Module 4

Pumps for small-scale irrigation

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Introduction

Water can be conveyed by means of natural slopes, by lifting to a higher point and by means of pumps and pressurized pipelines. Devices for water lifting range from age-old indigenous water lifts to highly efficient pumps, which operate by electric, petrol or diesel motors (Garg 1989; Michael 1990). A pump is a device used to raise, transfer, or compress liquids and gases. There are four general classes of pumps, namely reciprocating, centrifugal, jet and other pumps. In each of the four classes, steps are taken to prevent cavitation (the formation of a vacuum), which would reduce the f ow and damage the structure of the pump. Pumps used for gases and vapors are usually known as compressors.

The indigenous water lifts were manually operated or animal-operated (Michael 1990). Based on the optimum range in the height of lift, they can be grouped as low, medium and high head water lift. The engine-powered pumps are classified into two major groups as positive and variable displacement pumps. The **positive displacement pumps** are again subdivided into reciprocating and rotary pumps. The reciprocating pump can either be a lift or a force pump. Both lift and force pumps can either be single acting or double acting pumps. The **variable displacement pumps** are subdivided into centrifugal, mixed-f ow, propeller, jet and air lift pumps. The centrifugal pumps are further subdivided into volute, diffuser and turbine pumps. The volute pumps can be a single stage or a multistage type. The turbine pumps can be grouped as deep well and submersible turbine pumps. This module deals with pumps that can be used for small-scale irrigation.

Reciprocating pumps consist of a piston moving back and forth in a cylinder that has valves to regulate the f ow of liquid into and out of the cylinder. These pumps may be single or double acting. In the single acting pump, the pumping action takes place on only one side of the piston, as in the case of the common lift pump, in which the piston is moved up and down by hand. In the double acting pump, the pumping action takes place on both sides of the piston, as in the electrical or steam-driven boiler feed pump, in which water is supplied to a steam boiler under high pressure. These pumps can be single-stage or multistaged. Multistaged reciprocating pumps have multiple cylinders in series.

Centrifugal pumps, also known as rotary pumps, have a rotating impeller known as a blade that is immersed in the liquid. Liquid enters the pump near the axis of the impeller, and the rotating impeller sweeps the liquid out toward the ends of the impeller blades at high pressure. The impeller also gives the liquid a relatively high velocity that can be converted into pressure in a stationary part of the pump, known as the diffuser. In high-pressure pumps, a number of impellers may be used in series, and the diffusers following each impeller may contain guide vanes to gradually reduce the liquid velocity. For lower-pressure pumps, the diffuser is generally a spiral passage, known as a volute, with its cross-sectional area increasing gradually to reduce the velocity efficiently. The impeller must be primed before it can begin operation—that is, the impeller must be surrounded by liquid when the pump is started. Placing a checkvalve in the suction line, which holds the liquid in the pump when the impeller is not rotating, can do this. If this valve leaks, the pump may need to be primed by the introduction of liquid from an outside source such as the discharge reservoir. A centrifugal pump generally has a valve in the discharge line to control the f ow and pressure.

Jet pumps use a relatively small stream of liquid or vapor, moving at high velocity, to move a larger f ow of f uid. As the high-velocity stream passes through the f uid, it carries some of the f uid out of the pump; at the same time, the high-velocity stream creates a vacuum that pulls f uid into the pump. Jet pumps are often used to inject water into a steam boiler. Jet pumps have also been used to propel boats, particularly in shallow water where a conventional propeller might be damaged.

A variety of positive-displacement pumps are also available, generally consisting of a rotating member with a number of lobes that move in a close-fitting casing. The liquid is trapped in the spaces between the lobes and then discharged into a region of higher pressure. A common device of this type is the gear pump, which consists of a pair of meshing gears. The lobes in this case are the gear teeth.

Chapter 1 Basic concepts of energy and power

Chapter objectives:

Upon the completion of this chapter, you will be able to:

- define energy and power
- calculate energy and power

1.1 Energy measurement

Energy enables one to lift or pump water. Joule (J) is the international energy unit in the metric measurement system. Since a joule is a very small amount of energy,[1] engineers use Watt-hour (Wh) where 1 Wh = 3600 joules or kilowatt-hour (kWh) = 1000 Wh. An important aspect of energy is that it can be changed from one form to another. People and animals can convert food (= chemical energy) into mechanical energy to drive their muscles. In a typical pumping system powered by a petrol engine, the energy is changed three times before the water uses it. Chemical energy contained within the gasoline is burnt in the engine to produce mechanical energy. This is passed to the pump via a drive shaft and finally to the water via an impeller in the case of centrifugal pumps (Figure 1).

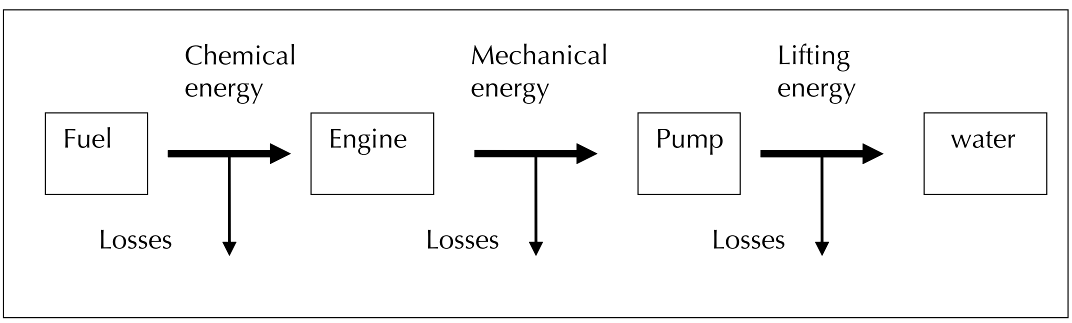


Figure 1. *Energy conversion and losses in a pumping system.*

The system of energy transfer is not perfect and energy losses occur through friction between the moving parts, water and pipes, and are usually lost as heat energy: An engine heats as fuel is burnt to provide power. Energy losses can be very high in pumping systems, and so can be costly in terms of fuel use.

1.2 Calculating energy

The amount of energy required to lift water depends on the volume of water to be lifted and the head (lifting height) required (equations 1a and b).

$$E = \frac{V_w H}{367} \quad (1a)$$

$$E = \frac{V_{wl} H}{367} \quad (1b)$$

where E is energy in kilowatt hour (kWh) or in Watt hour (Wh), V_w is volume of water in m^3, V_{wl} is volume of water in litres and H is the head in metres.

1. One joule enables to lift one litre of water of 10 centimetres.

Example 1.1

In a small irrigation scheme, irrigation water needs are 600 m^3/day. Calculate the energy required each day for lifting water 10 metres above the water source as in Figure 2.

(Answer: 16.3 kWh)

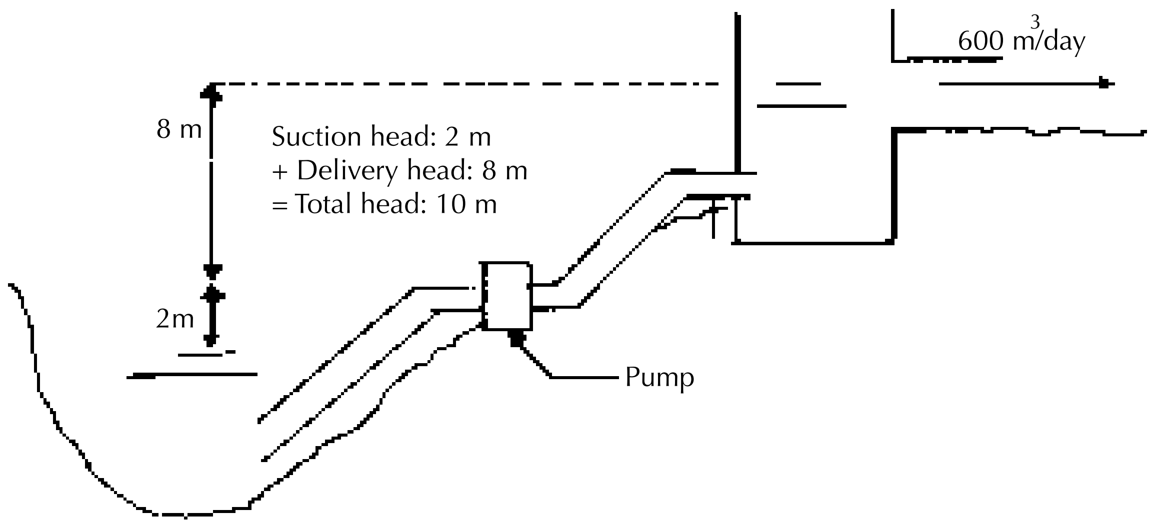


Figure 2. *Water lifting to a height of 10 m.*

1.3 Power

Power is often confused with energy. They are related but have different meanings. Energy is the capacity to lift water. **Power is the rate of using energy** and is commonly measured in watt (W) or kilowatt (kW), 1 kW = 1000 W. Another measure of power is horsepower (hp) (1 kW = 1.36 hp). Power is calculated as:

$$P = \frac{E}{t} \qquad (2)$$

where P is power in Watt, E is energy in watt hour and t is time in hour. Discharge is volume of water f ow divided by the time elapsed. Using this relationship, Equation 3 is derived from Equations 1 and 2.

$$P = 9.81QH \qquad (3)$$

where Q is discharge in litres per second (litres/sec).

Example 1.2

In example 1.1, it was calculated that the energy required each day to lift 600 m^3 of water through 10 metres was 16.3 kWh. Calculate the power required in kW if

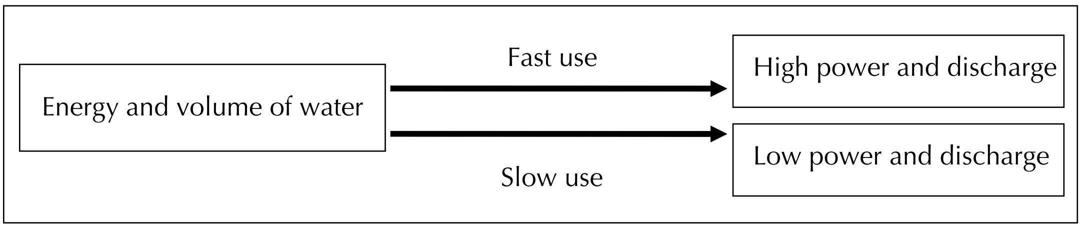
- Pumping is 12 hours/day
- Pumping is 8 hours/day
- Pumping is 4 hours 30′ per day

And in each case calculate the pump discharge in m^3/h and litre/sec.

Answers

	Power	Pump discharge	
Pumping 12 hours/day	1.36 kW	50 m3/h	14 litres/sec
Pumping 8 hours/day	2.04 kW	75 m3/h	31 litres/sec
Pumping 4 hours 30′/day	3.62 kW	133 m3/h	37 litres/sec

Reminder! Power is the rate of using energy.



Chapter 2 Selecting power source: Human power and engines

Chapter objectives:

Upon the completion of this chapter, you will be able to:

- understand the operation and irrigation capacity of treadle pumps
- understand centrifugal pumps
- explain the criteria for selecting irrigation pumps

There are many types of water pumps being used for irrigation and each pump type has different characteristics and capabilities (Michael 1990). A pumping unit or 'pump' has a source of power or engine to drive the pump that lifts water from the water source. The most common power sources in Ethiopia are human power, diesel and gasoline. Electric motors are more reliable and cheaper than petrol or diesel motors. As there is little rural electrification in Ethiopia they are seldom used. Developing micro hydropower units on streams of Ethiopian highlands is certainly an option worth considering.

Solar (still expensive) and wind-powered pumps (depending on wind conditions) are more appropriate for domestic or livestock water supply since they do not usually provide enough steady power to pump the volume of water required for irrigation. Animal powered pumps (noria, shadouf) have been in use for centuries in some parts of the world but not in Ethiopia. Furthermore animals have to be fed. Past experience in West Africa shows that this cost has been generally underestimated by people promoting animal-powered pumping.

2.1 Human power

The treadle pump (commonly known as pedal pump) is a water-lifting device similar in principle to the hand pump (Kay and Brabben 2000; Shigemichi and Shinohara 2004; Mangisoni 2006). The difference lies in the fact that a hand pump consists of a single barrel or cylinder and one has to pump up water with one's hands, whereas the pedal pump comprises two cylinders (Figure 3) and requires foot operation for lifting water (hence called a pedal pump). It is so simple to use that even a child, a woman or even an old person can operate the pump by manipulating his/her body weight on two foot pedals or treadles and by holding a bamboo or wooden frame for support. One can even make a comfortable sitting arrangement and pedal while being seated.

Most treadle pumps release water into furrows, as they have no delivery pressure. The '*Super Money Maker*' treadle pump manufactured by ApproTEC in Kenya has a delivery pressure of about 10 metres, and thus can release water through a f exible pipe on top of the crops. A reasonably fit man between 20 and 40 years old can produce a steady power output of 70 Watts (= 0.1 hp) (see Photo 1). However it is not possible to convert all the 70 Watts into useful water pumped because of losses through friction in the pump, valves and pipes. A useful water lifting power of 35 Watts is a reasonable estimation for a man operating a treadle pump. The discharge and head for a useful power of 35 Watts can be calculated (Equation 3) and are given in Table 1. Photos 2 and 3 show various treadle pumps.

Table 1. *Treadle pump discharge and head assuming a useful power output of 35 Watts.*

Head (m)	1.0	2.0	3.0	4.0
Discharge (litres/sec)	3.6	1.8	1.2	0.9

In practice, treadle pumps can be used when the required suction head does not exceed 4 to 6 metres.

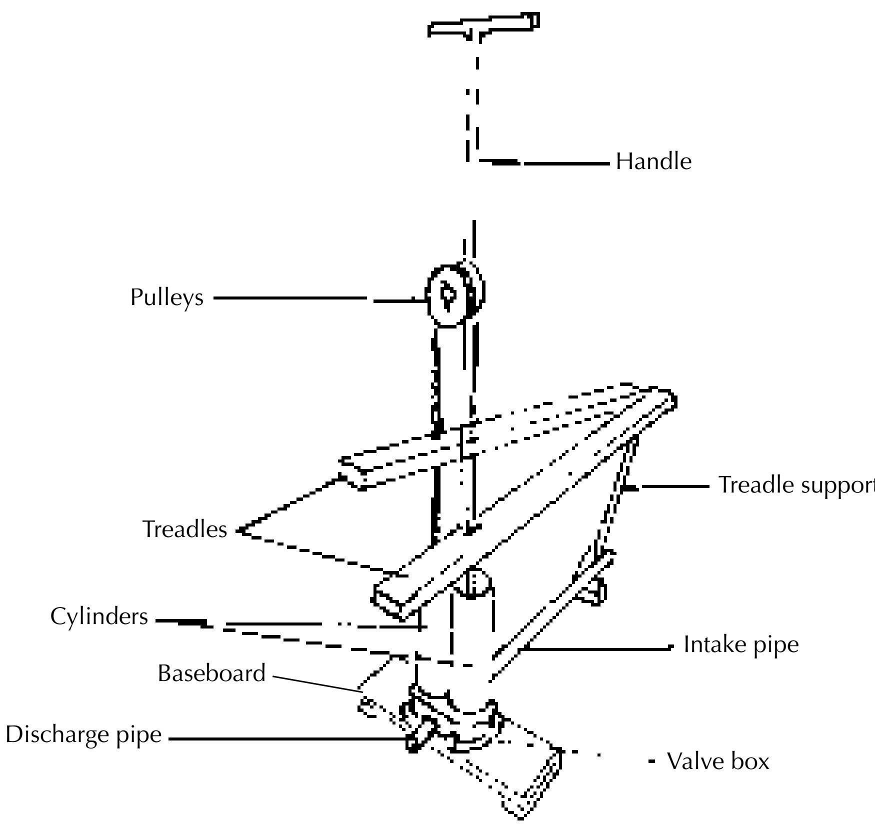


Figure 3. *Treadle pump.*

Photo 1. *Kickstart Money Maker Pump (Courtesy, Kickstart).*

Photo 2. *Treadle pumps (IWMI 2006).*

Malawi: Treadle pump models (from left)—Balaji metal treadles/pulley; MG Industries/pulley; Advaith, wooden treadles; Zim metal treadles/pulley; MG Industries/bicycle cog and chain; Pipeco, Mw wooden treadles/rubber pulley; Balaji metal treadles/pivot (Photo: Z Jere, Total Landcare Malawi and H Phombeya, Land Resource Centre Malawi).

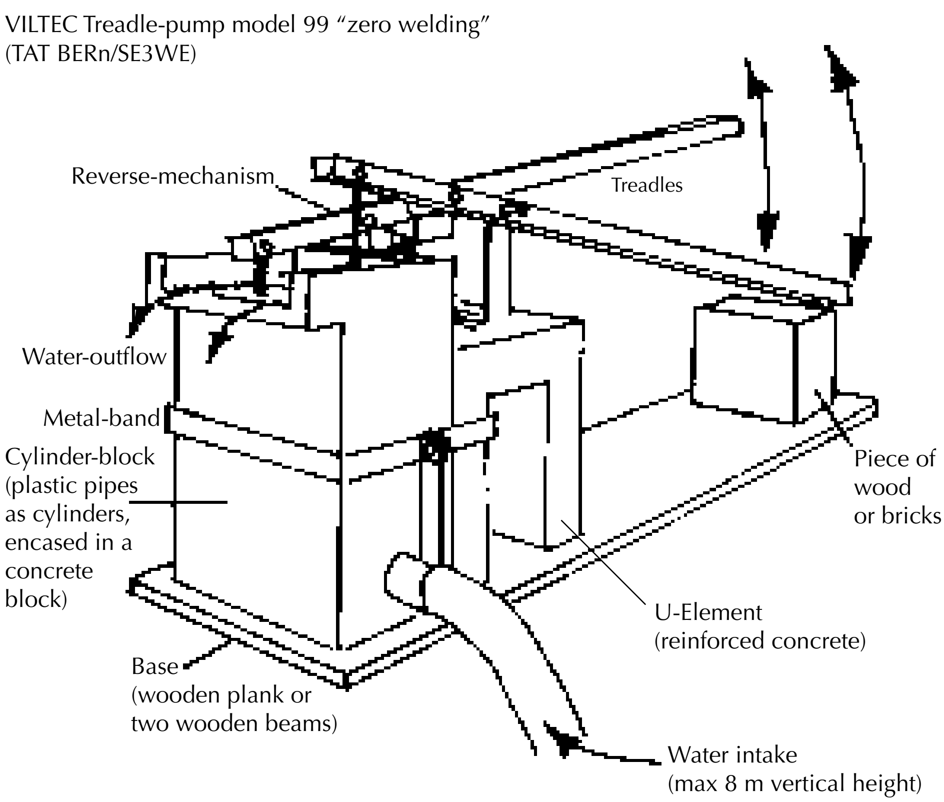


Photo 3.*Treadle pump of zero welding variant.*

Irrigation capacity of treadle pumps

In Ethiopia, peak crop water requirements are about 6 mm/day in the highlands and 8 mm/day in the lowlands. Irrigation efficiency is about 75%. Peak irrigation water requirements are then 8 mm/day (= 80 m^3/ha per day) and 11 mm/day (= 110 m^3/ha per day) in Ethiopian highlands and lowlands, respectively. Considering the human effort demanded to operate a treadle pump, 8 hours per day[2] is a reasonable estimation of maximum daily pumping time. Treadle pumps irrigation capacity (or irrigable area) is given in Table 2. Under most common conditions (head between 2 and 4 m), irrigation capacity of a treadle pump is between 0.2 and 0.6 ha in Ethiopia. However, considering human effort to operate a treadle pump, we recommend to limit irrigated area to 0.5 ha (Shah et al. 2000; Molza-Banda 2006).

Table 2. *Irrigation capacity of treadle pumps assuming a steady useful power of 35 watt 8 hours per day*

Head (m)	1	2	3	4
Discharge (litres/sec)	3.6	1.8	1.2	0.9
Volume pumped in 8 hours (m^3)	102.75	51.38	34.25	25.69
Irrigation capacity (ha) in highland	1.28	0.64	0.43	0.32
Irrigation capacity (ha) in lowland	0.93	0.47	0.31	0.23

Reminder!

For a farmer wanting to irrigate a small area from a shallow water source (less than 4 metres below the surface) a treadle pump may be a good choice.

Ethiopian farmers' labour is not necessarily cheap and plentiful. A very large amount of time and human effort is needed to provide the same power as a small engine. When using a treadle pump, it takes approximately 30 minutes of continuous human effort to pump what a small motorized pump (2.3 kW = 3 hp) can pump in one minute!

Name of pumps	Money maker	Super money maker	Swiss concrete pump
Manufacturer	ApproTEC, Kenya	ApproTEC	Salam vocational Centre, Addis Ababa
Pump body	Metal	Metal	Concrete
Cylinders	Metal	Metal	Plastic
Piston	Metal and rubber	Metal and rubber	Metal and rubber
Other components	Metal and rubber	Metal and rubber	Metal and rubber
Method of joining components	Welding	Welding	Bolts, nuts and screws
Practical max suction head	4 m	4 m	4 m
Max delivery head	0 m	13 m	0 m
Weight (kg)	15	20	60
Manufacturer selling price (USD)	54	75	

Four models of treadle pumps are manufactured in India. They are:

1. 3.5 inch pump (metal barrel) with bamboo treadles (Figure 4)
2. 3.5 inch pump (metal barrel) with metal treadles (Figure 5)
3. 5 inch concrete pump with (PVC sleeves) with wooden pedals (Figure 6)
4. 3.5 inch surface treadle pump (STP) (Figure 7)

The treadle pump is ideal for areas where the water table is high, ranging from 3 m to 7.5 m below the ground. Besides, most of the models of the treadle pump can be used for drawing surface water, such as from ponds, canals, streams and dug wells.

2. In this case, human energy provided each day is about 70 W × 8 hours = 560 Wh.

Figure 4. *Salient features of 3.5 inch pump (metal barrels) with bamboo treadles.*

Figure 5. *Salient features of 3.5 inch treadle pump (metal barrels) with metal treadles.*

Figure 6. *Salient features of 5 inch concrete pump (PVC Sleeves) with wooden pedals.*

Figure 7. *Salient features of 3.5 inch Surface Treadle Pump (STP).*

2.2 Diesel and petrol engines coupled with centrifugal pumps

2.2.1 Diesel and petrol engines

Petrol engines use a spark to ignite the fuel (gasoline) while diesel engines rely on the high temperature achieved by very high compression to ignite diesel oil. The result in practice is that diesel engines are about 3 times heavier than petrol pumps of equivalent power, more robust and with more precise fuel injection components. A diesel engine is therefore more expensive to buy than a comparable petrol engine; however, its working life (in years) will be normally longer than a petrol engine even if petrol engines run fewer hours each day. A diesel engine is also better suited for running many hours a day, day after day. By contrast small petrol engines are designed for running a few hours (up to 5 hours) each day. Usually, petrol engines require more regular maintenance than diesel engines. However, when a serious breakdown occurs to a diesel engine (i.e. troubles with injectors or injection pumps), intervention of a well-qualified mechanic is necessary and spare parts are costly. As fuel oil is cheaper than gasoline, operation costs of diesel engines are lower.

Reminder!

A petrol engine is a good choice when low weight for portability and low purchase price are important and when the pump will be operated only a few hours per day. A diesel engine is recommended when low maintenance and operation costs are important and when the pump is likely to be operated more than five hours each day.

2.2.2 Centrifugal pumps

Centrifugal pumps are the most commonly used engine-powered pumps for small-scale irrigation. They are relatively cheap and very easy to maintain. The centrifugal pump has an impeller with blades, which spins at high speed inside the pump casing (Figure 8). Water is drawn into the pump from the source through a short inlet pipe or suction pipe. As the impeller spins, the water is thrown outwards and is guided towards the outlet or delivery pipe. Centrifugal pumps are described by the diameter (in mm) of the delivery connection pipe where the hose is connected. A rough guide to select a pump in Ethiopia is presented in Table 3. **It is wise to seek advice from an irrigation engineer before selecting a pump.**

Table 3. *Rough guide for pump selection in Ethiopia*

Engine power kW (hp)	Pump size (mm)	Estimated highlands irrigable area	Estimated lowlands irrigable area
1.5 (2)	25	1.5 ha	1.2 ha
3.7 (5)	50	5.0 ha	4.0 ha
5.2 (7)	75	9.0 ha	6.5 ha
6.7 (9)	100	12.0 ha	9.0 ha

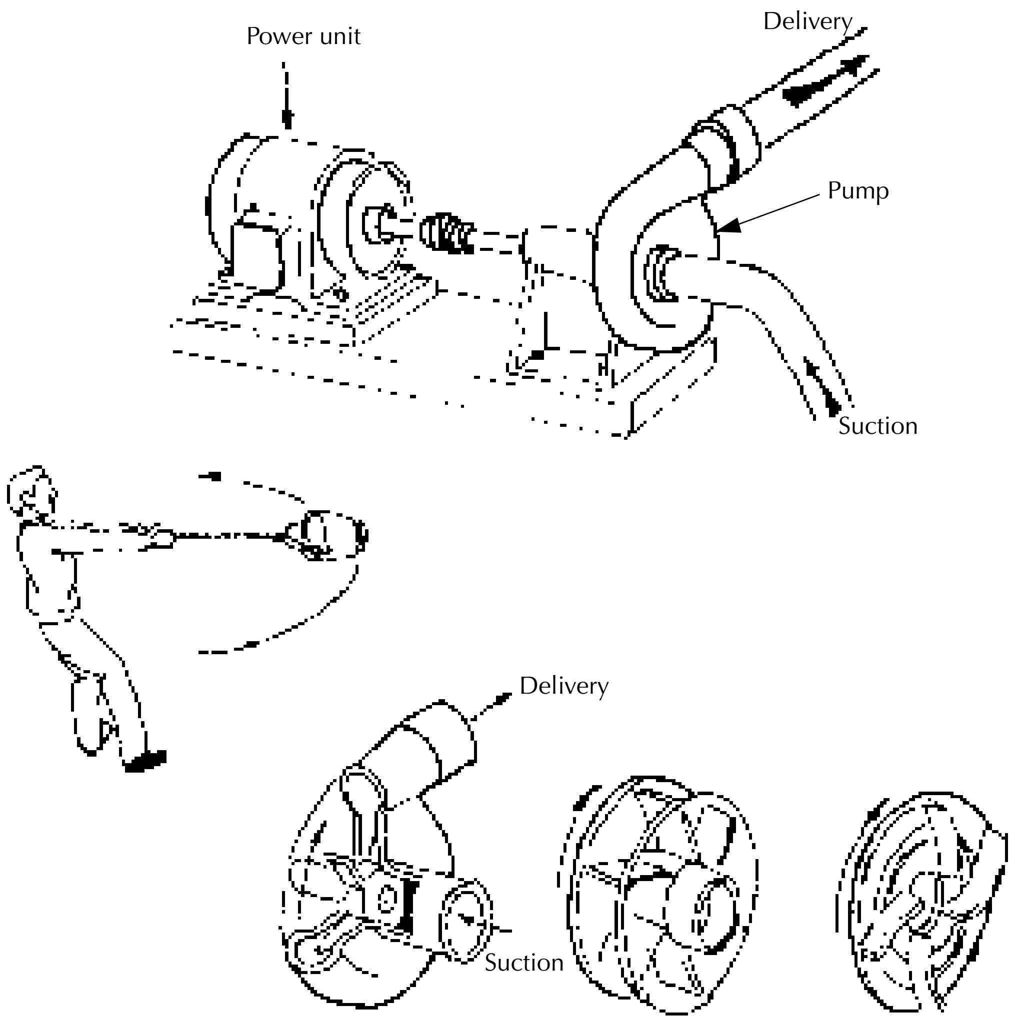


Figure 8. *Motorized centrifugal pumps.*

Irrigable area is estimated assuming irrigation efficiency is 50% and maximum pumping time is 12 hours per day. In practice:

- If actual maximum pumping time is for example 5 hours a day, reduce irrigation capacity by 5/12 ratio.
- An irrigation efficiency of 50% is an acceptable benchmark for surface irrigation with earthen canals. However, due to poor operation and maintenance, irrigation efficiency may be less than 50%. This will reduce irrigation capacity.

Manufacturers produce a range of different impeller designs for any size of pumps. Depending on the impeller design all motorized centrifugal pumps would give their best performance at a specific motor speed, head and f ow discharge. The pump manual will normally give the pump characteristics under the form of a graph showing the relationship between head and discharge at the optimal engine speed.

Adequacy between power/head per discharge and efficiency of centrifugal pumps

Motorized pumps efficiency is the ratio between power used to lift water and mechanical power provided by the motor. Centrifugal pumps are not very appropriate for surface irrigation. Because of global market demand, they are designed to provide relatively high head and low discharge for a given power while low head and large discharge is more suitable for surface irrigation. As there is no practical alternative, some level of inefficiency, i.e. fuel wasting, has to be accepted.

Example 2.1

A pump driven by a 3.7 kW (5 hp) motor is designed to deliver about 14 litres/sec at 18 m of water head. In this case the power delivered to lift water is 2.5 kW (calculated with Equation 3) and efficiency is 68% (= 100 × 2.5 kW/3.7 kW). If farmers need to raise water through a total head of 5 m only, the pump will then give a discharge of 21 litres/sec. The useful power to lift water will then be 1.0 kW and efficiency 27%. In this case, using the same amount of fuel the pump provides less power or, in other words, the pump uses more fuel to provide the same amount of energy.

Pump speed and efficiency

The pumps characteristic curve given by manufacturers assumes that the pump is run at its **optimum design speed**. Diesel or petrol engines driving centrifugal pumps have a throttle to adjust the pump speed and the optimum design speed is usually three-quarters of the maximum throttle. Farmers often run their pumps very slowly to reduce the discharge usually because they find it difficult to manage f ow in the field. In this case inefficiency (waste of fuel) becomes much worse: the pump will use more fuel even though the amount of water pumped is less. A pump gives its best performance at its optimum design speed.

> Reminder!
>
> To avoid wasting fuel:
>
> When selecting a pump, try to have the best possible adequacy between power and required discharge and head. An irrigation engineer who understands pump characteristics may help.
>
> Centrifugal pumps should be operated close to optimum design speed that is usually at three-quarters maximum engine throttle.

2.3 Criteria and tips for selecting irrigation pumps

When dealing with pumping technology, extension officers' job consists mainly in guiding farmers for selecting a technology well adapted to their needs and constraints. Suggested selection criteria are:

- Best possible adequacy between engine power and required discharge and head
- Low purchase cost
- Long working life
- High efficiency of human or fuel energy
- Low operating costs

- Easy access to spare parts at reasonable price and low repair cost
- Portability in case of multiple users in different places or for limiting risk of theft.

Photo 4: *Deep well pump, Kobo Girana Valley Development, Ethiopia (Courtesy, Sileshi B Awulachew).*

Chapter 3 Operation and maintenance of pumps

Chapter objectives:

Upon the completion of this chapter, you will be able to:

- understand suction and delivery head
- explain maintenance of pumps
- describe pumping cost
- determine the sustainability of pump-fed irrigation

3.1 Suction head

Treadle pumps or centrifugal pumps must be located above the water source and the pipe used to draw water from the source into the pump is the suction pipe (Shah et al. 2000 and 2002). The difference in height between the water surface and the pump is the suction head (or suction lift). **Suction head is the most important aspect affecting the operation of a pump.** Pumps do not actually 'suck' water as it is often imagined. A pump takes water from the source by creating a low pressure in the suction pipe. Atmospheric pressure does the rest, pushing down on the water and forcing water up into the suction pipe. At sea level atmospheric pressure is approximately 10 m head of water (= 1 kgf/cm^2). In theory it can push water up to 10 m; **this upper limit applies to all pumps.**

Because of friction losses and the difficulty to create an extremely low pressure, practical limit is 7 m (Figure 9). Even at this limit pumps will have difficulties to operate and discharge will drop. **At high altitudes as in Ethiopian highlands, atmospheric pressure is less than at sea level, practical limit decreases of 1 m for every 1000 m of altitude. At 2000 m above sea level, practical limit is 5 m.**

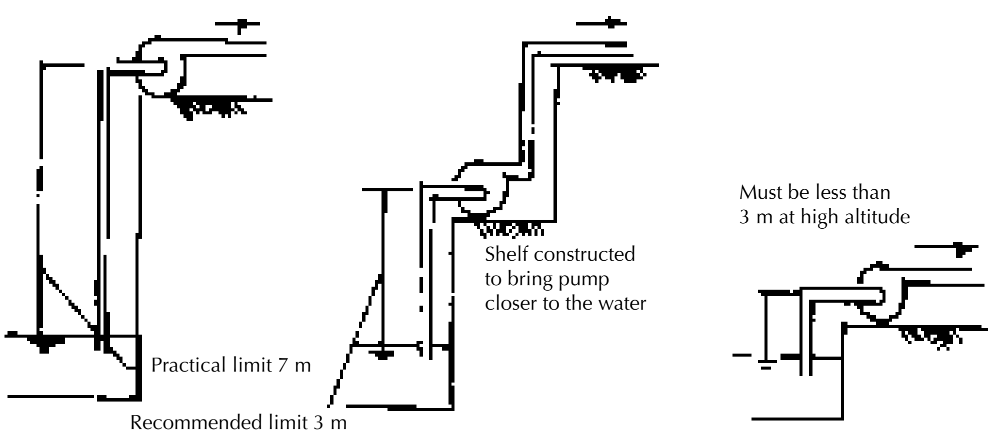


Figure 9. *Suction head limitation.*

Priming a pump

All treadle pumps and most centrifugal pumps have to be primed before starting pumping. Priming the pump simply means that the pumps casing and the suction pipe should be filled with water thus expelling all the air from the pump-system.

Reminder!

Locate the pump less than 3 metres above water source. It is better to use a pump to 'push' water rather than suck it, keep the pump as close to the water level as possible.

3.2 Suction and delivery pipe

The suction pipe must be stiff-walled to prevent the pipe from collapsing under atmospheric pressure when the pump creates a low pressure inside it. As a consequence, suction pipes are expensive, which is another good reason for keeping the pump close to the water surface. The suction pipe must be sufficiently immersed beneath the water surface so that there is no risk of drawing in air; to do so it may be necessary to dig into the bed of the stream. However, the suction pipe inlet should not be placed on the bed of the water source (stream, lake…) to avoid pumping dirt and mud. The delivery pipe does not have to be stiff-walled, as the water pressure will keep it open. Lay-f at pipes are very common but are not very durable and may be quickly damaged if moved around the farm.

With **treadle pumps**, water is usually released directly from the delivery pipe to the furrows (or on top of the crops for treadle pumps having a delivery pressure). With **motorized pumps**, delivering the full pump discharge directly to the crop beds or furrows is not wise. The f ow is usually too strong to be well controlled therefore can be damaging for crops and cause soil erosion. When they see this, farmers reduce the f ow by slowing the pump, which is also not wise. It is much better delivering water to a stilling basin located at the highest part of the farm and then dividing and distributing water through small canals to the crop bed or furrows.

Reminder!

Install pumps close to the water surface.

With motorized pumps:

- It is recommended to deliver water first to a stilling basin located at the highest part of the farm and then distribute water by gravity (canals) to crops.
- To avoid excessive fuel waste, motorized pumps should run at a speed close to the optimum design speed, i.e. about three-quarters of the maximum motor throttle.
- When selecting a pump, try to have the best possible adequacy between power and required discharge and head. An irrigation engineer who understands pump characteristics may help.

3.3 Maintenance of pumps

Irrigation pumps and engines should be maintained following the instructions provided in the manufacture's manual. Inform farmers about these instructions through leaf ets and training sessions. Try to involve local pumps dealers, spare parts retailers and mechanics in these sessions. Farmers should be trained to carry out routine maintenance tasks such as changing filters and bleeding fuel lines to remove air. Farmers should know reliable mechanics in case of major problems and where to find spare parts at reasonable prices.

3.4 Pumping cost

Farmers should be encouraged to keep a book for registering expenditures to run the pump: cost of fuel, oil (lubricant) and spare parts. Organizing sessions enabling farmers to compare their pumping cost/irrigated ha and pumping costs to their overall production costs would be useful to improve irrigation management.

Table 4 gives theoretical fuel consumption of well-maintained, not too old motorized pumps. As you can see fuel cost of diesel engine are usually much lower as petrol engines. These data can help for your follow-up activities.

Table 4. *Theoretical fuel consumption of well maintained motorized pumps*

Engine power kW (hp)	Diesel engine	Petrol engine
	Consumption of diesel oil (litre/hour)	Consumption of gasoline (litre/hour)
1.5 (3)	0.7	1.7
3.7 (5)	1.7	4.1
5.2 (7)	2.4	5.8
6.7 (9)	3.0	7.4

3.5 Sustainability of pump-fed irrigation

Even properly maintained pumps need replacement at the end of their working life. There are many examples of farmers having abandoned irrigated agriculture because they could not afford to replace their old worn out pump. This particularly occurs when pumps have been donated or subsidized and in group-based irrigation scheme with a relatively large number of farmers, says from experience more than 30. Extension officers should provide guidance and follow-up support to farmers about financial management of irrigation to help them saving money for pump replacement or major breakdown. Seeking advice of financial professionals such as bankers, accountants of cooperative or credit institutions is a good idea.

Reminder

- Saving money for pump replacement or major breakdown is a crucial issue for pump-fed irrigation sustainability
- Irrigation financial management requires skills most farmers don’t have. Hence farmers’ guidance and follow-up is important. Try to involve financial professionals in doing so. In group-based irrigation schemes, difficulty of financial management increases with number of farmers. Maximum group size should be about 30 persons.

In theory, the money to be saved each year should be equal to the cost of the pump divided by its working life expectancy. The latter varies with the conditions of operating the pump. Roughly life expectancy of petrol engine powered pumps is 3–5 years, 6–10 years for a diesel engine. However, more f exible management systems are possible, for instance based on profit made each season or year.

Chapter 4 Water-powered pumps (hydraulic ram)

Chapter objectives:

After reading and understanding this chapter, you will be able to:

- explain operation principles of hydraulic ram
- construct home-made hydraulic ram
- describe factors in design of hydraulic ram
- explain the components of hydraulic ram

A hydraulic ram or impulse pump is a device that uses the energy of falling water to lift a lesser amount of water to a higher elevation than the source (Figure 10). There are only two moving parts, and thus there is little to wear out. Hydraulic rams are relatively economical to purchase and install. They can be built with detailed plans and if properly installed, they can give many trouble-free years of service with no pumping costs. For these reasons, the hydraulic ram is an attractive solution where a large gravity f ow exists. A ram should be considered when there is a source that can provide at least seven times more water than the ram is to pump and the water is, or can be made, free of trash and sand. There must be a site for the ram at least 0.5 m below the water source and water must be needed at a level higher than the source.

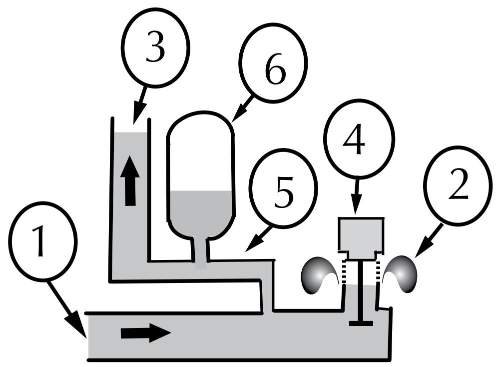
Figure 10. *A hydraulic ram that drives a fountain at the Centre for Alternative Technology.*

4.1 Operation principles and construction

4.1.1 Principles of operation

A hydraulic ram has only two moving parts, a spring or weight loaded 'waste' valve sometimes known as the 'clack' valve and a 'delivery' check valve, making it cheap to build, easy to maintain, and very reliable. In addition, there is a drive pipe supplying water from an elevated source, and a delivery pipe, taking a portion of the water that comes through the drive pipe to an elevation higher than the source. The sequence of its operation is shown below:

Referring to Figure 11, initially, the [4] waste valve is open, the [5] delivery valve is closed. The water in the [1] drive pipe starts to f ow under the force of gravity and picks up speed and kinetic energy until it forces the waste valve closed. The momentum of the water f ow in the supply pipe against the now closed waste valve causes a water hammer, raises the pressure in the pump and opens the delivery valve [5], so some water f ows into the delivery pipe [3]. Since this water is being forced uphill through the delivery pipe rather than it is falling downhill from the source, the f ow slows down and when it reverses the delivery check valve closes. If all water f ow has stopped, the loaded waste valve reopens against the now static head, allowing the process to begin again. A pressure vessel [6] containing air, cushions the hydraulic pressure shock when the waste valve closes, and it also improves the pumping efficiency by allowing a more constant f ow through the delivery pipe.



(1) Inlet — drive pipe; (2) Free f ow at waste valve; (3) Outlet — delivery pipe; (4) Waste valve; (5) Delivery check valve; and (6) Pressure vessel.

Figure 11. *Sequence of operation of a hydraulic ram.*

The optimum length of the drive pipe is 5 to 12 times the vertical distance between the source and the pump or 500 to 1000 times the diameter of the delivery pipe whichever is less. This length of drive pipe typically results in a period between pulses of 1 to 2 seconds. A typical efficiency is 60%, but up to 80% is possible. The drive pipe is ordinarily straight but can be curved or even wound in a spiral. The main requirement is that it is inelastic, strong and rigid as otherwise it would greatly diminish the efficiency.

4.1.2 Home-made hydraulic ram pump

The information in Figure 12 is provided as a service to those wanting to build their own hydraulic ram pump at home. The data from our experiences with one of these home-made hydraulic ram pumps is listed in Table 5.

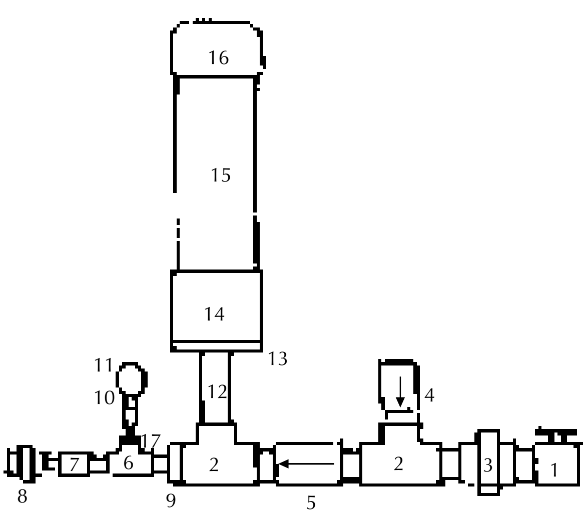


Figure 12. *Home-made hydraulic ram.*

Table 5. *Materials for Figure 12*

1	1 1/4″ valve	10	1/4″ pipe cock
2	1 1/4″ tee	11	100 psi gauge
3	1 1/4″ union	12	1 1/4″ × 6″ nipple
4	1 1/4″ brass swing check valve (picture)	13	4″ × 1 1/4″ bushing
5	1 1/4″ spring check valve	14	4″ coupling
6	3/4″ tee	15	4″ × 24″ PR160 PVC pipe
7	3/4″ valve	16	4″ PVC glue cap
8	3/4″ union	17	3/4″ × 1/4″ bushing
9	1 1/4″ × 3/4″ bushing		

All connectors between the fittings are threaded pipe nipples — usually 2″ in length or shorter. This pump can be made from PVC fittings or galvanized steel. In either case, it is recommended that the 4″ diameter fittings be PVC fittings to conserve weight.

Conversion note: 1″ (1 inch) = 2.54 cm; 1 PSI (pound/square inch) = 6.895 KPa or 0.06895 bar; 1 gallon per minute = 3.78 litre per minute. PR160 PVC pipe is PVC pipe rated at 160 psi pressure.

The samples for the installations are shown in Figures 13, 14 and 15.

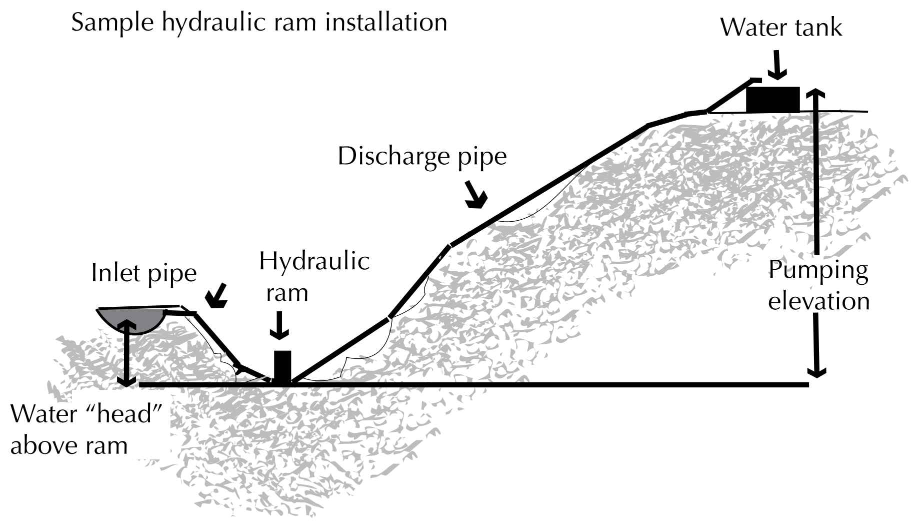


Figure 13. *This installation is the 'normal' ram system where the inlet pipe is less than the maximum length allowed. No stand pipe or open tank is required.*

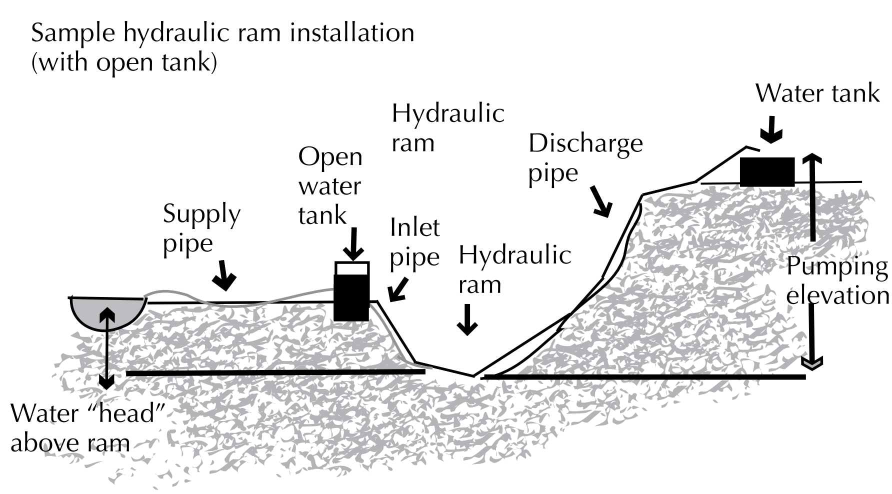


Figure 14. *This installation is one option used where the inlet pipe is longer than the maximum length allowed. The open water tank is required to allow dissipation of the water hammer shock wave.*

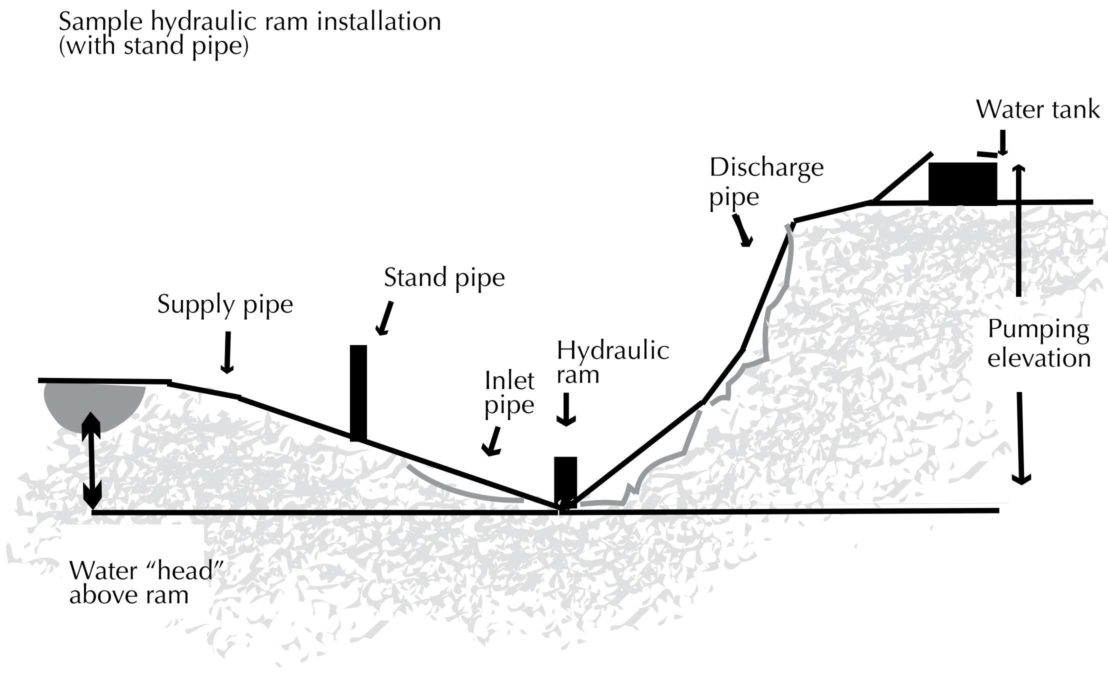


Figure 15. *This installation is another option used where the inlet pipe is longer than the maximum length allowed. The stand pipe (open to atmosphere at the top) is required to allow dissipation of the water hammer shock wave.*

4.2 Factors in design

Before a ram can be selected, several design factors must be known.

1. The difference in height between the water source and the pump site (called vertical fall).
2. The difference in height between the pump site and the point of storage or use (lift).
3. The quantity (Q) of f ow available from the source.
4. The quantity of water required.
5. The length of pipe from the source to the pump site (called the drive pipe).
6. The length of pipe from the pump to the storage site (called the delivery pipe).

Once this information has been obtained, a calculation can be made to see if the amount of water needed can be supplied by a ram. The formula is:

$$D = (S \times F \times E)/L$$

where:

D = amount delivered in litres per 24 hours
S = quantity of water supplied in litres per minute
F = the fall or height of the source above the ram in metres
E = the efficiency of the ram (for commercial models use 0.66, for home built use 0.33 unless otherwise indicated)
L = the lift height of the point of use above the ram in metres.

Table 6 solves this formula for rams with efficiencies of 66 percent, a supply of 1 litre per minute, and with the working fall and lift shown in the table. For supplies greater than 1 litre/minute, simply multiply by the number of litres supplied.

Table 6. *Ram performance data for a supply of 1 litre/minute*

Working fall (m)	Litres delivered over 24 hours											
	Lift—Vertical height to which water is raised above the ram (m)											
	5	7.5	10	15	20	30	40	50	60	80	100	125
1.0	144	77	65	33	29	19.5	12.5					
1.5		135	96.5	70	54	36	19	15				
2.0		220	156	105	79	53	33	25	19.5	12.5		
2.5		280	200	125	100	66	40.5	32.5	24	15.5	12	
3.0			260	180	130	87	65	51	40	27	17.5	12
3.5				215	150	100	75	60	46	31.5	20	14
4.0				255	173	115	86	69	53	36	23	16
5.0				310	236	155	118	94	71.5	50	36	23
6.0					282	185	140	112	93.5	64.5	47.5	34.5
7.0						216	163	130	109	82	60	48
8.0							187	149	125	94	69	55
9.0							212	168	140	105	84	62
10.0							245	187	156	117	93	69
12.0							295	225	187	140	113	83
14.0								265	218	167	132	97
16.0									250	187	150	110
18.0									280	210	169	124
20.0										237	188	140

4.3 Components of hydraulic ram

A hydraulic ram installation consists of a supply, a drive pipe, the ram, a supply line and usually a storage tank (see Figures 13–16).

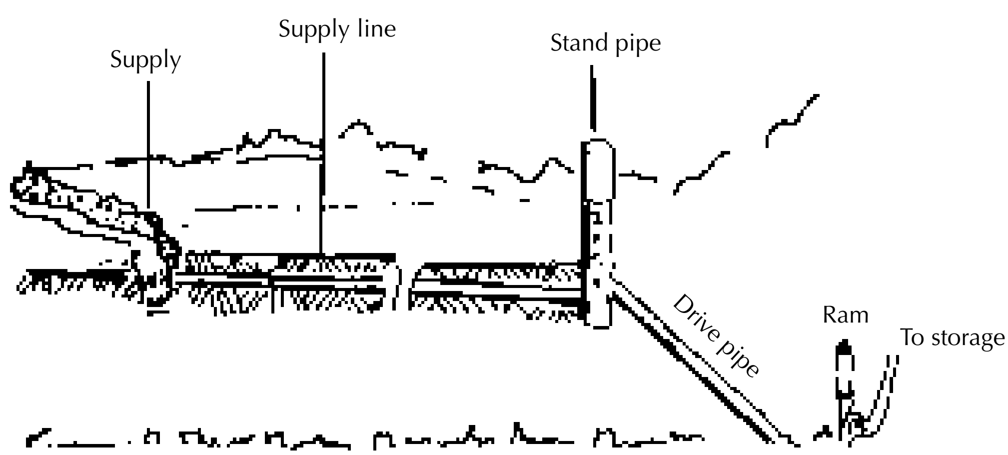


Figure 16. *Ram pump remote from source.*

Supply. The intake must be designed to keep trash and sand out of the supply since these can plug up the ram. If the water is not naturally free of these materials, the intake should be screened or a settling basin provided. When the source is remote from the ram site, the supply line can be designed to conduct the water to a drive pipe as shown in Figure 16. The supply line, if needed, should be at least one pipe diameter larger than the drive pipe.

Drive pipe. The drive pipe must be made of a non-f exible material for maximum efficiency. This is usually galvanized iron pipe, although other materials cased in concrete will work. In order to reduce head loss due to friction, the length of the pipe divided by the diameter of the pipe should be within the range of 150–1000. Table 7 shows the minimum and maximum pipe lengths for various pipe sizes.

Table 7. *Range of drive pipe lengths for various pipe diameters*

Drive pipe size (mm)	Length (metres)	
	Minimum	Maximum
13	2	13
20	3	20
25	4	25
30	4.5	30
40	6	40
50	7.5	50
80	12	80
100	15	100

The drive pipe diameter is usually chosen based on the size of the ram and the manufacturer's recommendations as shown in Table 8. The length is four to six times the vertical fall.

Table 8. *Drive pipe diameters by hydram manufacturer's size number*

Hydram size	1	2	3	3.5	4	5	6
Pipe size (mm)	32	38	51	63.5	76	101	127

Ram. Rams can be constructed using commercially available check valves or by fabricating check valves. They are available as manufactured units in various sizes and pumping capacities. Rams can be used in tandem to pump water if one ram is not large enough to supply the need. Each ram must have its own drive pipe, but all can pump through a common delivery pipe as shown in Figure 17.

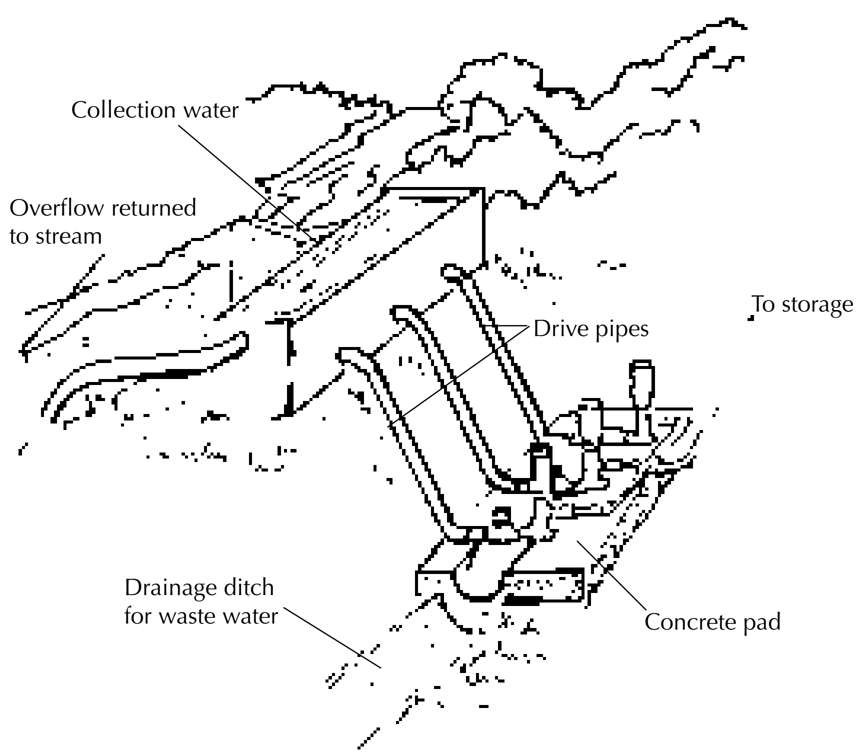


Figure 17. *Multiple ram with common delivery pipe.*

When installing the ram, it is important that it be level, securely attached to an immovable base, preferably concrete, and that waste-water be drained away. The pump cannot operate when submerged. Since the ram usually operates on a 24-hour basis the size can be determined for delivery over a 24-hour period. Table 9 shows hydraulic ram capacities for one manufacturer's hydrams.

Table 9. *Hydram capacity by manufacturer's size number*

	Size of hydram								
	1	2	3	3.5	4	5X	6X	5Y	6Y
Volume of drive water needed (litres/min)	7–16	12–25	27–55	45–96	68–137	136–270	180–410	136–270	180–410
Maximum lift (m)	150	150	120	120	120	105	105	105	

Delivery pipe. The delivery pipe can be of any material that can withstand the water pressure. The size of the line can be estimated using Table 10.

Table 10. *Sizing the delivery pipe*

Delivery pipe size (mm)	Flow (litres/min)
30	6–36
40	37–60
50	61–90
80	91–234
100	235–360

Storage tank. This is located at a level to provide water to the point of use. The size is based on the maximum demand per day.

Chapter 5 Wind powered pumps

Chapter objectives:

After reading and understanding this chapter, you will be able to:

- describe and adopt wind-powered water pumps for livestock watering
- explain kinds of windmills
- choose a location for a windmill
- estimate water delivered by wind-powered pump
- know kinds of pumps available for use with windmills

5.1 Wind-powered water pumps for livestock watering

Wind power is a non-polluting renewable energy resource that can be harnessed where access to power lines is not practical. There are three types of wind power systems. Two of them use mechanical power to pump water, while the third converts wind power to electrical energy.

Mechanical—piston pump—This system converts rotary wind power to vertical motion, using a snake rod and a piston pump to lift water.

Mechanical—air lift pump—This system uses wind power to charge a compressor that pumps air to lift water.

Electrical pump—The electrical pumping system channels the energy generated directly to the water pump, and/or to a battery storage system. The system design will depend on:

- your specific energy needs
- whether a battery storage system is required
- the amount of wind available to the site.

Batteries can account for more than 20% of the total capital investment, so they are a key factor if you are considering an electrical pumping system. Water supplies such as wells and dugouts can often be developed on the open range. However, the availability of power supplies on the open range is often limited, so some alternate form of energy is required to convey water from the source to a point of consumption. Wind energy is an abundant source of renewable energy that can be exploited for pumping water in remote locations, and windmills are one of the oldest methods of harnessing the energy of the wind to pump water (Figure 18).

5.2 Kinds of windmills

There are generally considered to be two types of windmills, with the classification depending on the orientation of the axis of rotation of the rotor. Vertical-axis wind turbines are efficient and can obtain power from wind blowing in any direction, whereas horizontal-axis devices must be oriented facing the wind to extract power. Most windmills for water-pumping applications are of the horizontal-axis variety, and have multi-bladed rotors that can supply the high torque required to initiate operation of a mechanical pump. Windmills can also be used to generate electricity, but electricity-generating units usually consist of vertical-axis rotors or high-speed propellor rotors, due to the requirement for low starting torques. Figure 18 illustrates a typical water-pumping windmill.

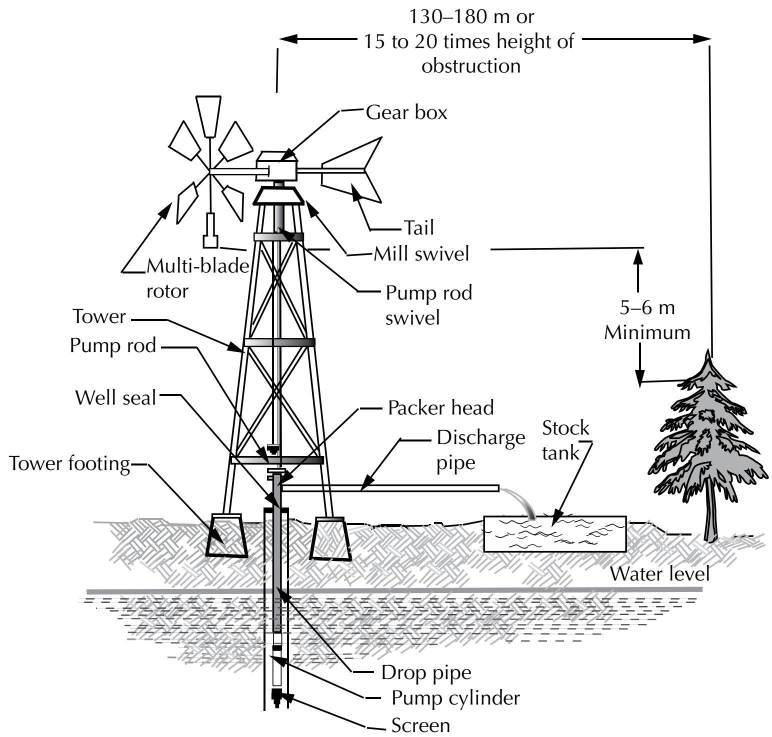


Figure 18. *Typical windmill water pump.*

5.3 Choosing location for a windmill

The primary consideration in choosing a site for a windmill is whether there is sufficient wind for such a device to be feasible. Obtaining site-specific measurements of wind speed and duration during the period over which water pumping is required is the only reliable way of determining whether a wind-powered pumping unit will be a viable option. To take such measurements, an anemometer is required (Figure 19).

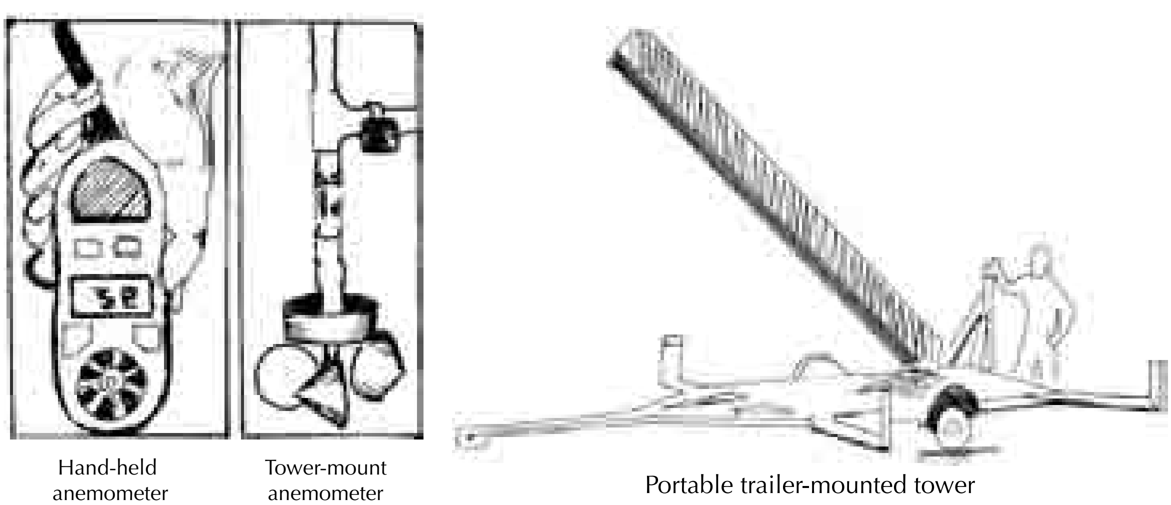


Figure 19. *Anemometer for measuring wind speed.*

Economical hand-held anemometers are available, but their use requires that a considerable amount of time be spent on site to establish meaningful records. A better way of gathering wind data would be to mount an anemometer (with an automated data recording device) on a tower similar in height to the proposed windmill for the entire period of interest.

Typically television or radio antenna towers can be used, and some are available as portable, trailer-mounted units.

Windmills used to generate electricity to power an electrical pump can be located away from the pumping unit, and windmills that power an air compressor, which operates an airlift pump, can also be located away from the pump. However, most windmills are designed to operate a reciprocating piston-type pump and must be located directly over the water source (usually a well).

To ensure that the windmill receives a free f ow of air from all directions, the rotor of a windmill should be located at least 5 to 6 m (15 to 20 feet) higher than any obstruction within about 130 to 180 m (450 to 600 feet) of the windmill site. In fact, wind speeds generally increases with altitude, so the tower should be as high as reasonably possible, regardless of the presence of obstructions. Topographic effects, such as confined draws and hills, should also be considered.

5.4 Water delivered by wind-powered pump

The amount of water a wind-powered water pumping system can deliver depends on the speed and duration of the wind, the size and efficiency of the rotor, the efficiency of the pump being used, and how far the water has to be lifted. The power delivered by a windmill can be determined from the following equation:

$$P = 0.0109 D^2 V^3 \eta$$

where P is power in watts, D is the rotor diameter in metres, V is the wind speed in kilometres per hour, and η is the efficiency of the wind turbine. As can be seen from this expression, relatively large increases in power result from comparatively small increases in the size of the rotor and the available wind speed; doubling the size of the rotor will result in a four-fold increase in power, while doubling the wind speed will result in an eight-fold increase in power. However, the efficiency of wind turbines decreases significantly in both low and high winds, so the result is that most commercially-available windmills operate best in a range of wind-speeds between about 15 km/hr and 50 km/hr.

5.5 Kinds of pumps available for use with windmills

If the windmill is used to generate electricity to power an electrical pump, it will probably be necessary to store the electricity in batteries due to the variability in generation. Therefore, a pump powered by an electrical motor for use in conjunction with a windmill that generates electricity should have a Direct Current (DC) motor. For such systems, it is important to use good-quality deep-cycle batteries and to incorporate electrical controls such as blocking diodes and charge regulators to protect the batteries.

The most common type of pump used with windmills is the positive-displacement cylinder pump driven by a reciprocating rod connected to a gearbox at the windmill rotor (Figure 20). The performance of these pumps can be enhanced through the addition of springs, cams and counterweights that alter the stroke cycle and off-set the weight of the drive rod, thereby reducing the starting torque and allowing the system to perform better in light winds.

An alternative to the traditional cylinder pump is the airlift pump (Figure 21). The air-lift pump is a type of deep-well pump, sometimes used to remove water from mines. It can also be used to pump slurry of sand and water or other ‘gritty’ solutions. In its most basic form this pump has no moving parts, other than an air compressor driven by the windmill. The efficiency of the air compressor is a prime factor in determining the overall efficiency of the pump. Compressed air is piped down the well to a foot piece attached to the discharge pipe. As air is discharged into the water column in the discharge pipe, a two-phase mixture of air and water is formed that is less dense than the surrounding water in the well. This apparent density difference is what causes water to rise in the discharge pipe.

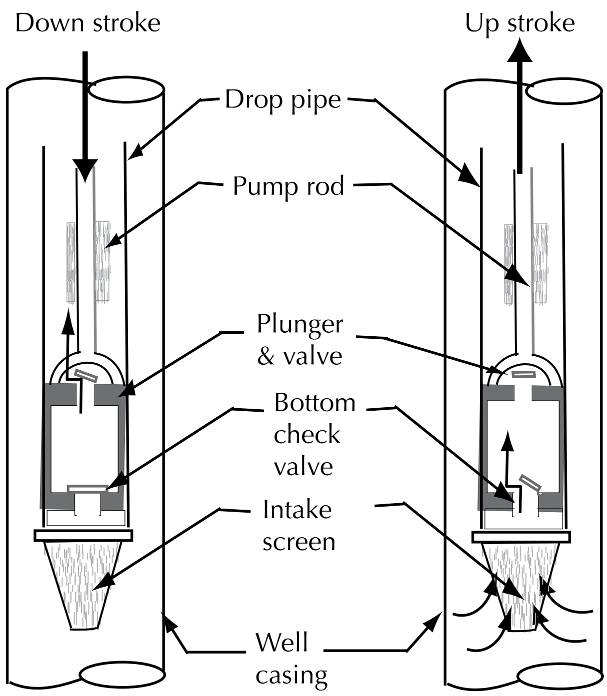


Figure 20. *Typical windmill pump cylinder.*

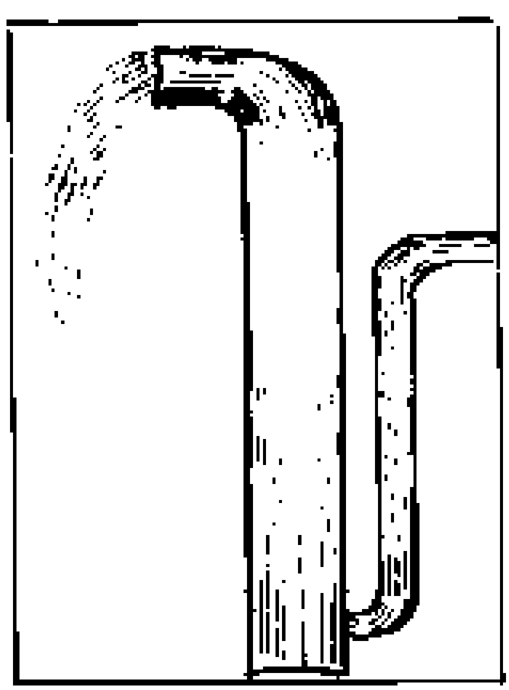


Figure 21. *Air-lift pump.*

Airlift pumps can lift water at rates between 20 to 2000 gallons per minute, up to about 750 feet. The discharge pipe must be placed deep into the water, from 70% of the height of the pipe above the water level (for lifts up to 20 feet) down to 40% for higher lifts. This is the most significant drawback to airlift pumps, because many wells do not have the required depth of standing water. An advantage to this kind of pump is that the windmill can be located away from the well, and the windmill/air-compressor combination can also be used to aerate dugouts.

Chapter 6 Solar-powered pumps

Chapter objectives:

After reading and understanding this chapter, you will be able to:

- explain working principles of solar-powered pumps
- install solar pumps
- know some types of solar pumps such as small solar pump with fountain head, large solar fountain pump, submersible solar pump, solar pool pump system (centrifugal surface pump), and solar pond pump system

A solar powered pump is a pump running on the power of the sun. A solar powered pump can be more environmental friendly and economical in its operation compared to pumps powered by an internal combustion engine (ICE). A solar powered pump consists of two parts, namely (a) the actual pump, and (b) the energy source being powered by the sun. It can provide a reliable water supply and eliminate the installation of power lines in environmentally sensitive areas. Because power lines are not needed, there is no need to spray chemicals around the base of poles. Solar-powered pumps rely on photovoltaic (PV) panels or modules—composed of silicone cells connected in parallel or series—which generate electricity when sunshine strikes the surface of the cells. Power modules are available in various wattages and voltages. PV panels pose little or no threat to the environment, wildlife and people. Because PV systems must be custom designed to user and site characteristics, costs vary. Prices range from USD 900 to more than USD 6000.

A combined solar and wind powered pump system is designed for getting water to remote rural locations and is used extensively worldwide. The main application is for getting water from wells or boreholes for livestock or drinking water. Solar and wind powered pumps can also be used for surface water management and the irrigation of fields.

6.1 Working principles of solar-powered pumps

The process is simple, the pump is submersible and is lowered into the water source and it is powered by a direct drive renewable energy system: either a wind turbine or solar panels (PV). The solar panels or wind turbine produce electricity, which is passed through a control unit and can be connnected to batteries as well, and this drives the pump. The pump can be powered by wind turbines, solar panels, generators and a combination of some or all three.

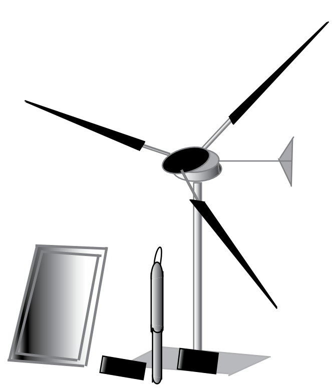


Figure 22. *Combination of solar and wind-powered pumps.*

6.2 Solar pump installations

Solar PV water pumping systems are used for irrigation and drinking water in India. The majority of the pumps are fitted with a 200–3000 watt motor and is powered with 1800 Wp PV arrays, which can deliver about 140 thousand litres of water/day from a total head of 10 metres. By the 30th of September 2006, a total of 7068 solar PV water-pumping systems have been installed.

6.3 Some examples of solar pumps

(A) Small solar pump with fountain head

A small solar pump with fountain head is powered by direct sunlight that is gathered by the solar panel (Figure 23). There is no need for batteries or wiring. It includes three different fountain heads for different fountain shapes. The solar pump has an extra-long cord that allows the solar panel to be placed up to 4.5 m from the fountain.

Figure 23. *Small solar pump with fountain head.*

(B) Large solar AC fountain pump

These powerful, compact, solar- and AC-powered pumps are easy to set up yourself (Figure 24). Not only do they include a separate solar panel you stake into the ground where sunlight is most accessible, it also comes with a UL-listed AC transformer and jack so you can power the fountain even at night. It includes 4.5 m-long cord (from solar panel to pump), adjustable solar panel spike, assorted spray nozzles, and LED accent light.

Figure 24. *Large solar AC fountain pump.*

(C) Submersible solar pump

A submersible solar pump is directly powered by solar panels, thus requiring no batteries. When the sun shines, the variable speed DC brushless pump will start pumping and continue pumping until there is insufficient sun. As an option the solar panels can be mounted on a mechanical sun tracking system that will provide maximum output from the solar panels.

Water can be pumped from as deep as 240 metres and systems can be configured to suit your daily water needs and lift requirements.

Application:

- Drinking water supply
- Livestock watering
- Pond management
- Irrigation
- Almost any other application you can think of

Characteristics:

- Lifts up to 240 m
- Flow rate upto 11.0 m^3/h
- Simple installation
- Maintenance-free
- High reliability and life expectancy
- Cost-effective pumping

(D) Solar pool pump system (Centrifugal surface pump)

A solar pool pump system is shown in Figure 25.

Application:

- Swimming pool water circulation through a filter system and thermal collectors
- Pond management
- Irrigation
- Aquariums
- Fish farms

Characteristics:

- Flow rate upto 15.0 m^3/h
- Maintenance-free thanks to brushless DC motor
- Excellent efficiency

Components and features:

- Controller PS 600
- Controlling of the pump system and monitoring of the operating states
- Mounted at surface (no submerged electronic parts)
- Two control inputs for well probe (dry running protection), f oat or pressure
- Switches, remote control etc.

- Automatic reset 20 minutes after well probe turns pump off
- Protected against reverse polarity, overload and high temperature
- Speed control, maximum pump speed adjustable to reduce f ow rate to approximately 30%
- Solar operation: integrated MPFT (Maximum Power Point Tracking)
- Battery operation: low voltages disconnect and restart after battery has recovered
- Maximum efficiency 92% (motor ÷ controller)
- Motor ECDRIVE 600 BADU Top
- Brushless maintenance-free DC motor
- Pump End (PE) BADU top 12
- Monoblock-type pump with integrated strainer tank
- Bellow mechanical seal is mounted on a plastic shaft protected sleeve
- Motor/pump shaft has no contact with f uid
- Total electric separation
- Strainer capacity approximately 3 litres
- Strainer basket mesh size approximately 3.2 × 2.6 mm

Figure 25. *Solar pool pump.*

(E) Solar pond pump system

Solar pond pumps allow free operation by using solar energy; independent of power grids anywhere sunlight is available (Figure 26). It is environmentally friendly using sunlight as an alternate energy source. The high quality module makes solar powered fountains possible until sunset and with the addition of a battery system operation can be extended.

(a)

Figure 26. *Solar pond pump with (a) solar panels; and (b) the pump.*

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