Selecting a Solar Water Pumping System

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.

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.

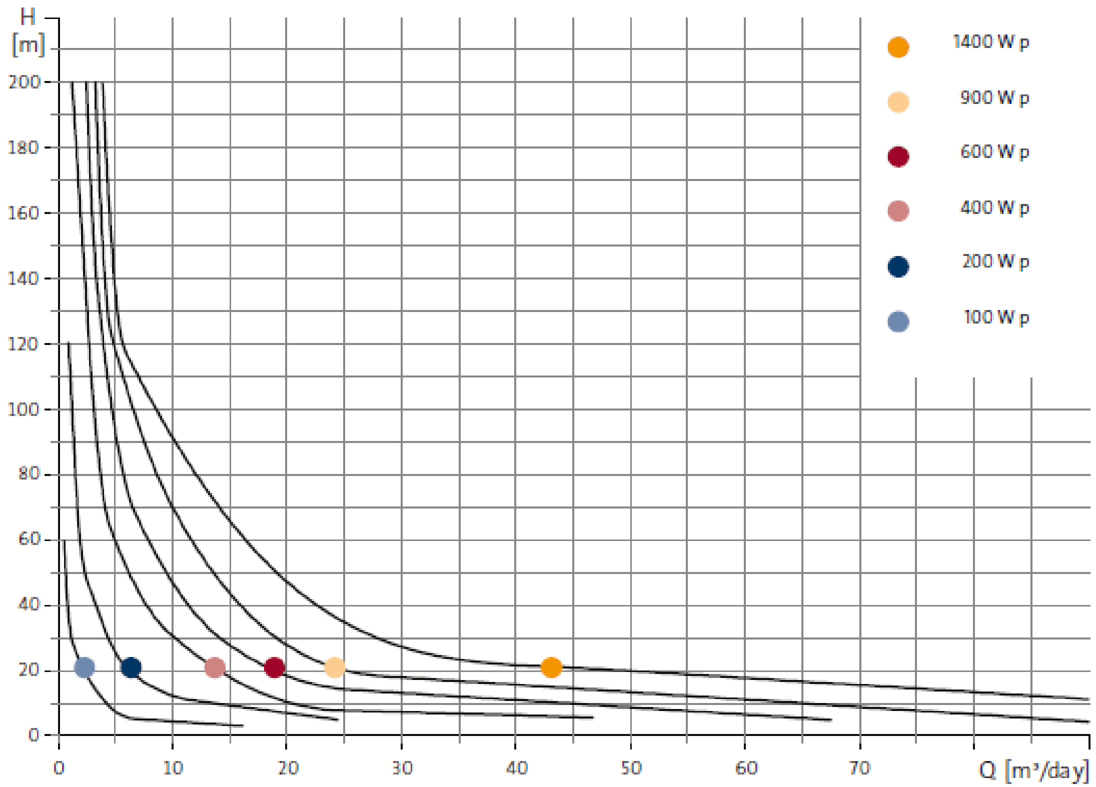
Pump Selection

- 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;

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.

Pump datasheet extract



based on:
- Irradiation on a tilted surface
- Ht = 6 kWh/m² per day
- 20° tilt angle
- Ambient temperature at 30°C
- 20° northern latitude
- 120V DC

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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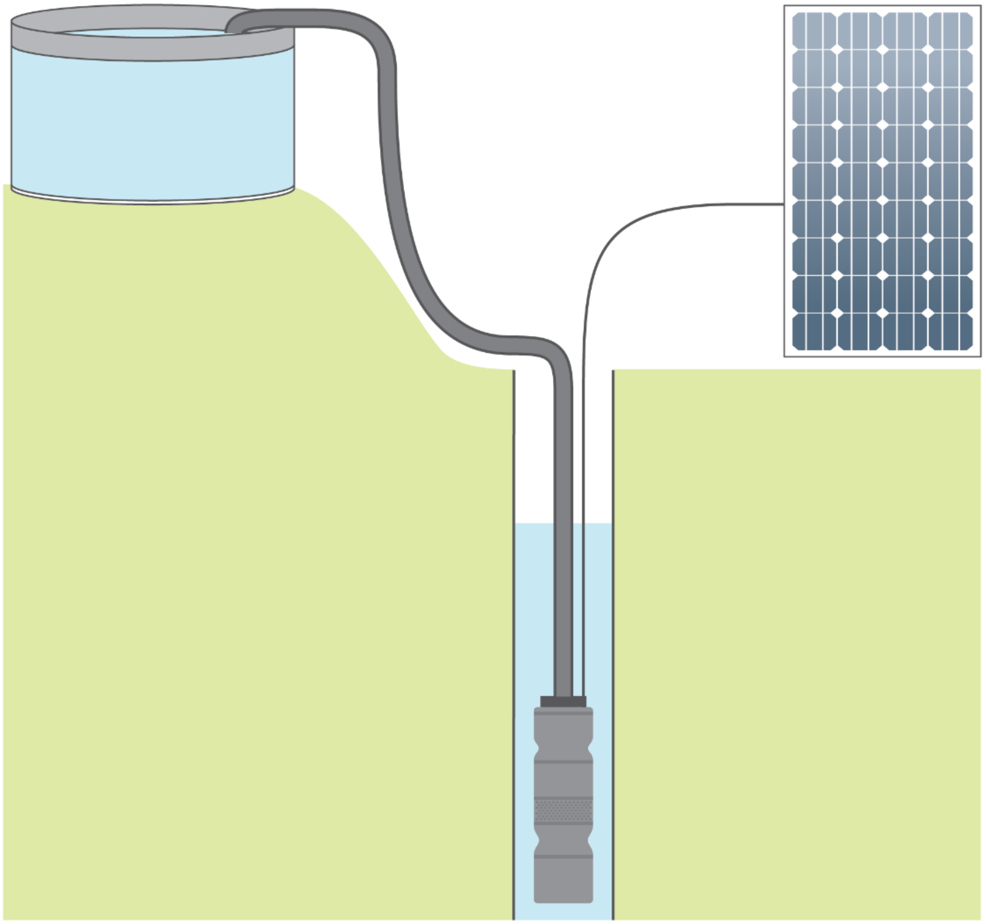
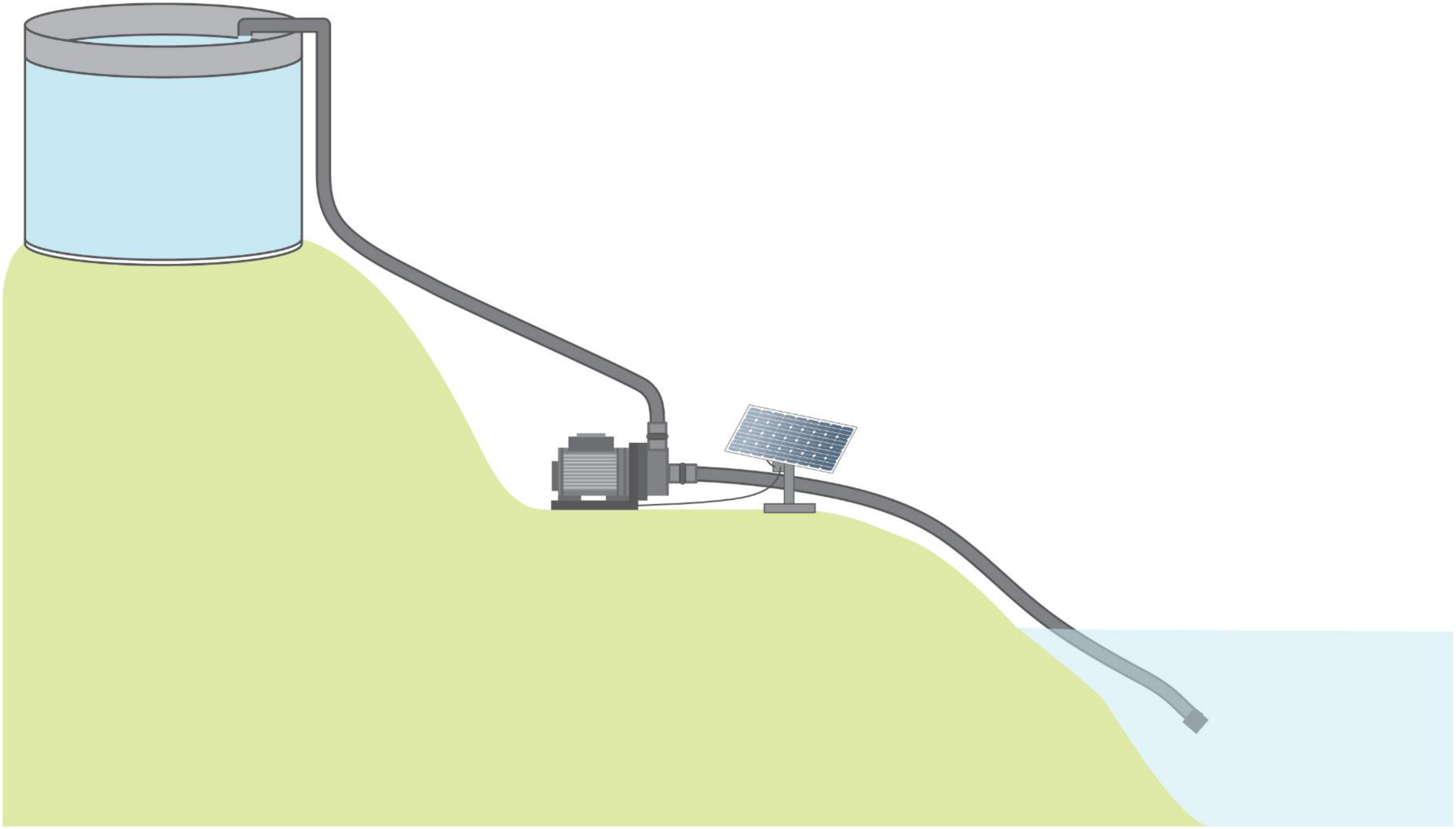
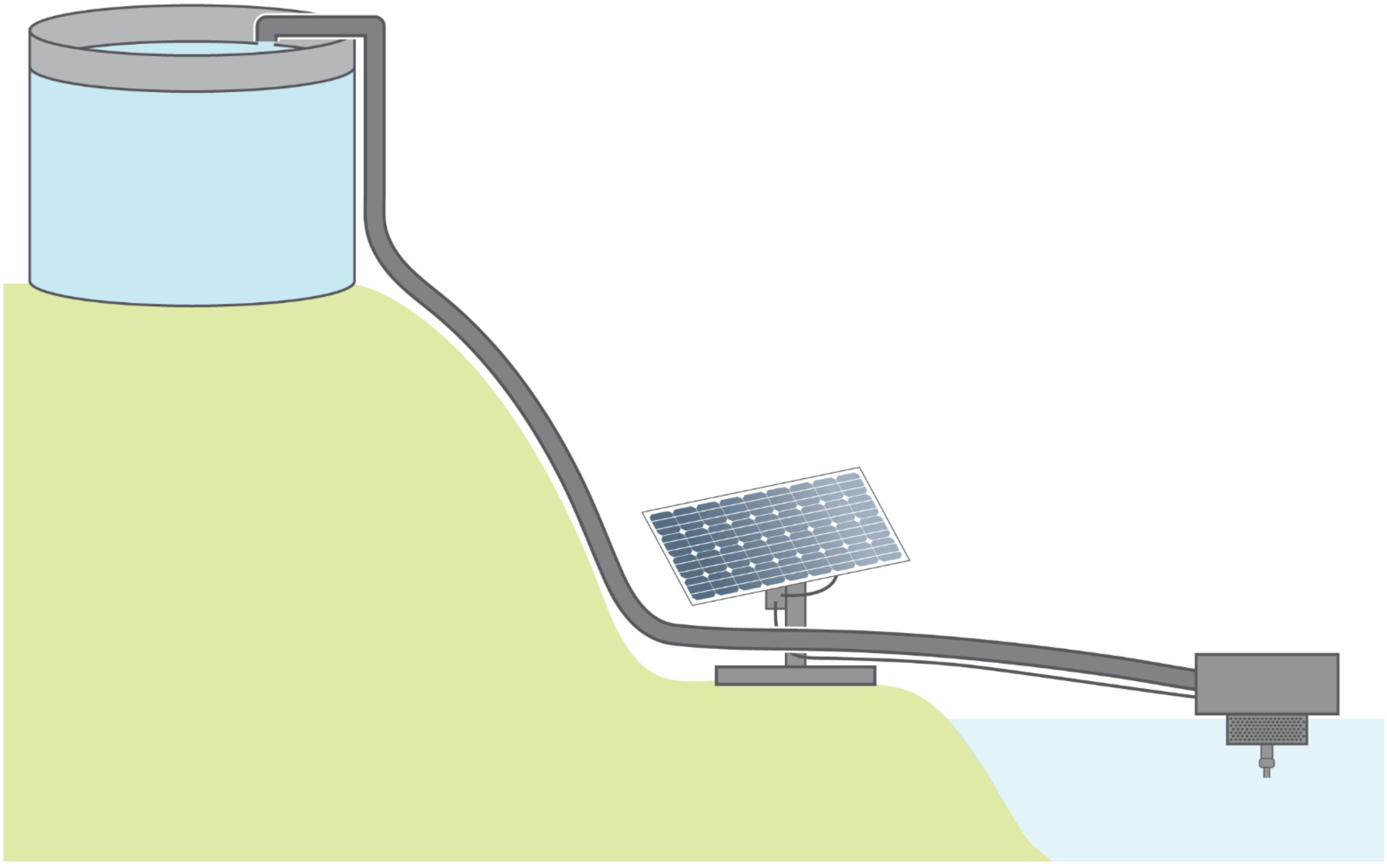
Borehole/Well Pump (Submersible Pump)



Surface Pump



Floating Pump



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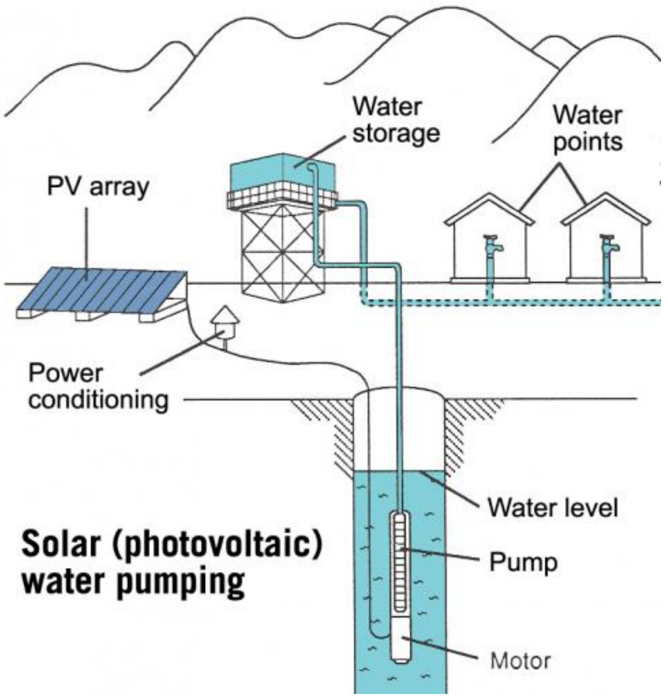
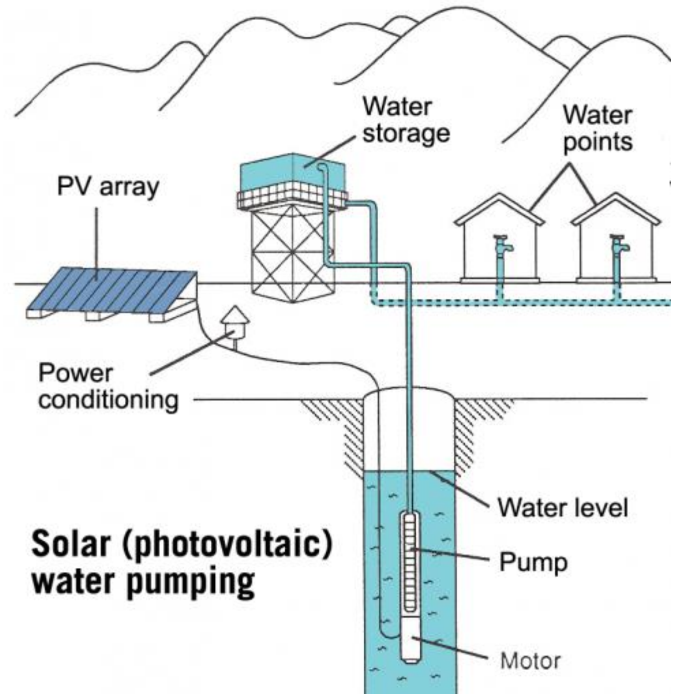
Designing and Selecting a Solar Water Pumping System-Summary

- 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



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

Worked Example 1– Calculating the daily water requirement

- Assume the required water requirements for a village is estimated at 45 litres (11.9 US gallons) per person.
- There are 200 people in the village. The required daily volume of water required is: 45 x 200 = 9000 litres or 9 m^3 (2378 US gallons).

- *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.*

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 Table 1

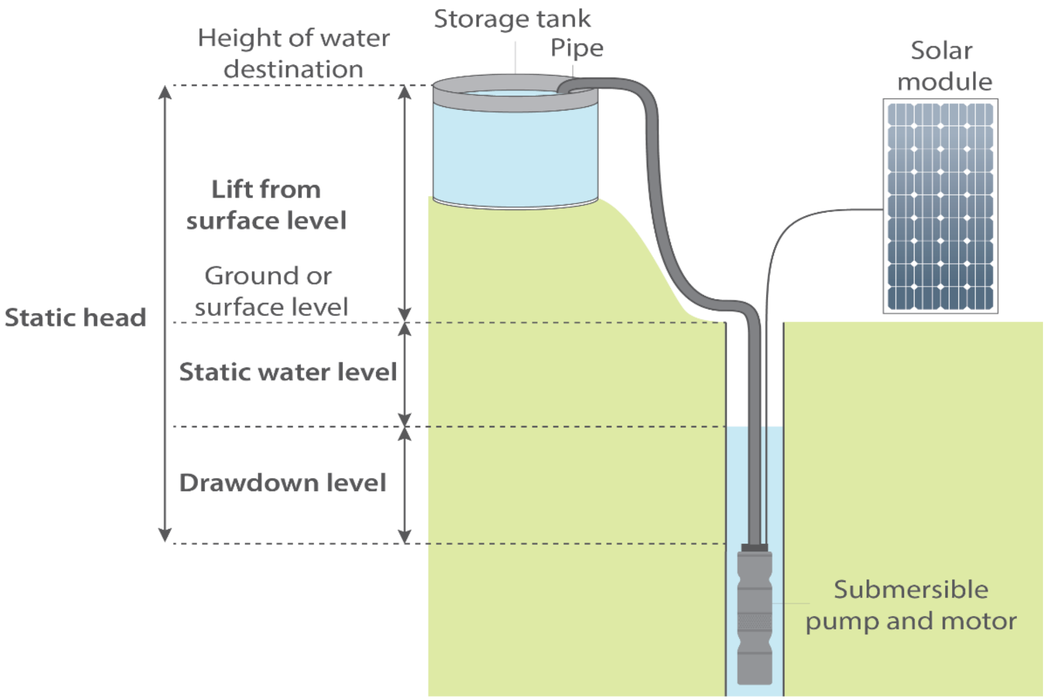
Daily flow rate that is required each month

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

MEASURING STATIC HEAD

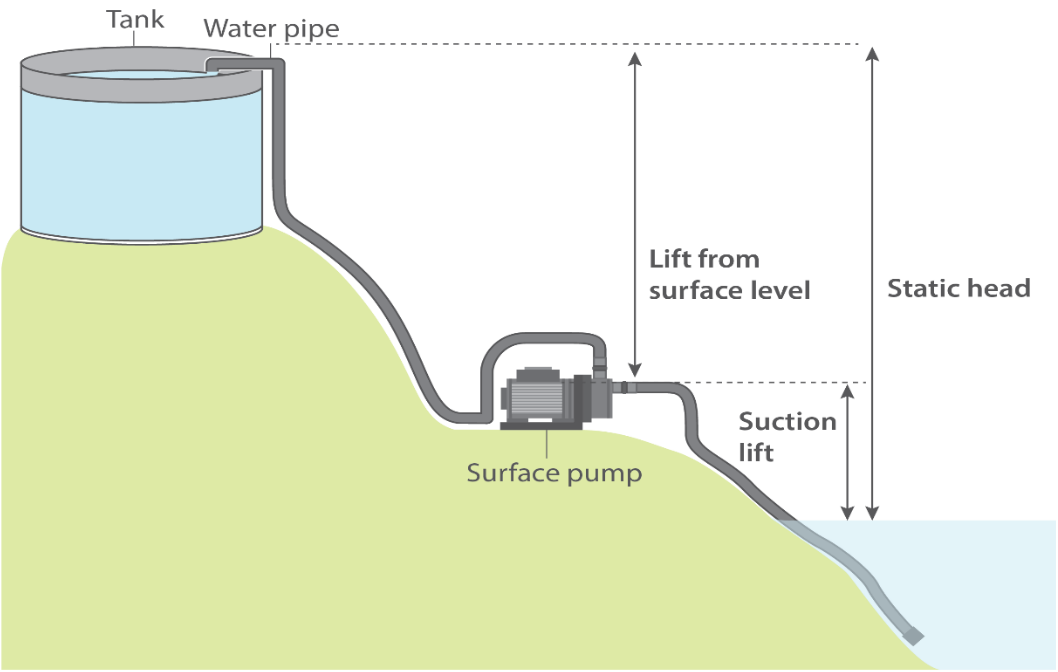
Calculating Static Head- Borehole/Well Pump

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



Calculating Static Head- Surface Pump

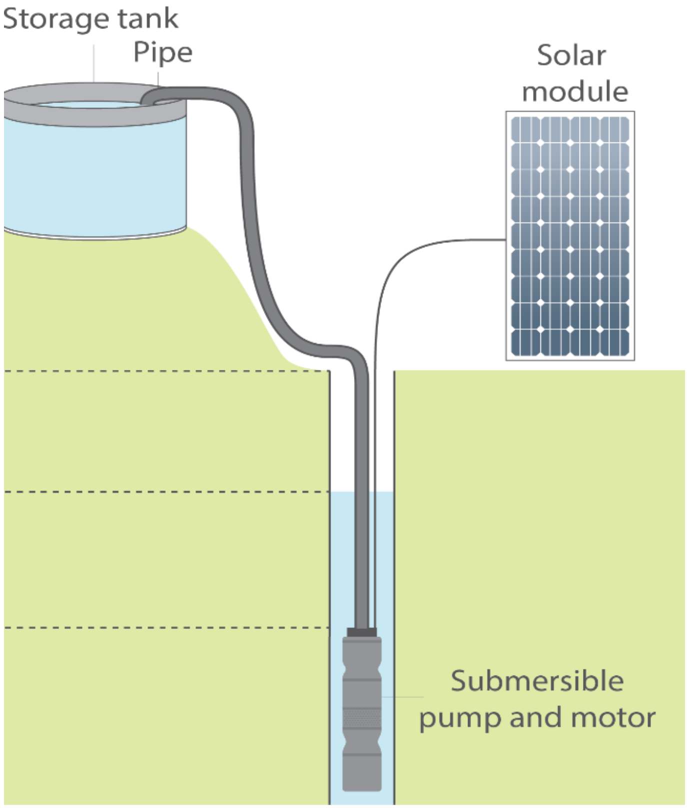
- Static head = Suction lift + Lift from the pump location on the land surface



Measuring the distance

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.*



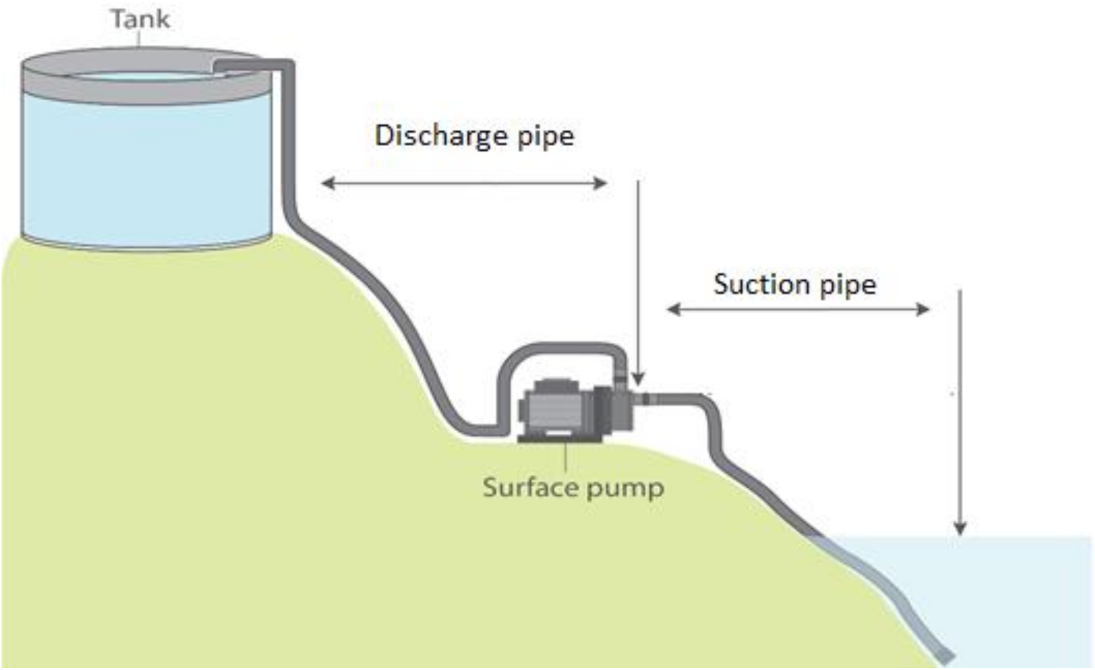
Surface Pump

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.



Solar Irradiation

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/.
- 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.*

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

Selecting the water pipe

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

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.

Friction in Pipes

- The Australian Pump Manufacturers Association, Ltd. (https://pumps.asn.au) produces a Pipe Friction Handbook that is a useful resource that provides friction losses for a variety of pipe types for various flow rates.

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

Worked Example 4 - 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 20 metres head?
- From table given, the flow with a tracking system = 14m^3 (3,699) US gallons)
- 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 14 m^3 = 10.77m^3 (2,845 US gallons) on the same day.

6.5kWh/m^2 average performance tracking system						
	System Size (watts)					
Head (m)	200	400				
5	33	53				
10	24	46				
15	17	39				
20	14	31				
25	11	25				
30	9	20				
35	7	16				
40	6	12				
45		10				
50		8				

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Worked Example 5 – 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 20m?
- The flow adjusted for fixed system system = 10.77m^3 (2,845 US gallons)
- The flow with irradiation of 5kWh/m^2 is expected to produce = 5/6.5 x 10.77 m^3 = 8.28m^3 (2,187 US gallons)

6.5kWh/m^2 average performance tracking system						
	System Size (watts)					
Head (m)	200	400				
5	33	53				
10	24	46				
15	17	39				
20	14	31				
25	11	25				
30	9	20				
35	7	16				
40	6	12				
45		10				
50		8				

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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.

Total Dynamic Head

The total dynamic head =

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

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.

Worked Example 8: (Metric) – Calculating Friction Loss

- A village is located beside a river.
  - The surface pump is 4 metres above river level.
  - The suction pipe will be 12 metres in length.
  - The water tank is located 100 metres away from the river and 10 metres 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 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?

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 and
- Frictional head loss of a gate valve.
- The total static head = 4 + 10 = 14 metres.
- Estimate 3 to 5 metres for estimated frictional head loss — this would assume a total dynamic head is 17 to 19 metres.

Worked Example Cont'd

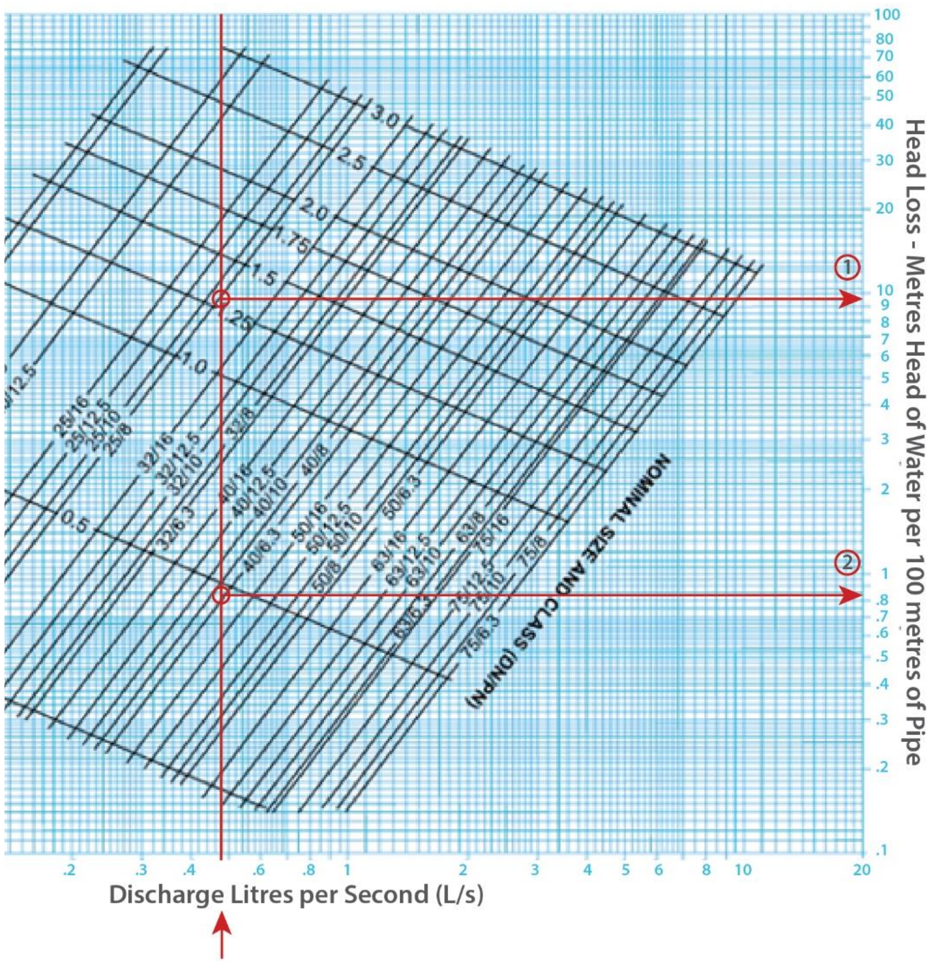
- Referring to table 7a, the 200W solar system can provide 14 m^3 with a head of 20 metres using a tracking solar system. If the array frame is fixed, this should produce 1/1.3 x 14m^3 = 10.7m^3. This system should meet the requirement of providing a minimum of 9 m^3 of water per day.
- The corresponding pump model to the table is the SRX CP25 with a maximum flow rate of 28 l/min or 0.47 l/sec.

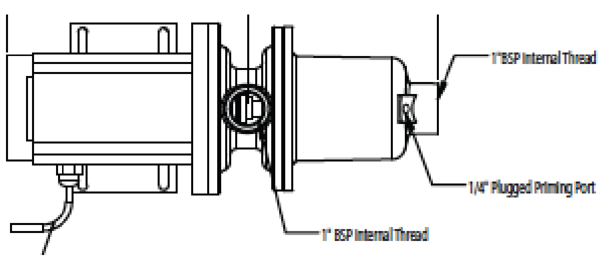
6.5kWh/m^2 average performance tracking system		
	System Size (watts)	
Head (m)	200	400
5	33	53
10	24	46
15	17	39
20	14	31

SRX CP25
Up to 50 Mts
Up to 28 L/min

Worked Example Cont'd

- Referring to Figure below for the CP25 pump. the inlet and outlets are 1 inch diameter. Therefore, start with 25mm diameter (1 inch equivalent) water pipes for the inlet and outlet
- Reading off a pipe datasheet, It can be seen that at 0.47 l/sec with 25mm/8PN poly pipe the frictional head loss is about 9 metres per 100 metres of pipe; this is too much particularly considering the discharge pipe is 100 metres in length.
- Selecting a 40mm/6.3PN poly pipe the friction loss decreases to approximately 0.8 metres per 100 metres of pipe, so this will be selected.
- So the 40mm/6.3PN poly pipe will be selected for the water piping system.
- The total length of pipe is 12 metres (suction) plus 100 metres (discharge)= 112 metres.
- So friction head loss due to water pipe = 112 m x 0.8m/100 m= 0.986M





Worked Example Cont'd

- the velocity for the 40mm/6.3PN pipe @0.47litres per second is approximately 0.49m/sec
- The K for the foot valve in a 40mm pipe is 8.82 while the k for the gate valve in a 40mm pipe is 0.17
- The frictional head loss of the foot valve:

$$= K \times v^2/2g$$
$$= 8.82 \times 0.49^2/(2 \times 9.8)$$
$$= 0.108 \text{ metres}$$

The frictional head loss of the gate valve

$$= K \times v^2/2g$$
$$= 0.17 \times 0.49^2/(2 \times 9.8)$$
$$= 0.002 \text{ metres}$$

K Values

K Values for Some Fittings (metric)

Size (mm)	16	20	25	32	40	50	63/80	100	125	150
Foot valve	11.34	10.50	9.66	9.24	8.82	7.98	7.56	7.14	6.72	**6.30**
Gate Valve	**0.22**	**0.20**	**0.18**	**0.18**	**0.17**	**0.15**	**0.14**	**0.14**	**0.13**	**0.12**

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**

Worked Example Cont’d

The total frictional head of the water piping system

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

= 0.986+0.108+0.002

= 1.096 m

This is within the 3-5m estimate used to select the pump.

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

- A village located beside a river would like to install a solar water pumping system:
  - The surface pump will be located 13 feet above river level. The suction pipe will be 39 feet in length.
  - The water will be stored in a water tank that is located 330 feet away from the river and 33 feet 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 6.5kWh/m^2
  - the solar array will be mounted on a fixed array frame.
  - The village requires a minimum of 2378 $gallons^3$ of water per day.

What pipe would you select 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 pipe plus the frictional head loss of the discharge pipe plus the frictional head of a foot valve plus the frictional head loss of a gate valve
- The total static head = 13 + 33 = 46 feet allowing 10 to 16 feet for an estimated frictional head loss, assume the total dynamic head to be 56 to 62 feet.

Worked Example Cont’d

- Referring to table 7b the 200W solar system can provide 3698 gallons with a head of 65.6 feet using a tracking system. Using a stationary array frame it will produce at least 0.77 x 3698 gallons = 2847 gallons. This system should therefore meet the requirement of providing a minimum of 2378 gallons of water per day. From figure 13 it can be seen that the appropriate pump is the CP25 with its maximum flow rate of 7.4 gallons per minute.

Worked Example Cont'd

- Referring to Figure 14a, the inlet and outlets are 1 inch. Therefore, for the design start with 1 inch diameter water pipes for the inlet and outlet pipes.
- In table 6 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.

Worked Example Cont'd

- Selecting a 1 ½ inch poly pipe the friction loss decreases to approximately 0.196 PSI which is an acceptable 0.453 feet of frictional head per 100 feet of pipe, so this will be selected.
- So 1 ½ inch poly pipe (tubing) will be elected for the water piping system.
- The total length of pipe is 39 feet (suction) plus 330 feet (discharge) = 369 feet.
- So the friction head loss due to the water pipe = 369 ft x 0.453ft/100 ft= 1.67 feet.

Worked Example Cont'd

- From Table 6 the velocity for the 1 ½ inch poly pipe @7.4 gallons per minute is approximately 1.175 feet per second.
- The K for the foot valve (table 7) in a 1 ½ inch pipe is 8.80 while the k for the gate valve in in 1 ½ inch pipe is 0.15
- The frictional head loss of the foot valve.:

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

$$= 8.80 \times 1.175^2/ (2 \times 32.185)$$

$$= 0.189 \text{ feet.}$$

Worked Example Cont'd

The frictional head loss of the gate valve

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

$= 0.15 \times 1.175^2 / (2 \times 32.185)$

= 0.003 feet

The total frictional head of the water piping system = Frictional head of the total water pipe plus the frictional head of the foot valve plus the frictional head of the gate valve:

=1.67+0.189+0.003

= 1.862 feet

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Velocity Head

- The velocity head is determined by the following formula:

$$\text{Velocity head} = v^2/2g$$

where

- v is the velocity of the water in metres per second (m/s) or feet per second (FPS)
- g is gravity (9.81m/s) or (32.185 feet/s).
- The velocity of the water is provided in the friction loss tables and charts.

Worked Example 10- Calculating Velocity Head (Metric)

- For the water pipe system determined in the previous worked example, what is the velocity head.
- The velocity was 0.49 metres per second.
- The velocity head

$$= v^2/2g$$

$$= 0.49^2/ (2 \times 9.8)$$

$$= 0.012 \text{ metres}$$

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 1.175 feet per second.
- The velocity head

$$= v^2/2g$$

$$= 1.175^2/ (2 \times 32.185)$$

$$= 0.021 \text{ feet}$$

Calculating Total Dynamic Head (Metric)

The total dynamic head =

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

To calculate the total dynamic head for the previous worked example:

- The static head = 4 + 10 = 14 metres
- The total frictional head loss based on maximum flow of the pump was calculated as 1.096 m
- The velocity head was determined as 0.012 metres
- The total dynamic head = static head + friction head of the complete water piping system + velocity head.
- = 14 + 1.096 + 0.012 = 15.108 metres

Worked Example 13– US/Imperial Calculating Total Dynamic Head

- For the solar water pumping system used in example 9, what is the total dynamic head.

- From Example 9 the static head = 13 + 33 = 46 feet

- The total frictional head loss based on maximum flow of the pump was calculated = 1.862 feet

- The velocity head was determined in example 11 as = 0.021 feet

- The total dynamic head = static head + friction head of the complete water piping system + velocity head.

  = 46+ 1.862 + 0.021 = 47.883 feet

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/

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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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