HUMAN-POWERED HANDPUMPS FOR WATER LIFTING

Introduction

This technical brief outlines the main types of hand pumps currently used for domestic and community water supply. The purpose of this Technical Brief is to provide basic features of each and suggest their potential use. A separate technical brief is available discussing human and animal powered water lifting for irrigation.

Hand pumps are capable of lifting relatively small amounts of water from depths of up to 100 metres. They are widely used in places where access to other potential water pumping power sources is constrained; where financial resources available for investment, operation and maintenance are limited; and where there is a relatively limited domestic water requirement. Hand pumps are relatively easy to install and simple to operate making them one of the most commonly used water-lifting technologies.

This technical brief provides guidance on the key criteria that needs to be taken into account when selecting a hand pump and discusses the applicability of different types to specific local conditions.

Selection criteria for human powered water lifters

Table 1 provides a summary of the technical, financial, economic, institutional and social questions that need to be answered when selecting a hand pump for domestic or communal water supply.

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technical brief

Citeria	Key Questions	Important Points to Note
Technical Aspects		
Lift height and yield	How much water does the community need? How high does the lifter have to raise the water? How deep is the groundwater and is it likely to fall in future due to over-use?	Water consumption is usually estimated at 15-60 litres/person/day for rural water supply projects. The maximum flow capacity of the hand pump should be matched to community demand. (Pump flow rates are given by the flow-rate/lift-height, or "Q/h", curve, usually supplied by the manufacturer.) The choice of hand pump should anticipate growth in demand and any hence any potential drops in groundwater levels.
Water Quality Limitations	Are there any water quality limitations which need to be taken into account?	Although most pumps are fitted with a strainer/sieve to prevent sand or sediment in the water causing pump damage, some pumps are particularly sensitive to these particles and hence their use with water with a high proportion of solids will lead to frequent breakdowns.
oil Conditions	What are the local soil conditions? Can you access water using a hand-dug well or is drilling required?	Where there is very rocky soil a borehole will usually need to be drilled to reach the groundwater.
Criteria	Key Questions	Important Points to Note
Technical Aspects		
Operators	Is the lifter suitable and acceptable to the people who will operate it? Is the operation ergonomic (comfortable to use) and realistic for the group responsible for water collection? Are there health and safety considerations, such as dangerous machinery or risk of contamination?	The choice of pump should take into account which group of people are tasked with water collection. In many cases this women and children undertake this activity. It is therefore important to determine if average and maximum handle forces required are realistic for these two groups.
Financial and Economic Aspects		
Capital Cost	What is the initial cost of the water lifter? Does the village have sufficient funds or is a loan required?	
Material and Manufacturing Costs	Can the lifter be manufactured using local skills and materials?	
Operating Costs	What is the operating cost of the lifter? Does the village have sufficient manpower to operate the lifter for all the time it is needed?	
Maintenance Costs	What is the cost of maintaining/ repairing the lifter? Are the skills to maintain/ repair the water lifter available locally? Are spare parts available and affordable? How often is the lifter likely to need maintenance and/or repair? How long will repairs take and what will the villagers do in the meantime?	Maintenance is an integral part of lifter management. For more complicated designs, such as the deep-well pumps, it is important to carry out preventative maintenance. Serious problems can be avoided by undertaking regular inspections and servicing of the mechanical parts. Wear and tear will be less severe this way and any problems will be solved before they cause major damage.
Life expectancy	How long is the lifter expected to last before it has to be replaced? How resistant is the lifter to vandalism or abuse?	

Criteria	Key Questions	Important Points to Note
Institutional and Social Aspects		
Community	Is there a community organisation capable of overseeing operation, maintenance and management of the device and the water? Will the users be instructed how to use and look after the device?	The lifter should be suitable for Village Level Operation and Maintenance (VLOM) or Management of Maintenance (VLOMM). This reduces the reliance of villagers upon large institutions to sustain the water supply.

Table 1: Checklist for water lifting device selection.

Types of human-powered water lifters

Human Powered Water Lifters can be split into two categories, those designed to raise **groundwater**; and those designed to lift **surface water**.

- **Groundwater** is water that flows or seeps downward through the earth filling up the spaces between soil, sand and rock to form a saturated zone. The upper surface of this saturated zone is called the "water table." The "water table" may be just below the surface like a spring or oasis or it may be over 100 metres down. The only way to get access to this water is by digging and/or drilling.
- **Surface Water** is water present in depressions, lakes, rivers, reservoirs, and oceans. Water lifting for domestic and community water supplies is most commonly related to raising groundwater. This Technical Brief therefore focuses upon groundwater. Water lifting from surface water sources is most often related to irrigation, which is covered in the Technical Brief *Human- and Animal-Powered Water Lifters for Irrigation.*

Open-well pumps

The simplest and cheapest method of lifting groundwater remains the rope and bucket in a wide, shallow well. Open wells are usually lined with brick, stone or concrete to retain the well walls. This type of well can operate up to a depth of 100 metres, although they rarely exceed 45 metres. The job of drawing water from the well can be made easier by adding a "windlass" (a horizontal cylinder with a winch which can be turned to raise the bucket on a rope) or a "shadouf" (an upright frame with a long pole suspended on top with the bucket hanging from one end and a weight which serves as the counterpoise of a lever at the other.)

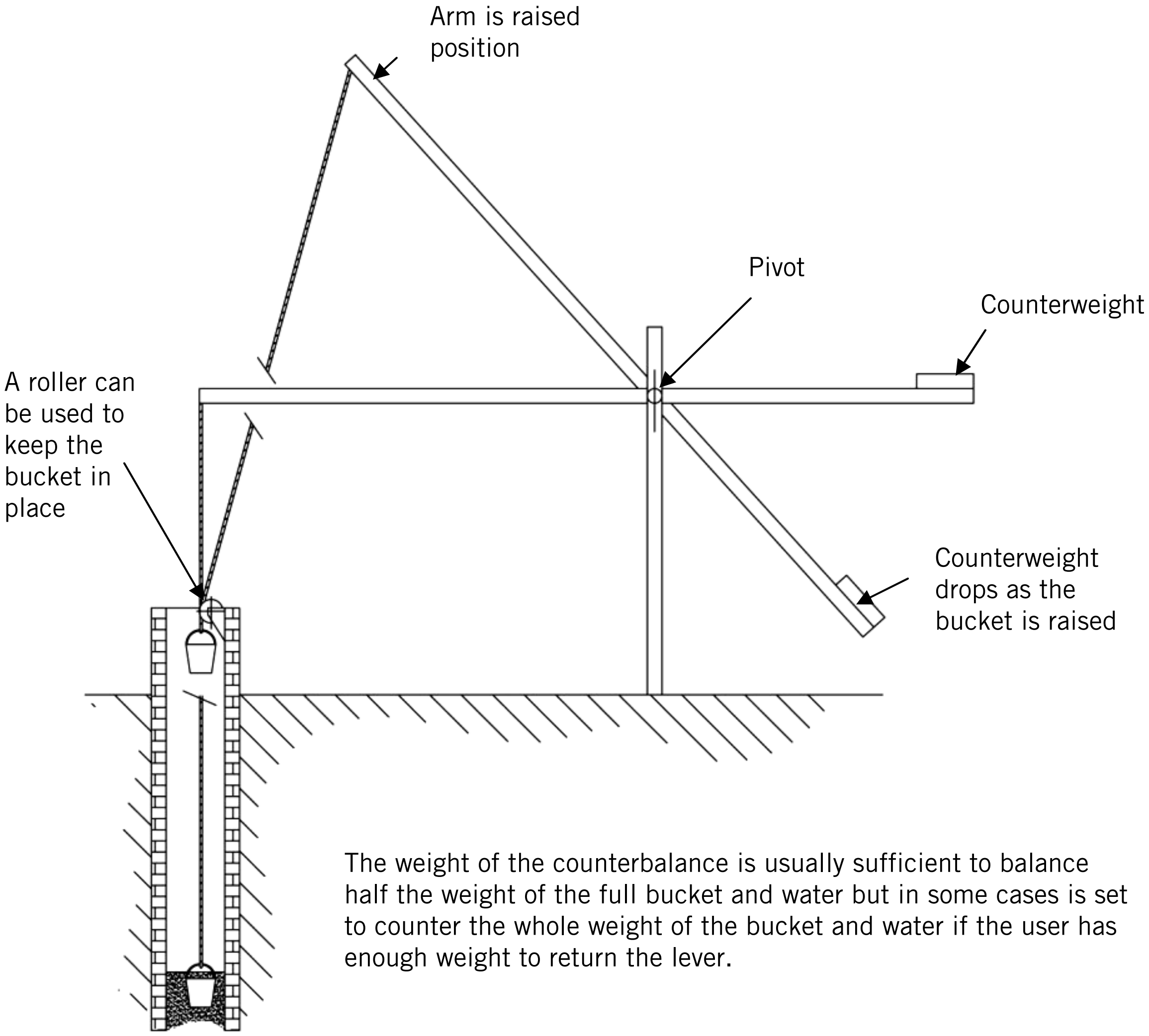

Figure 1: A counterpoise lifting device, also known as a shadouf, over an open well. A counterbalance helps lift the bucket of water.
Illustration: Neil Noble / Practical Action

However, when the water table is very deep or where the ground is very hard rock and groundwater needs to be accessed via a borehole, it is usually necessary to install a **hand pump** to raise the water. Introducing hand pumps also allows the water source to be sealed and reduces the potential for source contamination during water collection. Groundwater hand pumps can be split into two categories, **shallow-well** and **deep-well**.

Shallow-well pumps

The following section presents the main type of pump used for shallow-well water lifting.

A **reciprocating suction pump** has a plunger or piston which moves up and down in a two-valve closed cylinder. As the plunger moves upward it forces water out through the outlet valve and at the same time draws water into the cylinder through the inlet valve. Moving the plunger down brings it back to its starting position.

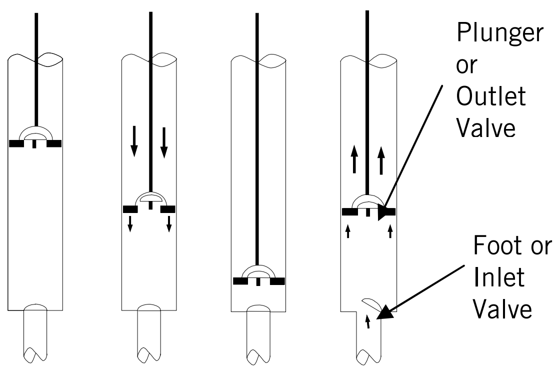

Figure 2: How most types of pump cylinders work.

The reciprocating suction pump has the pump cylinder situated above ground or near the surface. Pulling up the plunger lowers the atmospheric pressure in the cylinder (creates suction) causing the atmospheric pressure outside the cylinder to push the water upwards. The main limitation of this pumping method is that the atmospheric pressure difference between the inside and outside of the cylinder is only large enough to raise water up to a maximum of 7m from the water table. If the shallow well is over used, the level of the water-table may fall as the underground water reservoir is depleted. If the water table level falls to a depth of greater than 7 metres, the pump will no longer work.

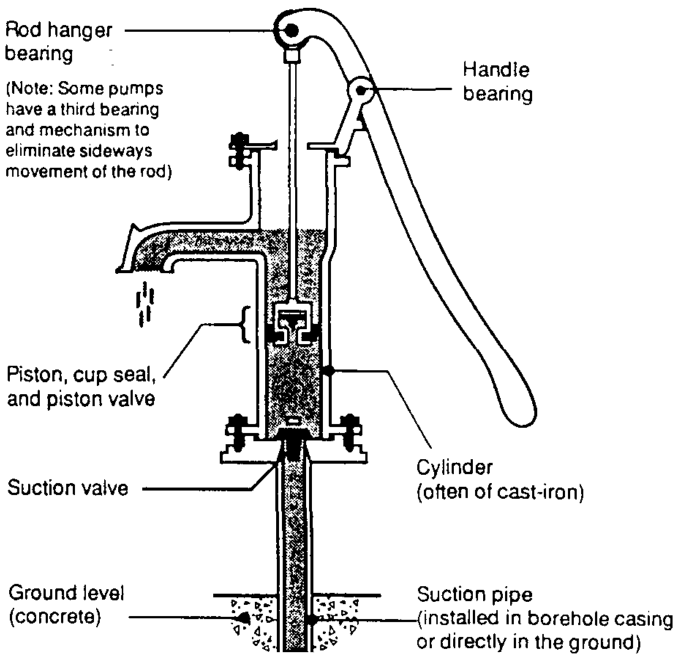

Figure 3: Shallow-well piston pump

The following section describes three different types of reciprocating suction pump used for raising water from shallow-wells of up to 7 m in depth i.e. the **piston pump**, the **rower pump** and the **treadle pump.**

Shallow-well piston pump

Piston pumps, based on the same design shown in *Figure 2*, are relatively cheap and are widely used as household hand pumps.

Traditional piston pumps have to be "primed" before use which means pouring water into the cylinder so that the seal around the piston is airtight. It is very important that clean water is used for priming, to avoid contamination of the pump and the spread of water-borne diseases.

More recent VLOM designed piston pumps using better suction valves have removed the need for priming.

The shallow-well piston pump can be adapted to deliver water to a higher elevation than the pump e.g. to a water storage tank or to deliver water under pressure to village water mains. This "**force**" pump uses the same operating principle as the piston pump but the design is slightly altered so that the top is airtight. This is done by putting a valve on the spout and adding a "trap tube" and air chamber which maintains the pressure (and hence flow) during the up-stroke. Typical elevations achieved using force suction pumps are between 5 – 10 metres.

Advantages	Disadvantages
Relatively simple maintenance (main pump components positioned above ground) Large piston diameter gives fast water delivery (24-36 litres/min at 7 m depth)	Limited to wells of less than 7 metres in depth Pump priming may cause water contamination. Most designs have maximum usage of around 50 people/day

Rower

The rower pump is a simpler and cheaper version of the traditional reciprocating suction pump. The pump is set at an angle of 30˚ and water is lifted through a rowing action.

Its simple design means it can be easily manufactured and maintained using locally available skills and materials.

This type of pump also needs to be primed before used.

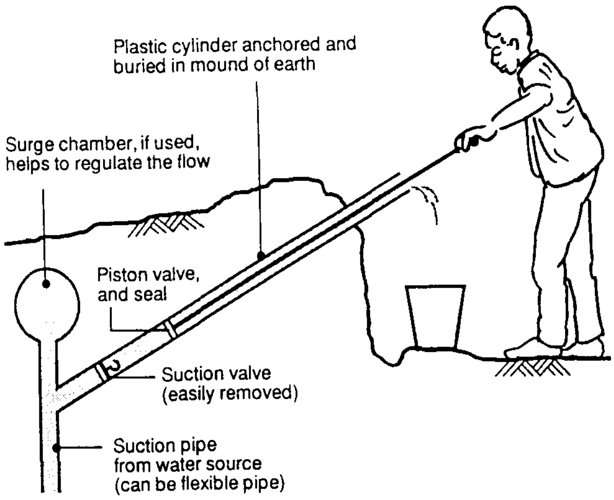

Figure 4: Rower pump

Advantages	Disadvantages
Cheaper construction than most reciprocating suction and lift pumps Maintenance using local skills and materials Long piston stroke gives fast water delivery (up to 90 litres/min at 4 metres depth)	Limited to wells of less than 7 metres in depth Pump priming may cause water contamination. Upward facing delivery tube may lead to water contamination. Most designs have maximum usage of around 50 people/day

Treadle pump

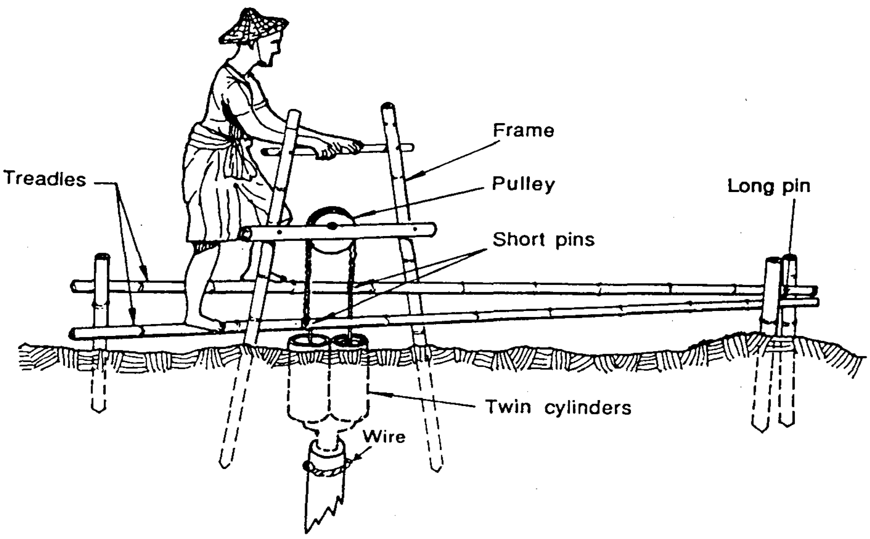

Figure 5: Treadle pump

A **treadle pump** is another type of suction pump designed to lift water from a depth of 7 metres or less. The treadle pump has a lever pushed by the foot to drive the pump. Because leg muscles are stronger than arm muscles, this design is less tiring to use than other human powered water lifters. Most of the parts can be manufactured locally hence the treadle pump is relatively simple and inexpensive to build.

Advantages	Disadvantages
Simple and inexpensive construction Less intensive operation (foot operated) Maintenance uses local skills and materials High water delivery (up to 100 litres/min at 4 metres depth)	Limited to wells of less than 7 metres in depth

Comparison of Different Types of Shallow-Well Pump

Table 2 provides a comparison of the shallow well suction pumps discussed in the previous section. All of these pumps can only be used to raise water from depths of up to 7 metres.

Type of Pump	Water Delivery	Typical Use	Application	Construction	Operation & Maintenance
Piston	24-36 litres/min at 7 m depth	Shallow Well	Household and Small Community	Industrial	Village Level with local skills and purchase of spare parts
Rower	up to 90 litres/min at 4 metres depth	Shallow Well Open Well Surface Water	Small Community and Irrigation	Traditional	Village Level with local skills and materials
Treadle	up to 100 litres/min at 4 metres depth	Shallow Well Open Well Surface Water	Small Community and Irrigation	Basic / Traditional	Village level with local skills and materials

Table 2: Comparison of different types of shallow well pump

Deep-well pumps

Deep-well pumps can be used to raise water from depths of over 7 metres and in some cases can lift water from wells as deep as 180 metres. The following section describes five different types of pumps used to raise from deep-wells i.e. the **direct action pump**, the **rope pump**, the **diaphragm pump**, the **helical rotor pump** and the **deep-well piston pump**.

Direct action (or "direct drive") Pump

The direct action pump design (Figure 5C) replaces the narrow pump rod present in the reciprocating piston pump with a hollow plastic pipe. This pipe displaces water as the pump handle is pushed down. During the up-stroke, the valve on the piston closes and water is lifted up. The pump is capable of pushing water up the rising main during both strokes.

The direct action pump depends upon the strength of its user to lift the column of water in the pipe. However, because the pipe is hollow, it floats, so in practice the handle does not have to be pulled up so hard. The direct action pump is capable of lifting water from a depth of up to 12 metres at a rate of approximately 26 litres/min. Compared to piston hand pumps, this type of pump is relatively cheap to buy and simple to install and maintain.

Advantages	Disadvantages
Relatively cheap, and easy to manufacture. Maintenance facilitated by easy access to piston which can be pulled up through the rising main.	Limited to depths of up to 12 m. Most designs have a maximum usage of around 50 people/day.

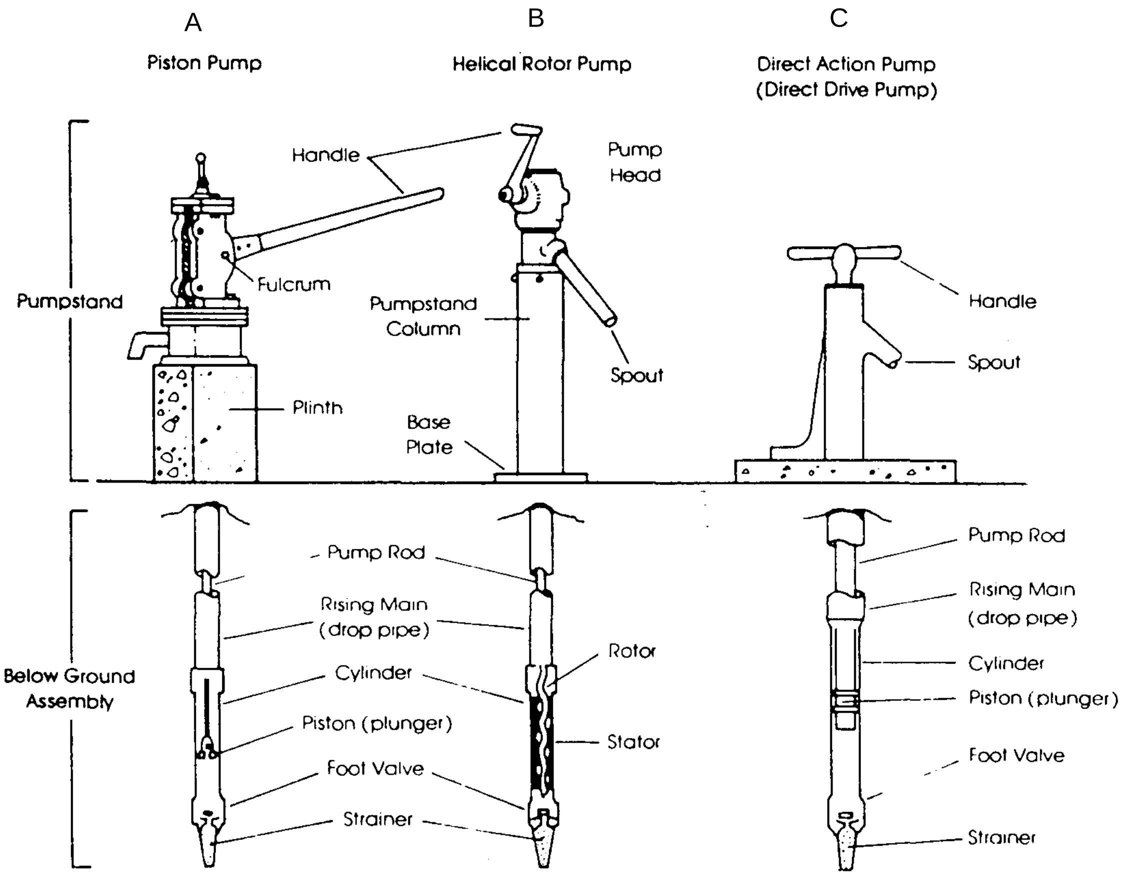

Figure 6: Types of deep-well pumps – deep-well piston, helical rotor and direct action

Rope pump

The **rope pump** is a **rotary pump** which can lift water from depth the average yield is calculated as 10 litres/ min. Hov operate at depths of up to 10 m with a water yield of 40 li used for household and small community water supply.

The main wheel is turned by hand in the direction indicated in Figure 6 and feeds the rope and washers down the well shaft, over the guide pulley and through the riser pipe to the discharge point. The washers are an exact fit with the riser pipe and force water up towards the surface.

Rope and washer pumps require less maintenance than other equivalent pumps. Their simple design means that repairs can often be done by users and require few spare parts. Models can use parts that incorporate commonly available materials such as PVC pipe, rope, and old car parts.

The main disadvantage of this type of pump is that it is not 100% closed which may lead to well contamination. In addition, since this is not a pressurised system it may take time to receive water from the well with the water falling back to the level of the bottom of the well when not in use.

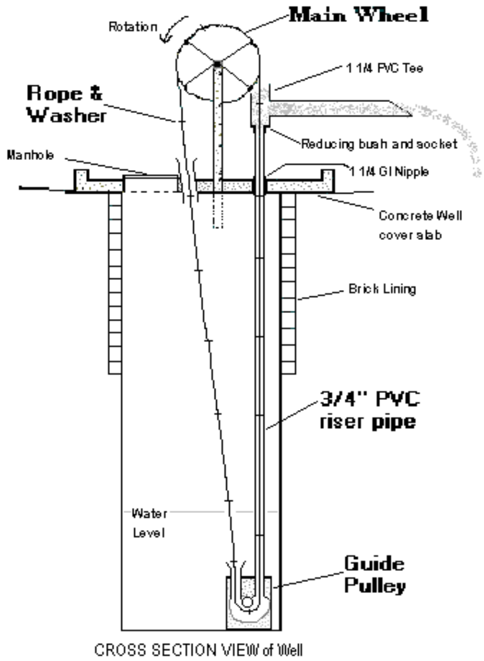

Figure 7: Rope and washer pump.

Advantages	Disadvantages
Relatively cheap, and easy to manufacture (for wells down to 35 m rope pumps are five times cheaper than piston lift pumps.) Maintenance uses local skills and materials	Operation limited to depths of up to 35 m. Initial water delivery is relatively slow at greater depths. Water contamination possible because well is not totally sealed. Frequent simple maintenance required

Diaphragm pump

The diaphragm pump is a deep-well pump which can operate at depths of up to 70 metres. The diaphragm pump delivers 25 litres/ min at 45 metres depth.

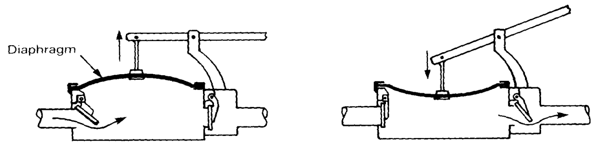

Figure 8: Diaphragm pump

The flexible diaphragm is situated inside a cylindrical pump body at the bottom of the well. The pump operates by the expansion and contraction of the flexible diaphragm which forms one wall of a closed chamber. The diaphragm is expanded and contracted using a secondary piston pump, which in turn is moved by a foot pedal or hand lever.

The closed chamber has an inlet and outlet valve. On the contraction of the diaphragm the inlet valve opens to draw water into the closed chamber and the outlet valve closes. When the diaphragm is expanded the inlet valve closes and the outlet valve opens to pump water up a flexible rising main.

The main disadvantage of this pump is that replacement diaphragms are required at relatively short intervals. These diaphragms are expensive and can make the maintenance costs of this pump prohibitive for many village water management organisations. In addition, this type of pump is not suitable for water with sediment or sand particles in it since these will lead to pump breakdown.

Advantages	Disadvantages
Suitable for deep well applications up to 70 metres in depth. Several pumps can be installed in the same well or borehole. Maintenance facilitated by easy access to main wearing parts in the upper cylinder.	Relatively expensive to manufacture. Replacement diaphragms expensive and required at short intervals. Not suitable for water with sediment or sand particles which damage the pump.

Helical rotor (or "progressive cavity") pump

The helical rotor pump is a **rotary pump** which can lift water from depths of up to 100 metres. Typical water yields at 45 metres are around 16 litres/ min. Instead of a piston, the helical rotor pump has a metal "rotor" which has a corkscrew shape and which turns inside a rubber "stator" or sleeve (see Figure 5B). There is a continuous seal between the two parts of the pump and the turning action forces the water upwards. Instead of a pump lever there is one or two turning handles. The faster the handles are turned the more water is obtained from the well.

The pump is relatively reliable. Nevertheless a key disadvantage is that pump maintenance requires that the whole pump be lifted and dismantled using specialist equipment and hence it is not suitable for maintenance by a village level organisation.

Advantages	Disadvantages

Suitable for deep well application up to 100 metres in depth.	Expensive to manufacture. Maintenance requires specialist equipment and skills. Not suitable for village level organisation maintenance.

Deep-well piston pump
The design of the deep-well piston pump is very similar to that of the shallow-well piston pump. The main difference is that the pump cylinder is situated deep underground at a point below the water table. The cylinder is connected to the pump handle via a long rod called a pump-rod (Figure 5A.) This type of pump is also known as a **reciprocating "lift" pump.** This pump is capable of lifting water from depths of up to 100 metres. Typical yields from this type of deep-well pump at 45 metres depth vary from around 11-17 litres/min. Like reciprocating "suction" pumps, lift pumps can be converted into force pumps by adding a spout valve, air chamber and trap tube.

Since the cylinder and plunger are located under ground, the maintenance and repair of these pumps is usually more complicated than that of shallow-well piston pumps. It is necessary to dismantle the pump, removing the pump-rod in order to access the cylinder. Sometimes the outside pipe or "rising main" is of a larger diameter so that it is possible to pull the whole cylinder up to the surface for repair without taking the pump apart. This type of pump is generally more expensive but has the advantage that a village level organisation can take charge of pump maintenance.

Advantages	Disadvantages
Suitable for a wide range of well depths including application in wells over 100 metres deep. Design can be strong enough to cope with intensive use.	Accessing the piston and foot valve during maintenance in traditional piston pumps is relatively difficult and may require specialist lifting equipment. Newer piston pumps where cylinder can be removed separately from large diameter rising main can be relatively expensive.

Selecting a water-lifter
The main questions that need to be answered to determine the most appropriate water lifter to be used for domestic and community water supply are:
- where does the water come from (source); and
- where does it need to go (destination)

Figure 9 illustrates the main water sources and destinations and Table 3 summarises the suggested option for each combination of source and destination.

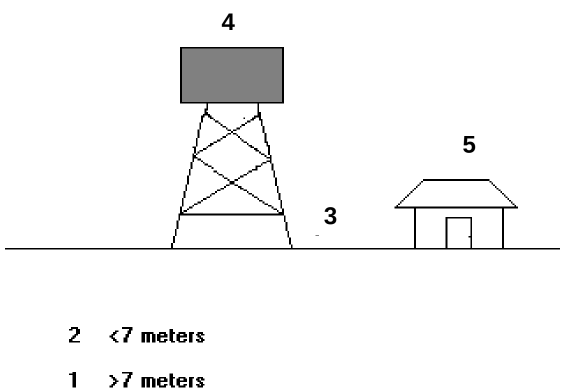

Figure 9: Main sources and destinations for water

Destination	Source	
	1. (> 7m)	2. (<7m)
3 (Surface)	Deep-well Lift Pump	Shallow-well Suction Pump or Open-well
4 (Tank)	Deep-well Lift & Force Pump	Shallow-well Suction & Force Pump
5 (Village)	Deep-well Lift & Force Pump	Shallow-well Suction & Force Pump

Table 3: Water-lifter options

Comparison of water-lifting device application and performance

Table 4 provides an assessment of the different technologies considered in this technical brief. A large number of hand pumps have been designed according to the principles of Village Level Operation and Maintenance (VLOM) i.e. the water lifting device should be:

- Easy to maintain by a village caretaker requiring minimal skills and few tools;
- Manufactured in-country, primarily to ensure the availability of spare parts;
- Robust and reliable under field conditions; and
- Cost effective.

These criteria along with that of depth of the groundwater and the water yield from the pump are considered below. It should be noted that as lift height increases, flow rate falls, so at maximum lift, the *actual* flow rate will be much less than the *maximum* flow rate. Flow rates are given for one person operating the pump. The values given in the table are approximate and should be taken only as a rough guide.

Type	Manufacture	Investment Cost	Village Level Operation and Maintenance (VLOM)	Max. lift height (metres)	Typical flow rate (l/min)	Typical lift height (metres)
OPEN WELL						
Shadouf	Basic/ Traditional	Low	Yes	4	60	2
Rope & Bucket	Basic/ Traditional	Low to Medium	Yes	100	15	10
SHALLOW WELL						
Suction piston	Industrial	Low to Medium	Yes	7	24-36	7
Rower	Traditional	Low to Medium	Yes	7	50	4
Treadle	Basic/ Traditional	Low to Medium	Yes	7	100	4
DEEP WELL						
Direct action	Traditional/ Industrial	Medium to High	Yes	12	15-26	12
Rope	Basic/ Traditional	Low to Medium	Yes	35	40 10	10 35
Diaphragm	Industrial	High	No	70	30 15	10 45
Helical rotor	Industrial	Medium to High	No	100	16	45
Lift piston	Industrial	Low to High	Depends on design.	100	15-22 11-17	25 45

Table 4: Technology Assessment

References and resources

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Organisations

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Producers of a range of pumping equipment

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