems

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Friction in Pipes

- Pipe manufacturers provide tables or graphs depicting the friction loss in their pipes at various flow rates. These are generally expressed as friction head per length of pipe for a specified flow. The distance value can be per metre of pipe or, as is often expressed, per hundred metres of pipe.
- Hence, by knowing the flow rate in a pipe, the diameter of the pipe and the length of the pipe, the friction losses (and therefore the dynamic head) can be determined using the manufacturer's tables or graphs.

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Flow Rates

- In solar water pumping systems without batteries, the flow rate will vary throughout day with the sun
- The actual flow rate will also vary depending on the actual total dynamic head of the system.
- The solar pump manufacturer will often provide the maximum possible flow rate for the water pump that is supplied with the system

Mono Pump surface pumps' maximum flow rate

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Worked Example - Calculating Daily Flow (stationary array frame)

- The solar water pumping system uses a stationary solar array with daily irradiation of 6.5kWh/m^2. What would be the approximate daily flow of a 200Wp solar system at 65.6 ft (20 metres) head?
- From table given, the flow with a tracking system = 3,698 US gallons (14m^3)
- Tracking systems produce up to 1.3 times more energy than fixed arrays. Therefore, a fixed system is expected to produce 1/1.3 x 3,698 US gallons = 2,845 US gallons (10.77m^3) on the same day.

Daily Flow in gallons

6.5kW/hr average performance tracking		
	System Size (watts)	
Head (ft)	200	400
16.4	8718	14001
32.8	6340	12152
49.2	4491	10303
65.6	3698	8189
82.0	2906	6604
98.4	2378	5283
114.8	1849	4227
131.2	1585	3170
147.6		2642
164.0		2113

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Worked Example – Calculating Daily Flow (Adjust for local irradiation)

- Following from the last example, daily irradiation was measured to be 5kWh/m^2 only. What is the approximate daily flow of a 200W system at 65.6 ft?
- The flow adjusted for a fixed system = 2,845 US gallons (10.77m^3)
- The flow with irradiation of 5kWh/m^2 is expected to produce = 5/6.5 x 2,845 US gallons = 2,188 US gallons (8.28m^3)

Daily Flow in gallons

6.5kW/hr average performance tracking		
	System Size (watts)	
Head (ft)	200	400
16.4	8718	14001
32.8	6340	12152
49.2	4491	10303
65.6	3698	8189
82.0	2906	6604
98.4	2378	5283
114.8	1849	4227
131.2	1585	3170
147.6		2642
164.0		2113

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Selecting the size of water pipe

- The length, diameter and material (which affects the roughness of internal surfaces) of the water pipes all affect the dynamic head of the pumping system.
- A larger diameter and/or pipe with a smoother internal surface will reduce the frictional head; installing a suitable diameter and smoother internal surface pipe will reduce frictional losses and possibly reduce the size of the pump required.
- However, a larger diameter and/or smoother internal surface pipe will generally also increase the system costs.

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Total Dynamic Head

The total dynamic head =

static head + friction head of complete water piping system + velocity head at the discharge point.

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Calculating Total Frictional Head of Water Piping System

- Frictional head of the pipe is based on:
  - the length of the straight pipe,
  - the maximum flow of the water in the pipe,
  - losses experiences at pipe valves, and
  - the size of the pipe.
- Curves or tables can be used to determine the frictional head of the pipe based on
  - known maximum flow (provided by the solar water pump manufacturer)
  - and the size of water pipe selected.

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Worked Example 9: (US/Imperial) – Calculating Friction Loss

- A village is located beside a river.
  - The surface pump is 13ft above river level.
  - The suction pipe will be 39ft in length.
  - The water tank is located 330ft away from the river and 33ft vertically above the location of the surface pump.
  - There will be a foot valve in the suction pipe and a gate valve in the discharge pipe.
  - The daily irradiation is 6.5 kWh/m^2 and the solar array will be mounted on a fixed array frame.
  - The village requires a minimum of 2378 US gallons (9 m^3) of water per day.

  How do you select the pipe and what would be the total frictional head loss of the water piping system?

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Worked Example Cont'd

- The total frictional head loss of the water piping system will consist of:

  Frictional head loss of suction and discharge pipe

  + Frictional head of a foot valve

  + Frictional head loss of a gate valve.
- The total static head = 13 ft + 33 ft = 46 ft.
- Estimate 10 to 16 ft for estimated frictional head loss — this would assume a total dynamic head is 56 to 62 ft.

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Worked Example Cont'd

- Referring to table 7b, the 200W solar system can provide 3698 US gallons with a head of 65.6 ft using a tracking solar system. If the array frame is fixed, this should produce 1/1.3 x 3698 US gallons = 2845 US gallons. This system should meet the requirement of providing a minimum of 2378 US gallons of water per day.
- The corresponding pump model to the table is the SRX CP25 with a maximum flow rate of 7.4 gallons/min.

Daily Flow in gallons

6.5kW/hr average performance tracking		
	System Size (watts)	
Head (ft)	200	400
16.4	8718	14001
32.8	6340	12152
49.2	4491	10303
65.6	3698	8189

SRX CP25
Up to 164 ft
Up to 7.4 US gallons/min

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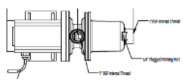
Worked Example Cont'd

- Referring to Table (on the next slide) for the CP25 pump. the inlet and outlets are 1 inch diameter. Therefore, for the design start with 1 inch diameter water pipes for the inlet and outlet
- Reading off the pipe friction table (next slide), it can be seen that at 7 gallons per minute with 1 inch poly pipe (tubing) the frictional head loss is about 1.41 PSI per 100 feet of pipe and 1.80 PSI at 8 gallons per minute. At 7.4 gallons per minute it would be approximately 1.56 PSI which is 3.6 feet of frictional head per 100 feet of pipe, this is too much particularly considering that the discharge pipe is 330 feet in length.
  - 1 PSI = 2.31 feet of head (Table 3 in guidelines)
- Selecting a 1½ inch poly pipe the friction loss decreases to approximately 0.196 PSI which is 0.453 feet of frictional head per 100 feet of pipe, so this will be selected.
- So 1½ inch poly pipe (tubing) will be selected for the water piping system.
- The total length of pipe is 39 ft (suction) plus 330 ft (discharge) = 369 ft
- So friction head loss due to water pipe = 369 ft x 0.453ft/100 ft = 1.67ft, which is less than the estimated loss so this is acceptable.



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Worked Example Cont'd

PSI Loss per 100 feet for Poly Pipe (tube)

Size	1/2"		¾"		1"		1 ¼"		1 ½"		2"		2 ½"	
ID	0.622		0.824		1.049		1.380		1.610		2.067		2.169	
Flow G.P.M	Velocity F.P.S	PSI Loss	Velocity F.P.S	PSI Loss	Velocity F.P.S	PSI Loss	Velocity F.P.S	PSI Loss	Velocity F.P.S	PSI Loss	Velocity F.P.S	PSI Loss	Velocity F.P.S	PSI Loss
1	1.05	0.49	0.6	0.12	0.37	0.04	0.21	0.01	0.155	0.00	0.095	0.00		
2	2.10	1.76	1.2	0.45	0.74	0.14	0.42	0.04	0.31	0.02	0.19	0.01		
3	3.16	3.73	1.8	0.95	1.11	0.29	0.63	0.08	0.47	0.04	0.29	0.01	0.20	0.00
4	4.21	6.35	2.4	1.62	1.48	0.50	0.84	0.13	0.62	0.06	0.38	0.02	0.26	0.01
5	5.27	9.60	3	2.44	1.85	0.76	1.05	0.20	0.78	0.09	0.48	0.03	0.33	0.01
6	6.32	13.46	3.6	3.43	2.22	1.06	1.26	0.28	0.93	0.13	0.57	0.04	0.40	0.02
7	7.38	17.91	4.2	4.56	2.59	1.41	1.47	0.37	1.09	0.18	0.67	0.05	0.46	0.02
8	8.43	22.93	4.8	5.84	2.96	1.80	1.68	0.47	1.24	0.22	0.76	0.07	0.53	0.03
9	9.49	28.52	5.4	7.26	3.33	2.24	1.89	0.59	1.40	0.28	0.86	0.08	0.60	0.03
10	10.54	34.67	6	8.82	3.7	2.73	2.1	0.72	1.55	0.34	0.95	0.10	0.66	0.04
11	11.60	41.36	6.6	10.53	4.07	3.25	2.31	0.86	1.71	0.40	1.05	0.12	0.73	0.05
12	12.65	48.60	7.2	12.37	4.44	3.82	2.52	1.01	1.86	0.48	1.14	0.14	0.80	0.06
14	14.76	64.65	8.4	16.46	5.18	5.08	2.94	1.34	2.17	0.63	1.33	0.19	0.93	0.08
16	16.87	82.79	9.6	21.07	5.92	6.51	3.36	1.71	2.48	0.81	1.52	0.24	1.07	0.10
18	18.98	102.97	10.8	26.21	6.66	8.10	3.78	2.13	2.79	1.01	1.71	0.30	1.20	0.13

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Worked Example Cont'd

- The velocity for the 1 ½ inch poly pipe @7.4 gallons per minute is approximately 1.15 feet per second.
- The K for the foot valve in a 1½ inch pipe is 8.80 while the K for the gate valve in a 1½ inch pipe is 0.15 (next slide)
- The frictional head loss of the foot valve:

$= K \times v^2/2g$

$= 8.80 \times 1.15^2/ (2 \times 32.185)$

$= 0.181$ feet

The frictional head loss of the gate valve

$= K \times v^2/2g$

$= 0.15 \times 1.15^2/ (2 \times 32.185)$

$= 0.003$ feet

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K Values

K Values for Some Fittings (US/imperial)

Size (inches)	½	¾	1	1 ¼	1 ½	1 ¾	2	2 ½ to 3	4	6
Foot valve	11.3	10.50	9.7	9.3	8.80	Not supplied	8.00	7.6	7.1	**6.30**
Gate Valve	**0.22**	**0.20**	**0.18**	**0.18**	**0.15**	**0.15**	**0.14**	**0.14**	**0.12**	**0.11**

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Worked Example Cont'd

The total frictional head of the water piping system

= Frictional head of the total length of water pipe + frictional head of a foot valve + frictional head of a gate valve:

= 1.67 + 0.181 + 0.003

= 1.854 feet

This is less than the 10 – 16 ft estimate used to select the pump – therefore a conservative approach.

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Velocity Head

- The velocity head is determined by the following formula:

Velocity head= $v^2/2g$

where

- v is the velocity of the water in feet per second (FPS)
- g is gravitational acceleration constant (32.185 feet/s^2).
- The velocity of the water is provided in the friction loss tables and charts.

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Worked Example 11 - Calculating Velocity Head (Imperial)

- For the water pipe system determined in worked example 9, what is the velocity head.
- The velocity was 1.15 feet per second.
- The velocity head
  - = $v^2/2g$
  - = $1.15^2/ (2 \times 32.185)$
  - = 0.021 feet

Worked Example 9 – US/Imperial Calculating Total Dynamic Head

- For the solar water pumping system used in example 9, calculate the total dynamic head.
- The static head = 13 + 33 = 46 ft
- The total frictional head loss based on maximum flow of the pump was calculated = 1.862 ft
- The velocity head was determined in example 11 as = 0.021 ft
- The total dynamic head = static head + friction head of the complete water piping system + velocity head.
  = 46 + 1.862 + 0.021 = 47.883 ft

Calculating Total Dynamic Head

- The guideline has shown how to calculate the total dynamic head but it will require the designer to have access to
  - pipe friction data
  - K values for various water pipe fittings.
- There are many websites, typically provided by water pump suppliers and manufacturer's or pipe manufactures, where this data is available.
- Many of these websites include calculators for determining the total dynamic head of a water pumping system.

Tools/website – Dynamic Head/Friction losses

- Some websites that provide tools for calculating dynamic head or pipe friction losses include:
- http://www.pumpworld.com/total-dynamic-head-calculator.htm .
- http://www.ajdesigner.com/phppump/pump_equations_total_head.php
- http://www.csgnetwork.com/csgdynamichead.html
- https://www.nationalpump.com.au/calculators/friction-loss-calculator/
- https://www.tuhorse.com.au/total-dynamic-head-tdh-calculator/

Examples of Sizing Software

- Some manufacturers provide sizing software online to assist individuals/communities to select the most appropriate solar water pumping system. This section of the guideline provides some examples.

Grundfos Pumps

- Grundfos Pumps provides their sizing tool through the following link: https://product-selection.grundfos.com/front-page.html?qcid=399449727 .
- On that screen select: Sizing (in blue) and then "Advanced sizing by application" and select "solar water solutions". That will bring up a screen where the data for a site is entered for either a surface or borehole/well pump and the program will select the solar water pumping system.

Examples of Sizing Software

- **Mono Pumps**
- The Mono Pumps sizing software is called CASS (computer aided solar simulation), downloadable from www.solarcass.com. It includes their main solar pumping products.

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