Water Engineering and Development Centre

UNIT 7

MANAGEMENT OF VILLAGE WATER SERVICES (MVWS)

Handpumps – an overview

What this unit is about

This unit introduces the most common types of handpumps used for delivering groundwater as a drinking water supply for low-income communities. *It is principally delivered through a sequence of short videos which collectively last for an hour.* (See the following page for the video links). These notes are presented here as an additional reference guide to the pumps described in the videos. However we recommend you read Section 7.6 in particular which will be of relevance when you come to study *Unit 14: Choosing technologies and service options.* Note that the maintenance of handpumps is not covered in detail in this unit.

What you will learn

On completion of this unit, you should be able to:

- distinguish between different types of handpump;
- be aware of the technical features of particular types of handpump; and
- understand the general principles to be followed when installing a handpump.

Loughborough University

Handpumps – an overview: video links

Note that these films are the principal means for delivering this unit. The notes that follow are for further reference. However, we recommend that you familiarize yourself with Technical Brief No. 41 and Section 7.6 of this document.

	Part 1 of 6: Introduction 12 mins 15 secs 1.2Gb	ONLINE USB
	Part 2 of 6: Suction pumps 4 mins 16 secs 426Mb	ONLINE USB
	Part 3 of 6: Direct action pumps 9 mins 34 secs 1.1Gb	ONLINE USB
	Part 4a of 6: Deepwell pumps: The India Mark II 7 mins 13 secs 793Mb	ONLINE USB
	Part 4b of 6: Deepwell pumps: The Afridev 14 mins 41 secs 1.7Gb	ONLINE USB
	Part 5 of 6: Progressive cavity, hose and rope pumps 13 mins 04 secs 1.5Gb	ONLINE USB
	Part 6 of 6: Summary 5 mins 59 secs 638Mb	ONLINE USB
	Complete film 1 hour 3 mins 7.25Gb	USB

Should you have any difficulty opening these links, the videos are also available on YouTube

Credits

Demonstrated and narrated by Brian Skinner
Edited and illustrated by Ken Chatterton
Filmed by Rod Shaw and Ken Chatterton
Directed and produced by Rod Shaw

Contents

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Figures

Essential reading: *Technical Brief No. 41: VLOM Pumps* (Skinner and Shaw, 1994.) ONLINE USB

7.1 Introduction

Where pumps are human-powered and the operating forces are applied through the hands and upper body, they are usually called *handpumps*. Alternatively, operating forces can be supplied by body weight through the legs, and pumps using this mode of operation are called *footpumps*. Some pumps are operated by hands and a foot simultaneously. This unit will cover the use of handpumps and footpumps, but the word 'handpump' should generally be assumed to refer to both types of pump.

This unit first examines the main different types of handpump and how they work. It then looks at some important aspects concerning the choice and installation of handpumps. Finally, it will look at maintenance tasks and various options for maintenance systems.

There are hundreds of different designs of handpumps currently broken down around the world. Experience has shown that the most important thing about achieving a successful handpump project is that, as far as is possible, the handpump used is one which can be sustained using **V**illage **L**evel **O**peration and **M**aintenance (VLOM). (The term 'VLOMM' is sometimes used instead to indicate that the users may be responsible for the **M**anagement of **M**aintenance – i.e. they may choose to use someone from outside the village to assist with more complicated repairs). This unit will therefore highlight VLOM aspects of handpumps. These are also covered in Technical Brief No.41 (Skinner and Shaw, 1994), which you will also find in Shaw (1999) – to which frequent reference is made and which is supplied with this module.

This unit concentrates on handpumps used for domestic water supply and does not cover in detail human-powered pumps used for irrigation. Manually-operated irrigation pumps need to pump water at a faster rate than is possible with most handpumps used for domestic water supply and are therefore often foot powered. For irrigation pumps hygiene is not of importance, so there is a very wide range of options for manually-operated irrigation pumps. Such pumps are well covered in Fraenkel (1997). You will also find some of these pumps covered in Technical Brief No.35 (Elson and Shaw, 1993), which is also in Shaw (1999).

This unit can only mention some makes of handpump. If you want to find out more, then Harvey and Reed (2004) covers many aspects relating to handpump technology, manufacture, installation and maintenance.

Technical Brief No.13 (Franceys, 1987), which is also included, gives brief information about some types of handpump.

7.2 Pumping principles

There are three main physical principles used in handpumps to discharge water and these are illustrated in Figure 7.1. They are:

- **Direct lift** – where a piston progresses up a cylinder raising the water above it.
- **Suction** – where atmospheric pressure acting on the surface of the source water pushes it into the expanding space below a piston moving upwards in a cylinder. This is relevant when the cylinder is positioned above the level of the source water.
- **Displacement** – where a solid object is pushed into a confined body of water, causing some of the water to be displaced.

More than one of these principles can apply at the same time to the operating cycle of a handpump.

7.3 Types of handpumps

This unit looks at six categories of handpumps:

- **Reciprocating rod and piston pumps**: Most handpumps are of this type.

There are three subcategories:

– 'traditional' and 'rower' designs of suction pumps,
– direct action pumps, and
– deepwell pumps.

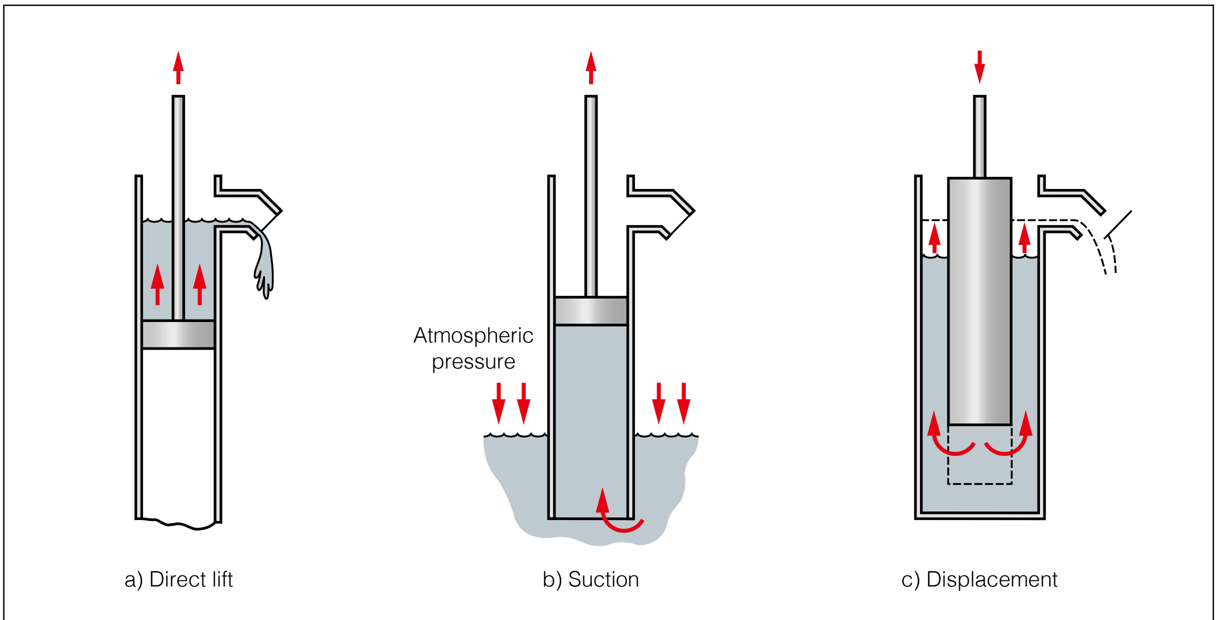

Figure 7.1 Basic principles of piston pumps

Source: WEDC. Adapted from: Fraenkel (1997)

- **Cylindrical diaphragm pump**: This is a hydraulically operated pump, often a footpump, but now also available as a handpump (e.g. Vergnet hydropump).
- **Progressive cavity pump**: This is operated by a rotating rod, which turns a helical rotor which moves inside a rubber stator (e.g. Monolift pump).
- **Oscillating water column pump**: This type of pump is rare, but its interesting mode of operation, which uses compressible rubber balls, is explained.
- **Rope and washer pump**: With this pump, a continuous rope, with washers attached to it, is pulled through a pipe to raise water.
- **Blair bucket pump**: Brief mention is made of this system, which uses a narrow valved bucket, chain and windlass to raise water.

Each type is considered in turn.

7.4 Reciprocating piston pumps

7.4.1 Method of operation of reciprocating piston pumps

Most handpumps work when a valved piston is alternately raised and lowered in a valved cylinder. This reciprocating (up and down) action is usually achieved by a hand- or foot-operated lever, but some pumps use instead a hand-operated flywheel and crank (e.g. the Volanta, see Figure 7.7).

Figure 7.2 shows a cylinder of a typical rod-operated reciprocating piston pump. This type of piston is sometimes called a 'plunger' or 'bucket', but we do not use either of these terms. In Figure 7.2, the cylinder is shown below water in a borehole, but the cylinder could equally be submerged in a tank of water or even above water (as it is in the case of the 'suction pump' mentioned later).

Look at Figure 7.2, which should be self-explanatory. Note that on the upstroke, the piston valve is closed and the seal on the piston pushes tight against the inside of the cylinder, so that water above the piston is lifted to be discharged at the pump outlet (which is not shown on the diagram). On the downstroke, the piston valve opens, the seal does not push tightly against the cylinder wall and the piston passes through the water held above the suction valve/foot valve.

Usually virtually no water is discharged on the downstroke. However, if a large diameter rod is used at the pumphead, the volume of rod entering the water on the downstroke will displace an equal volume of water from the discharge spout. This double-action pumping is a feature of the direct action pump considered in Section 7.4.4.

There are many different designs of valve that are used with handpumps. The one shown in Figure 7.2 is known as a poppet valve. Flap valves (e.g. the suction valve of Figure 7.3a), diaphragm valves (as on the SWS rower pump see Figure 7.4b) and ball valves are all in use. With some valves, fast closure is facilitated by using a spring.

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7.4.2 Types of reciprocating piston pumps

There are three distinct subcategories of handpump within the 'reciprocating piston pump' category. These are:

- suction pump (or shallow well pump);
- direct action pump; and
- deepwell pump.

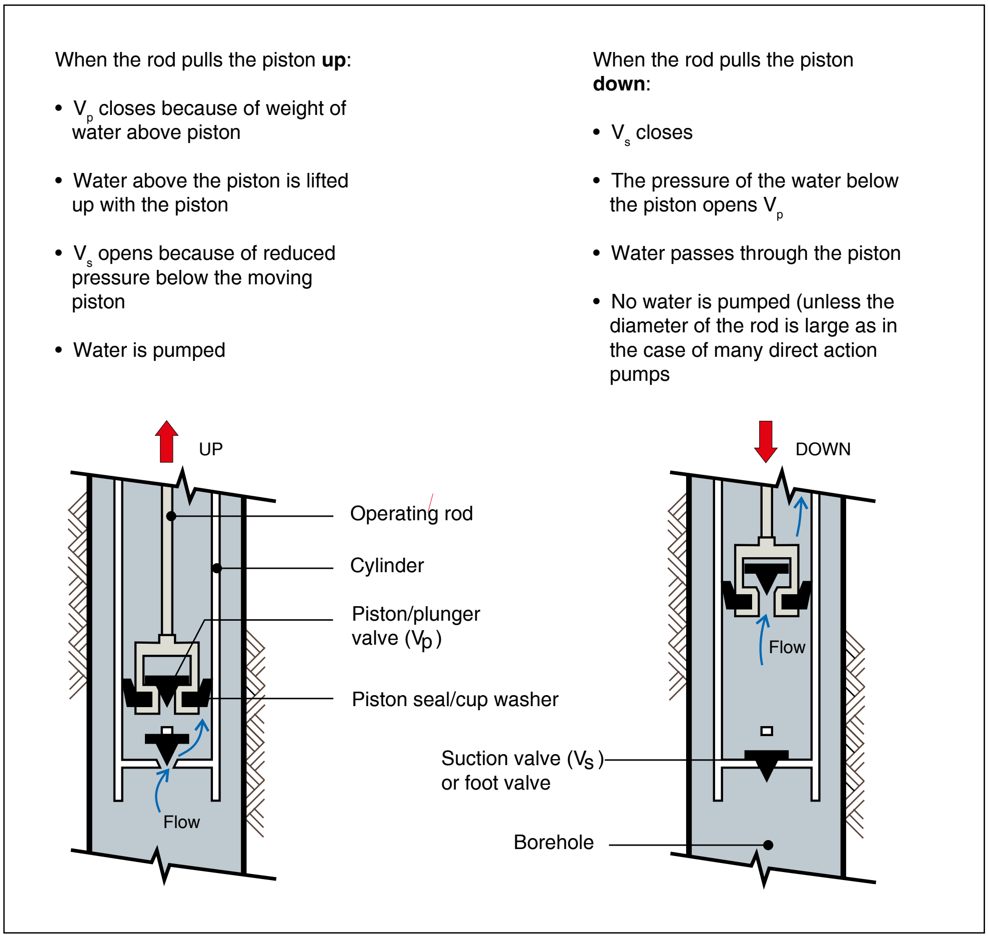


Figure 7.2 How most types of handpump cylinders work

Source: Skinner and Shaw (1994)

Most of these pumps freely discharge water at the pumphead, but the suction pump and deepwell pump can also be manufactured to pressurize water so that it can be pumped to a level above the pumphead. These types of pump are called **force pumps** (see Section 7.4.6 and Figure 7.3c and Figure 7.3d).

Each different type of reciprocating piston pump is now considered.

7.4.3 Suction pumps

7.4.3.1 Introduction to suction pumps

In all types of suction pump, the piston is located above the level of the water being pumped (Figure 7.3a). As the piston moves up, it reduces the water pressure below the piston, and atmospheric pressure acting on the surface of the source water pushes water up the suction pipe and into the cylinder to take up the space vacated by the piston (Figure 7.1b). To create sufficient suction to initially remove the air from the suction pipe below the cylinder, the piston seal, piston valve and suction valve all need to be fairly airtight. If the cylinder does not already contain water, this usually has to be added to make the seals for these components airtight. Adding this water is called 'priming', and if the water is not of good quality it can pollute the water subsequently drawn from the pump.

The suction pipe must not have any leaking joints that can allow air to be sucked into the pipe. If air enters through such joints, it can prevent sufficient suction pressure being created below the piston to raise the water from the source into the cylinder.

For a suction pump, the maximum operating depth (from the piston to the water being pumped) is about 7 to 8.5 metres for pumps located at sea level. At higher elevations, where the atmospheric pressure is lower, this distance will be less.

Because the suction pipe does not contain a rod, the pipe can be routed in any direction from the water source to the pump, but it should always slope upwards towards the pump so that no air can become trapped in the pipe.

7.4.3.2 Traditional designs of suction pump

A labelled diagram of a traditional design for a suction pump is shown in Figure 7.3a.

This design uses a lever system to apply more force to the piston than that applied to the handle. The use of two pivot points (the handle bearing and the rod hanger bearing) means that the rod moves from side to side at the top of the pumphead, which has to be slotted to allow this movement.

As previously mentioned, water is often needed to make the piston seal and the valve seals airtight so that air can be removed from the suction pipe. If the suction valve is good, it should hold water in the cylinder overnight so that priming is not necessary every day. Sometimes a second foot valve may be added on the bottom end of the suction pipe as an extra safety precaution, but access to maintain such a valve may be difficult.

The slot in the top of the pumphead is used for introducing priming water when first starting the pump. To cover the slot during normal operation of the pump, a few designs of pump use a large, fairly heavy washer on the pumphead, loosely fitted around the rod. This washer slides from side to side, always covering the slot. Alternatively, handle and lever mechanisms with three-pivot points can be used to avoid the sideways movement of the rod, and therefore the need for a slot. These are mentioned in Section 7.4.6 and are illustrated on the pumps in Figure 7.3c and Figure 7.3d.

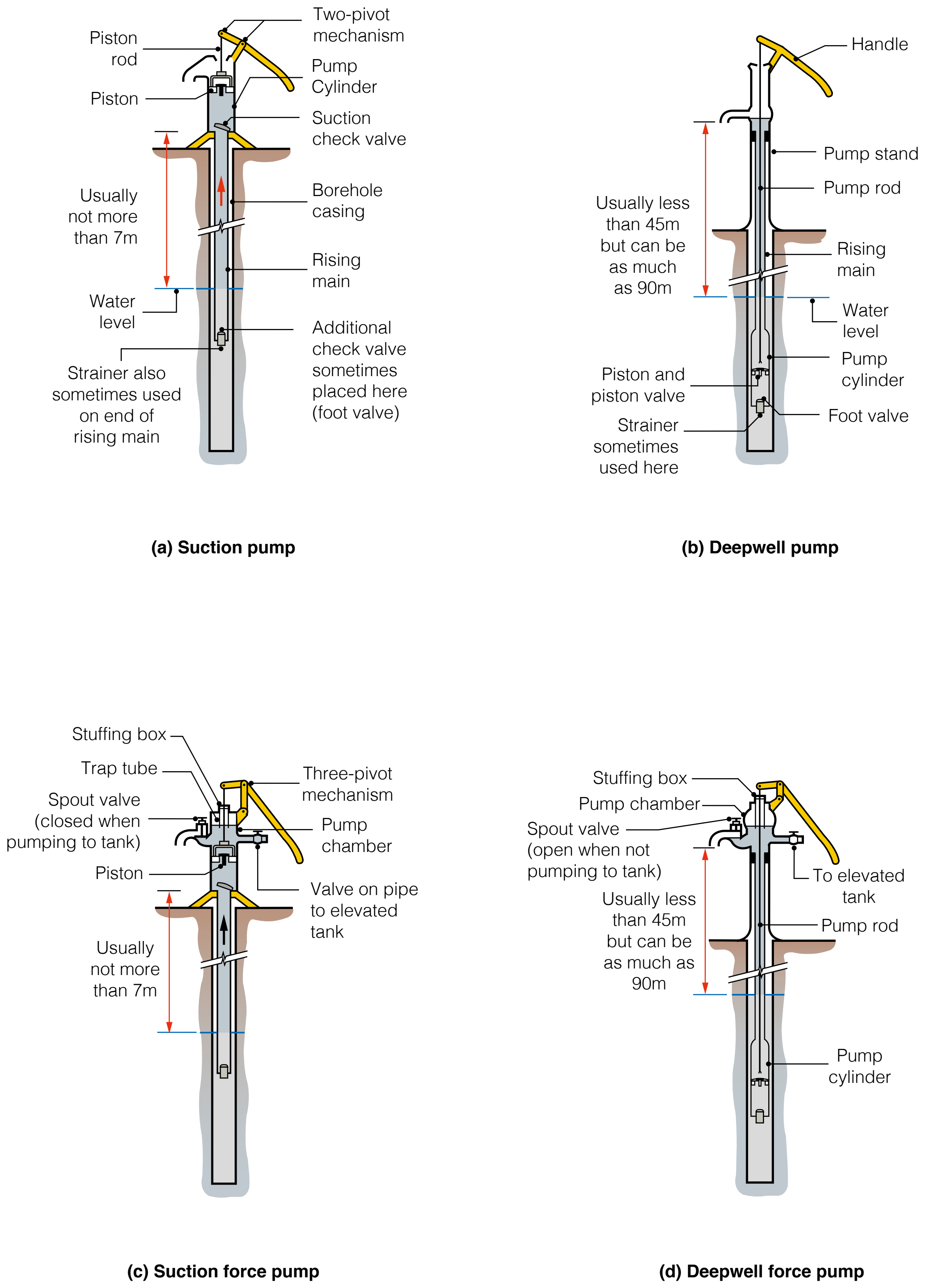


Figure 7.3 Types of reciprocating pumps

Source: WEDC. Adapted from: Hofkes et al (1983)

Question: Looking at Figure 7.3a, can you identify the advantages and disadvantages of the traditional suction pump?

When you have listed your ideas, look at the 'Suction pumps' box on the second page of Technical Brief No. 41. (Note also the VLOM features mentioned that may be associated with recent designs of this type of suction pump.)

The best-known version of the traditional suction pump is probably the New No. 6, which is widely used in Asia. It is almost entirely constructed from cast iron and is usually mounted directly on a 1.5-inch (38mm) diameter galvanized iron suction pipe, which is cast into a concrete foundation to support the pump. There are many other similar types available around the world. The diameter of the cylinder of such pumps is usually above 65mm but less than 90mm. Most cast iron pumps suffer from problems of wear of the simple pin bearings, corrosion of the cast iron and roughness in the unlined cylinder, which wears out the piston seal.

7.4.3.3 Rower design of suction pump

As you will have seen in Technical Brief 41, an inclined version of the suction pump, which is operated by pulling directly on a 'T' bar connected to the piston rod, is also available. This version, developed in Bangladesh, is often called the 'Rower Pump', because of the rowing action used by the operator. When the pump is used for irrigation purposes, the operator may be seated (see Technical Brief 35 [Elson and Shaw, 1993]).

With the rower pump, the piston stroke can be much longer than with a lever-operated pump. Although the diameter of the cylinder is smaller than that used in most traditional designs of suction pump, the long piston stroke means that it is able to deliver similar, or even greater, volumes of water than most traditional designs. A smaller diameter of cylinder is used (e.g. 65mm or less), because this reduces the force that needs to be applied to the piston to lift the water (the force is proportional to the area of the piston and the depth below the pump from which the water is being lifted). Reducing the force needed to operate the rower pump is important because, unlike the traditional design, no leverage can be applied when operating the handle.

The surge chamber shown for the rower pump in Technical Brief 41 and in Figure 7.4a is optional, but at suction depths greater than a few metres it will assist the pumping action in the following way. When the piston moves up the cylinder, in addition to drawing water from the source it draws water out of the surge chamber, expanding the air above the water. When the piston then moves down the cylinder, the suction valve closes but the expanded air in the chamber now contracts, continuing to draw water (albeit at a slower rate) from the water source, but this time into the chamber.

This means that during all stages of the pumping cycle, water is moving along the pipe from the source. This is much more efficient than the intermittent stop/start flow which would occur in the suction pipe if the surge chamber were not used. The SWS version of the rower pump uses a sealed pipe connected to a tee joint to create a surge chamber (Figure 7.4a). The Bangladesh version shown in Technical Brief No.41 uses an aluminium pot.

The SWS version has a simple foot valve (Figure 7.4b), which uses a rubber disk which can be cut from the inner tube from a lorry tyre. The valve body clips into place at the foot of the cylinder and has a hook attached to it – used to remove the valve for maintenance. After removing the piston and rod, the foot valve can be removed by 'fishing' for the hook with a plastic pipe and a loop on a piece of strong string longer than the length of the cylinder. The loop is stretched across notches in the end of the pipe, so that when the pipe is pushed down to touch the foot valve, the string is positioned correctly to engage in the hook that enters the end of the pipe. Instead of the string and pipe, a hooked rod can be used. Whichever method is used, when the hook on the valve is 'caught', pulling on the string (or on the hooked rod) unclips the valve so it can be pulled out through the cylinder.

The SWS rower pump also has an interesting piston, which is loose on the rod so that its movement opens and closes the piston valve (Figure 7.4c). The piston is made from strong plastic and the seals and valve are made from nitrile rubber. Other versions of the rower pump use a fixed piston, leather piston seal and a flexible rubber disk as the piston seal.

Question: Looking at the diagrams of the rower suction pump in Technical Brief 41 or that in Figure 7.4a, can you identify the advantages and disadvantages of this type of suction pump?

The rower pump is relatively easy to manufacture because it has no bearings, the cylinder and surge chamber can be made from a plastic pipe and standard fittings, and the valves can be made from a vehicle tyre inner tube. As with the traditional suction pump, access for maintenance is very easy. However, the pump has a few drawbacks in addition to those noted for suction pumps in general in Technical Brief 41.

Now download and open: *Technical Brief No. 41: VLOM Pumps* (Skinner and Shaw, 1994.) ONLINE USB

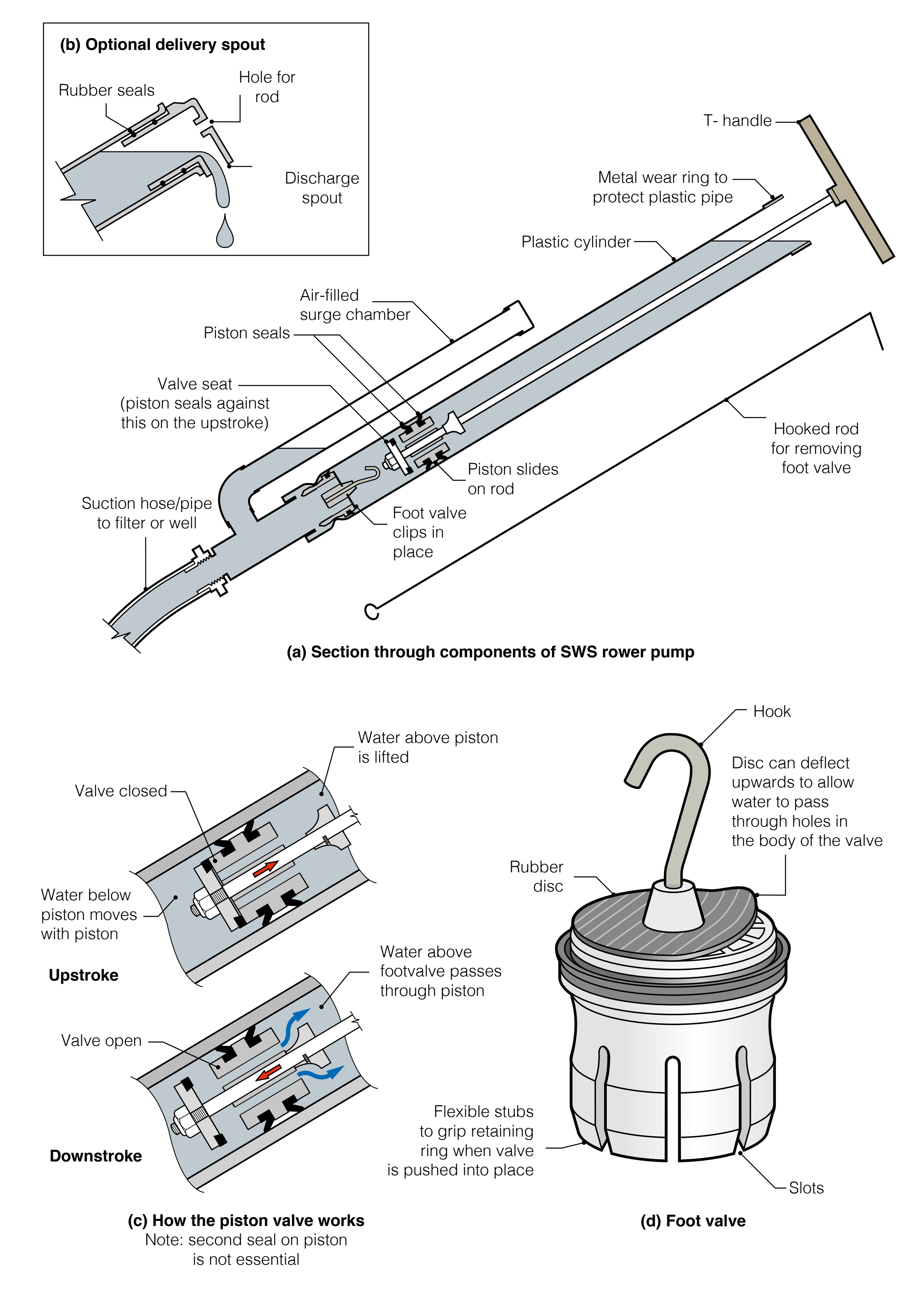


Figure 7.4 Section through components of SWS rower pump

Source: WEDC. Most adapted from: SWS (undated)

The drawbacks are:

- The top of the cylinder is open, so is prone to pollution and the rod and piston can easily be removed and stolen. (A downward pointing 'T' junction can be used, as shown in Figure 7.4a to reduce the risk of contamination. If the T piece is bolted to the pump, it also stops the rod and piston being stolen). Some communities remove the handle and padlock a tin can over the spout when it is not in use, to stop children filling the pump with stones.
- If the operator is pumping at a fast rate, the pump can sometimes spray water over them. (The T piece mentioned above considerably reduces this problem).
- Because of the trajectory of the discharged water, it is hard to fill a vessel, such as a 'jerry can', that has a small openings. (This problem can be reduced by putting a shaped lip on the spout of the pump. Alternatively, the discharging water can be collected in a box or chamber with a small diameter outlet pipe suitably positioned for filling the container, but it may be hard to keep such a system hygienic.)

SWS has developed a rower pump with a valveless piston and a valved delivery pipe connected to the side of the cylinder just above the foot valve. This overcomes some of the problems mentioned above.

The cylinder pipe of the rower pump is usually PVCu plastic, which deteriorates and becomes brittle when exposed to sunlight for long periods. Exposed portions of the pipe therefore need to be protected from sunlight.

7.4.4 Direct action pump

The cylinder of the direct action type of handpump, like that of the deepwell handpump considered in the next section, is *below* water level. This means that it does not need priming, because as soon as the pump is installed, water will flow into the cylinder and fill the rising main pipe above it, until the water level inside the pipe is the same as that in the water source.

The direct action handpump, like the rower suction pump, does not have a lever-operated handle; rather, the operator pulls directly on the vertical rod, which is often a plastic, air-filled pipe. This air-filled pipe is very lightweight compared to a metal rod and is corrosion resistant.

The absence of a lever on direct action handpumps means the force that can be applied to the rod is limited. To make the force acceptable to the user, the piston is usually only about 55mm diameter, much smaller than that used for most suction pumps. However, most people still find direct action pumps hard to use if they are raising water from more than 12m below ground level. With smaller diameter pistons, the force required to lift the piston is reduced and greater depths are possible. The smaller diameter means that discharge per unit length of cylinder is low, but this is partly compensated for in the direct action pump by the long piston stroke that is usually possible.

Direct action pumps that use air-filled pipes as the operating rod, discharge water on the downstroke as well as on the upstroke. This is a result of water being displaced by the large diameter rod (the air-filled pipe), as will now be explained. At the end of the upstroke, the rising main is full of water up to the outlet level and it is held at this level by the foot valve. Now when the rod is pushed down, the volume of rod entering the water held in the rising main will displace an equal volume of water, which will be discharged through the outlet. This is based on the principle illustrated in Figure 7.1c.

A diagram of a direct action handpump, which shows the important features of such pumps, can be found on the third page of Technical Brief 41.

Question: Look at the drawing of the direct action pump in Technical Brief 41. In view of what has already been said about this type of pump and what is shown on the diagram, what advantages do you think it has over traditional suction pumps?

See below for our opinion and also read the comments on the last page of Technical Brief 41.

The main advantage of the direct action handpump is that it can be used beyond the suction limit of suction pumps (i.e. it can raise water from more than 7m below ground level). This is becoming increasingly important where groundwater levels are falling and may seasonally be beyond the limit of suction pumps. Like the rower suction pump the pumphead is simple, without bearings, and the pump potentially has a long piston stroke so it can deliver water at a good rate – even with a relatively small diameter cylinder (e.g. 55mm internal diameter). Because the cylinder diameter can be small, direct action pumps can be installed in narrower boreholes than those needed for many deepwell pumps (Section 7.4.5).

Although the piston may be 12m or more below ground level, because with direct action pumps the rising main is of the same, or a slightly larger, diameter than the cylinder, the piston can be pulled out through the rising main when it needs servicing. (This type of cylinder, which is also used in some deepwell pumps, is called an 'open-top cylinder'). To facilitate easy removal of the piston, the rod pipes may have screwed joints. However, with support from suitable tall poles, a rod-pipe with solvent-cemented joints can be withdrawn in one piece, in a similar way to that illustrated in Technical Brief 41 for removing a complete rising main.

The best designs of direct action handpumps also provide facilities for the removal of the foot valve through the rising main. For example, one of the best-known direct action pumps, the Tara (see Technical Brief No.13), has a grapple device below the piston which can hook on to the foot valve, so this can also be extracted for maintenance. (The grapple can only reach the foot valve when an extension rod is added to the top of the rod, so the piston can then be pushed down lower than it ever reaches during normal operation). With some other types of direct action handpump, such as the Nira AF85 and the Malda (standard version and not the option that uses an Afridev cylinder), the rising main has to be removed to gain access to the foot valve. (Incidentally, both these pumps use polyethylene pipes with threaded couplings for the rising main and the operating rod). If an extractable foot valve system is used, and if a suitable screen (e.g. wellpoint) is provided in a section of pipe below the cylinder, it is possible to use the rising main pipe of a direct action pump as a permanent casing pipe to a narrow borehole.

The piston of a direct action pump will have a variable stroke, depending on the height and strength of the operator. The upstroke can be fairly fast and in some versions of the pump (like the Blair direct action pump [Morgan, 1990]), no piston seal is used because leakage through the small gap around the piston is minimal. Interestingly, with the Blair direct action pump, the water passes *through* the pipe that is used as an operating rod and it discharges this water from the *moving* operating pipe, which is bent over like a walking stick at ground level ( ). (Incidentally, Morgan's book gives instructions on how to build this pump and another direct action pump [the Nsimbi] from basic materials.)

Another interesting design of direct action handpump that does not use a piston and seal is the 'New Zealand' or 'Canzee' pump, which is illustrated in Figure 7.6. This is made with simple pipe fittings and has simple valves made from discs of rubber. Like the Blair pump, water in the Canzee passes through the operating rod/pipe; but unlike the Blair, it is discharged through a *fixed* spout connected to the rising main. With the version shown in Figure 7.6a, near the pumphead, water that has passed through the operating rod/pipe is discharged into the rising main through holes in the operating pipe. On the downstroke, water that has passed through the valve at the bottom of the operating pipe is discharged from these holes. Some water is also displaced from the rising main by the descending operating pipe, and this water flows up the annulus between the outside of the operating pipe and the inside of the rising main (some flows back down again when the operating pipe is on its upstroke). Figure 7.6c shows how the Canzee pump works. (Note that on the latest designs of this pump [the 'Vicanzee'], the handle is connected to a short metal rod, which is joined to the plunger pipe using a fitting that allows the water to leave the top of the pipe.)

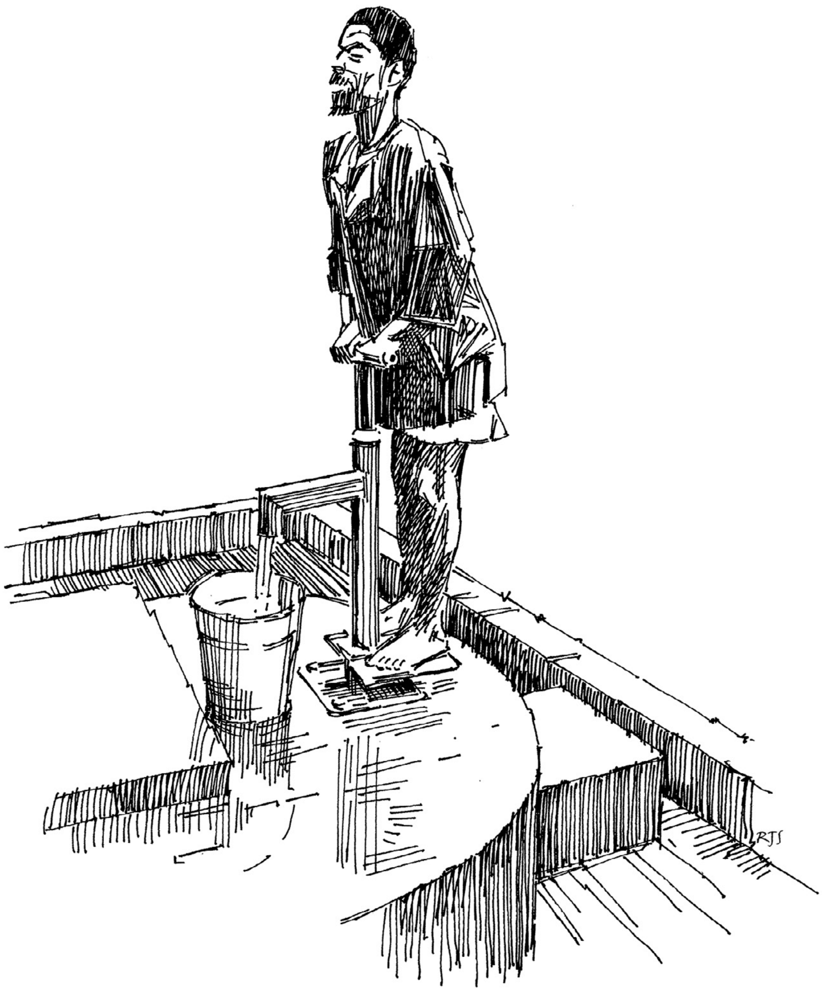
It should be noted that with most direct action handpumps, the operating rod is sealed and always full of air. The Blair and the Canzee pumps are exceptions.

Some versions of direct action handpump use a small diameter, metal rod all the way from the handle to the piston. This rod is much heavier than an air-filled pipe and this makes these pumps hard to operate, except at relatively shallow heights of lift. When a small diameter rod is used, like a conventional reciprocating piston pump, water is only discharged on the upstroke of the rod and piston.

The Tara, which is widely used in Bangladesh and more recently has been introduced to India, is probably the best-known direct action handpump. A virtually identical pump called the Maya-Yaku is used in Bolivia. Originally all the joints on the rising main and operating rod-pipe for the Tara were solvent cemented together, so each had to be carefully removed in one piece. The latest design uses coarse-threaded screwed joints on both pipes (Figure 7.9), which make installation and maintenance easier. Note that some versions of the Tara are not suitable for installation in large diameter wells without adaptation, because the pumphead/rising main connection is not designed to support the weight of the water-filled rising main. Instead, most of the weight is expected to be transferred from the end of the cylinder pipe (at the bottom of the rising main) to the casing pipe. To facilitate this, the end of the cylinder pipe has a tapered rubber seat which, when the main is installed, bears against the reducer at the bottom of the upper well casing pipe.

As mentioned in the Technical Brief 41, because of the nature of the design of many direct action pumps, they are not usually rugged enough to provide water daily for more than about 50 people – unless the community is willing to carry out frequent maintenance and regular repairs. You should therefore check the acceptable level of usage with the manufacturer.

It should be noted that once it is installed in a borehole, one version of the cylindrical diaphragm pump produced by Vergnet looks very similar to a direct action reciprocating piston pump. However, as explained in Section 7.5.1, this Vergnet pump works on a totally different principle.



A direct action pump mounted on a wellhead

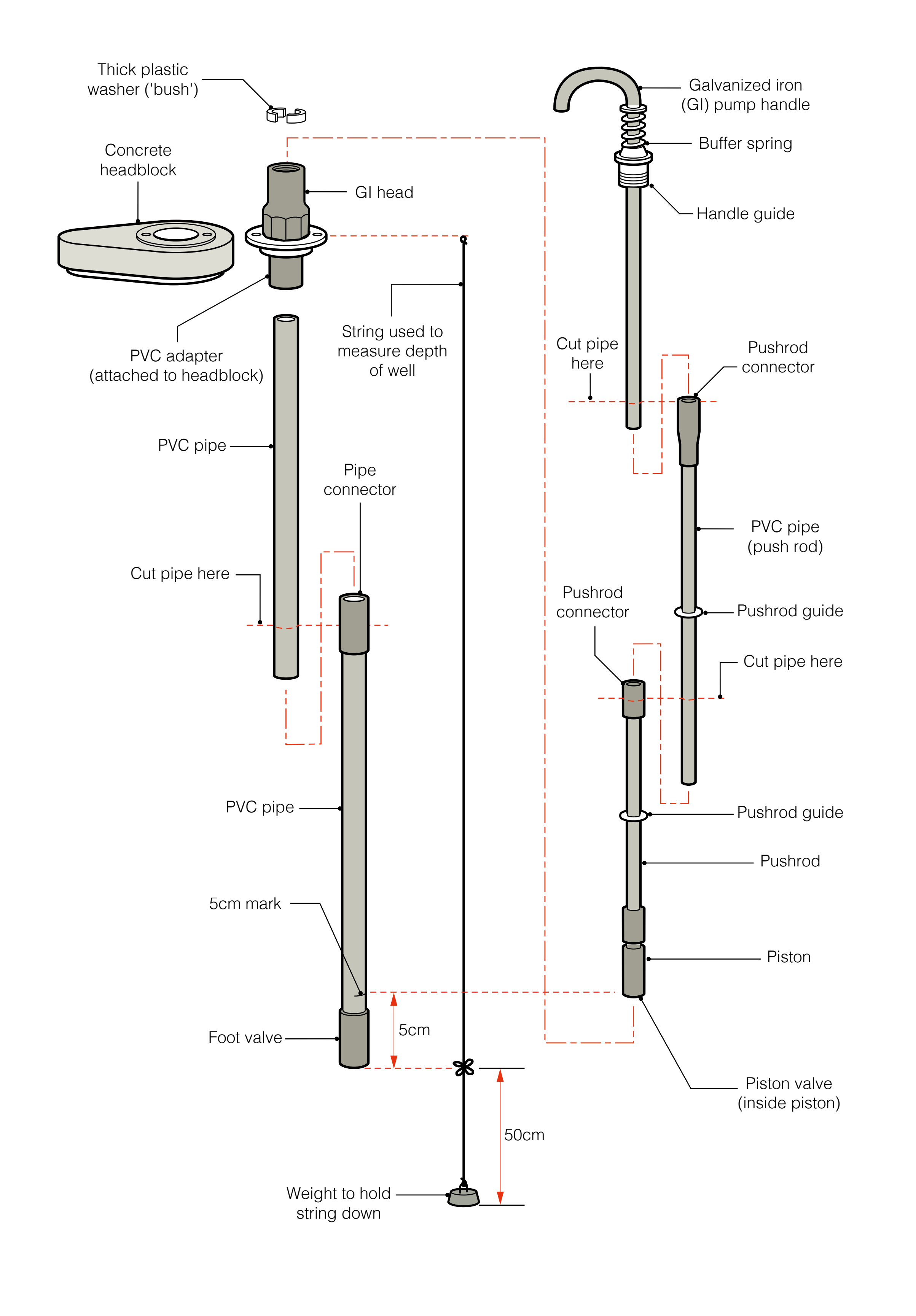


Figure 7.5 Working parts of the Blair direct action pump

Source: WEDC. Adapted from: Morgan (1990)

7.4.5 Deepwell pump

7.4.5.1 General

The term 'deepwell pump' refers to a pump where the cylinder is below water (usually, but not always, at a considerable depth below ground level). It is not uniquely used for reciprocating piston pumps. The direct action pump could be termed a deepwell pump, but may instead be called an 'intermediate depth pump'. Usually, deepwell pumps are lever operated so they can operate beyond the 12-15m limit of most direct action handpumps. Figure 7.3b shows a traditional deepwell handpump, in which the cylinder is usually suspended from a small diameter rising main in which the rod moves up and down.

Sections 9.3 and 9.5 of Smet and van Wijk (2002, pp.175-184) briefly cover reciprocating handpumps.

Question: Look carefully at the drawing of the traditional design of deepwell pump in Figure 7.3b. How would you gain access to the piston seals to maintain them? Can you think how the design of the pump could be changed to make it easier to gain access to the seals?

More recently 'open-top' versions of deepwell pump have become available. In these, the rising main diameter is slightly larger than that of the cylinder.

7.4.5.2 Specific rod-operated deepwell pumps and some limitations on their use

The deepwell type of pump can draw water from a depth far beyond the limit of direct action handpumps. In fact, the only limit on depth is the strength of the operator(s) and the strength of the pump components. Most deepwell pumps can lift water from at least 25m below the pump, but not many can raise it from beyond 45m.

The limit of the Afridev handpump, which has a PVCu plastic rising main, is usually stated to be 45m, although it has been used successfully on some projects at deeper settings. Recent work on methods of stabilizing the bottom of plastic rising main pipes, to stop them moving up and down the borehole during pumping, may mean that deeper settings will become more common in the future. (The pipe movement is a result of the slightly elastic nature of the plastic pipes).

The normal India Mark II handpump is suitable for lifting water up to 45m. Beyond this depth, the 'extra deepwell version' is needed – which can lift water from as deep as 90m.

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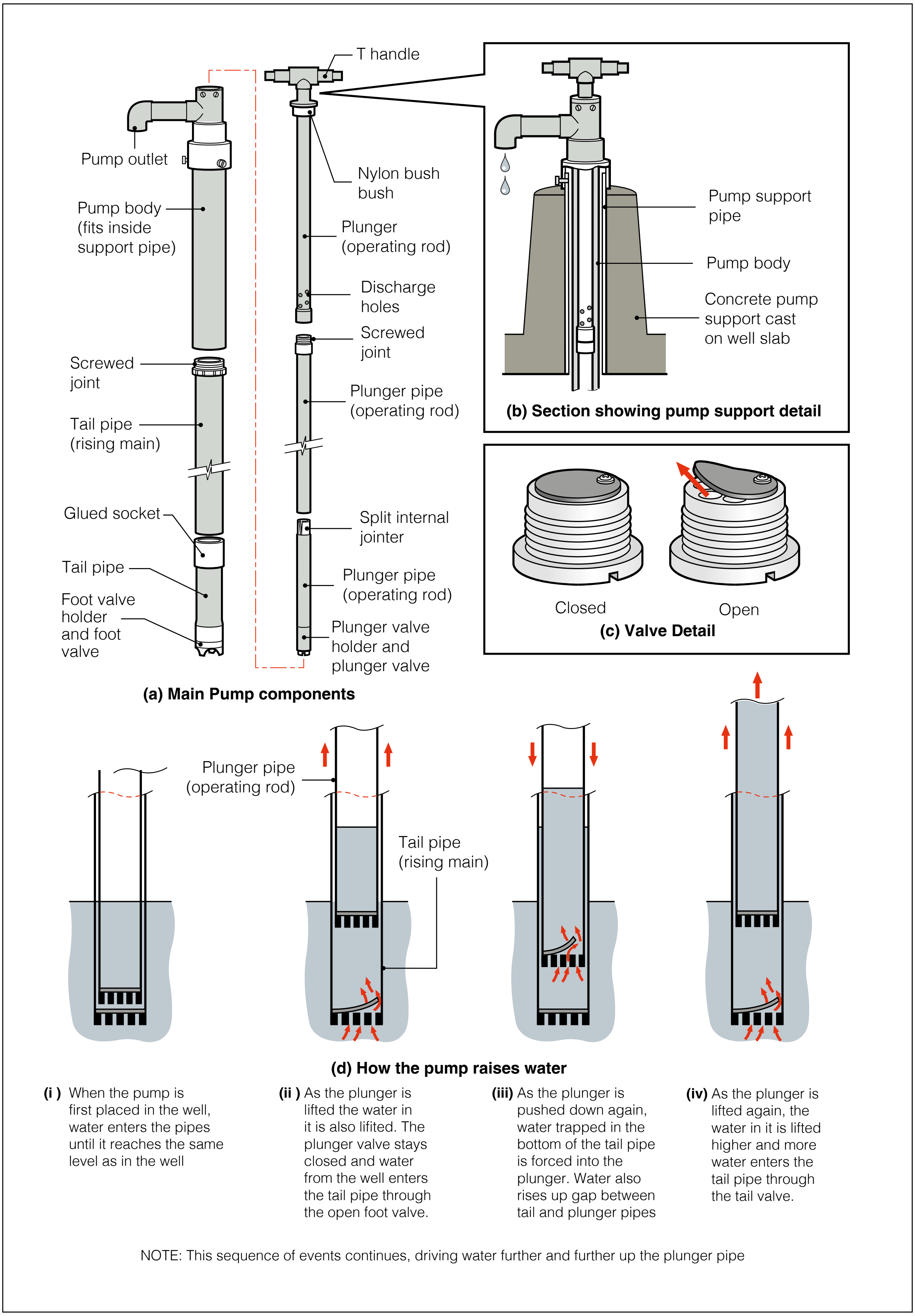

Figure 7.6 The New Zealand or Canzee direct action pump

Source: WEDC. Adapted from: SWS (1994)

With the India Mark III handpump (Figure 7.10), the lift height is usually limited to about 30m if normal 63mm (2.5-inch) diameter galvanized iron pipes are used. This limit is because beyond 30m, there is a risk of the threads on the pipe joints failing. Use of stabilizers, which hold the main central in the borehole and stop it swinging, reduce the risk. In India, plastic pipes with threaded couplings are available for a version of the Mark III type of pump. The pipes make it suitable for depths beyond 30m, the safe limit of the conventional India Mark III pump. The 'open-top cylinder' design (with an extractable cylinder [see Section 7.4.5.3]) makes maintenance of both versions of the Mark III much easier than for the Mark II pump.

Question: At deep settings, the weight of the rods that need to be lifted every stroke is very high. Can you think of a way to reduce the force which the operator needs to apply to the handle to lift the weight of the rods?

Compare your ideas with those mentioned in the fourth paragraph of the following text.

Some other deepwell reciprocating handpumps that can lift water from considerable depth are the Volanta flywheel operated handpump (80m) and the UPM pump (102m). Interestingly, both these use plastic rising main.

The Volanta pump (Figure 7.7) is unique in that it has a long, heavy, seal-less metal piston which moves in a glass-fibre reinforced plastic cylinder. The whole cylinder can be extracted through the rising main (it hangs in a conical seating at the bottom of this pipe). The gland around the operating rod (where it leaves the pumphead) means that this pump can act like a force pump (see Section 7.4.6).

The UPM pump uses a rope and pulley to transfer the force from a handle to the rods and has the unique feature of a piston and valve at every rod joint (Figure 7.8). These pistons are seal-less, but each contains a simple valve. The pulley and rope are used for installing and maintaining the pump, as well as when operating it.

At deep settings, the weight of metal rods of any handle-operated handpump can be counterbalanced by weights added to the handle. If the leverage applied by the counterweight on one side of the handle pivot balances the leverage of the weight of the rods on the other side of the pivot, then the operator only has to apply force to lift the water.

Glass-fibre reinforced plastic rods, which are lighter than metal ones as well as being corrosion resistant, can also be used. Presently, stainless steel rods are used where the water being pumped is corrosive, but these rods are expensive.

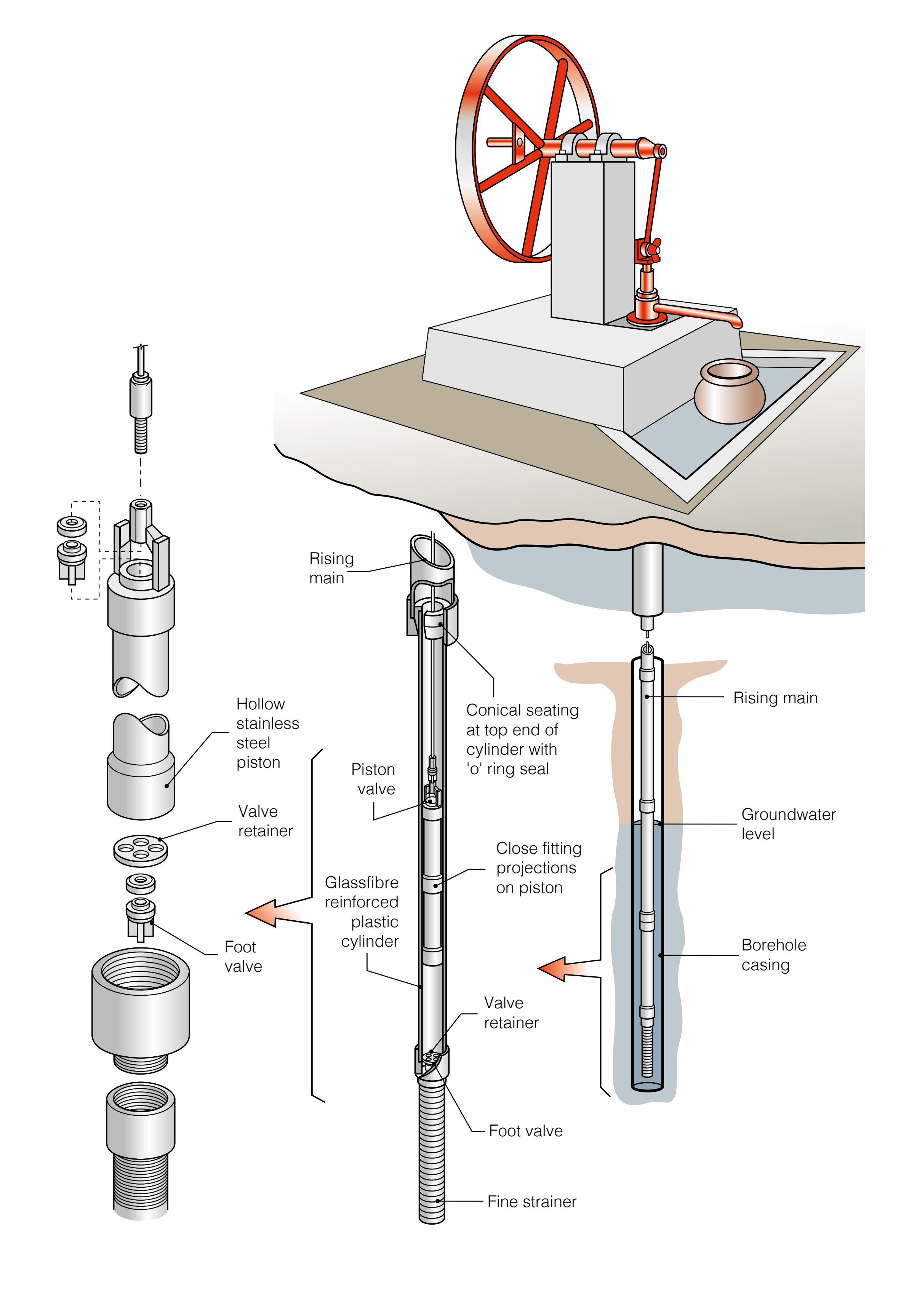

Figure 7.7 The Volanta handpump

Source: WEDC. Adapted from: Venneboer (1987)

The maintenance of traditional designs of deepwell handpumps is difficult because, unlike the suction pump, the cylinder which contains the three wearing parts (the piston seal and two valves) is far below the surface. With the traditional design, the diameter of the rising main is smaller than that of the cylinder. This makes it impossible to withdraw the piston through the rising main. Instead, the rising main full of water, the pump cylinder and the rod must all be lifted together. This is a heavy lift, particularly when the pump uses galvanized steel pipes (often called galvanized iron [GI] pipes). The lifting needs to be done with care to avoid everything being dropped down the borehole. As each pipe joint reaches the surface, the pipe is clamped firmly (see Figure 7.22), the joint is opened and the top pipe is lifted slightly. The rod joint inside the pipe can then be unscrewed, so that one section of rod and pipe can be removed together. This is a very tedious procedure and each time a joint is opened water sprays out! The risks associated with lifting the heavy galvanized rising main pipes, which are often used with traditional deepwell handpumps, mean that often such pumps are not suitable for maintenance by the villagers who use them.

To reduce the weight of the rising main, some manufacturers use plastic instead of galvanized iron for the pipes. Use of plastic pipes also has the added bonus of corrosion resistance. It is not normally possible to cut a thread on the standard, relatively thin walled, PVCu plastic pipe used in water distribution systems without the joints failing when in tension. (The root of normal 'V' threads causes a stress concentration point at which a crack soon develops, leading to the eventual failure of the joint, especially if the rising main is allowed to swing in the borehole). Therefore, plastic pipes used for rising mains are usually connected by special male and female thread mouldings, which are solvent welded onto each end of the pipe (Figure 7.9). Unlike PVCu pipes, polyethylene pipes can sometimes be successfully threaded, but preferably with a coarse thread.

The Inkar pump, which has a pumphead similar to an India Mark II pump, uses thick-walled PVCu pipes into which a very coarse thread can be cut. The ends of adjacent lengths of rising main are then screwed into a threaded coupling, and the joint is kept watertight by two compressed rubber 'O' rings, one against the flat end of each pipe. An identical pipe is used on the Kardia pump made by the same manufacturer.

The 'Ghana modified India Mark II' has lightweight, thin-walled, stainless steel pipes for its rising main. (It also has a modified arrangement for the bearings in the pumphead). One type of pipe is deformed at one end to form a male rope-like thread. A female screwed socket with a similar thread is made by deforming the other end of the pipe. These male and female ends are screwed together and made watertight by a rubber 'O' ring held in the socket. For another type, thicker machine-threaded male and female components are welded to the ends of each length of stainless steel pipe.

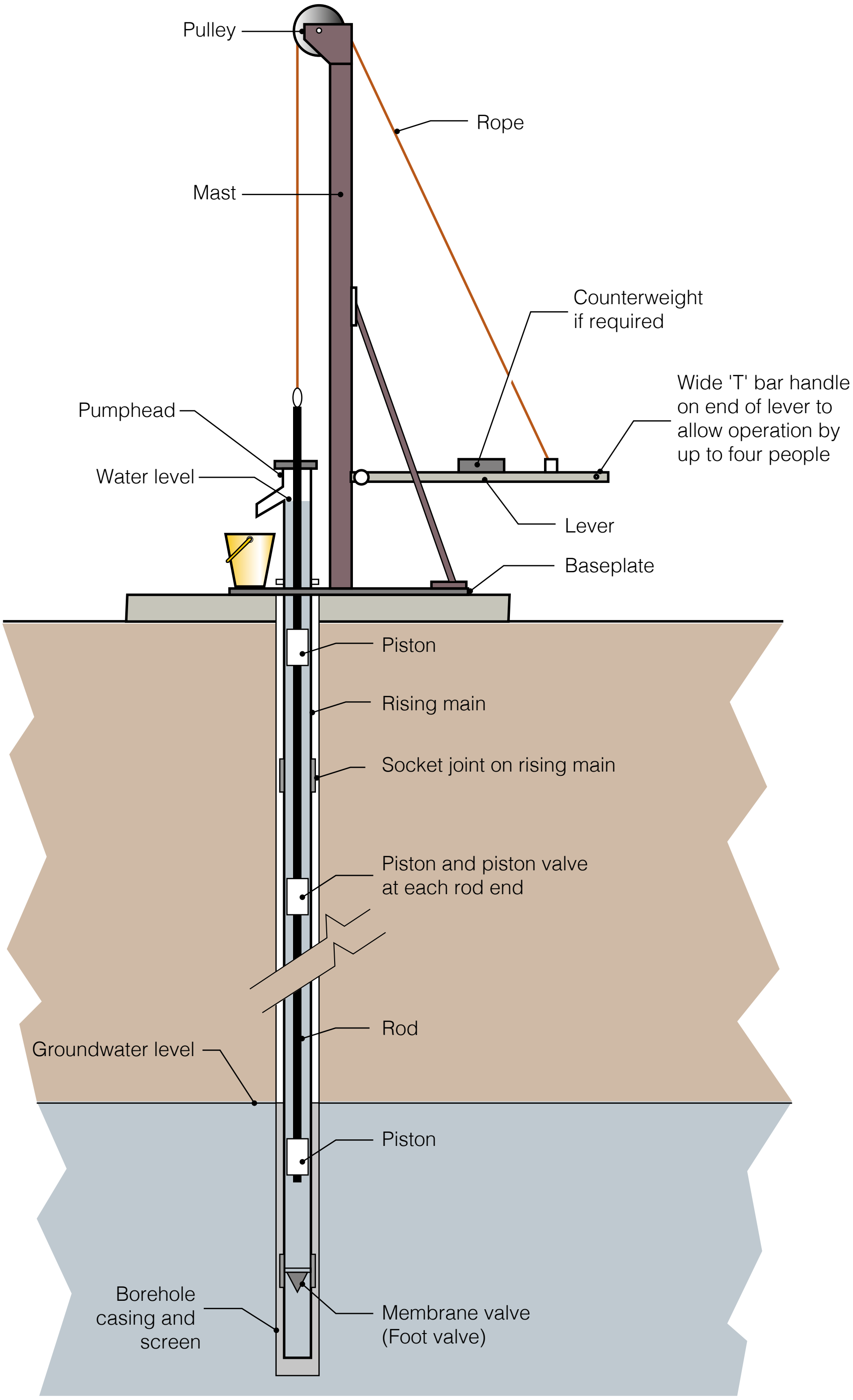

Figure 7.8 The UPM pump

Source WEDC. Adapted from: Maupu (undated)

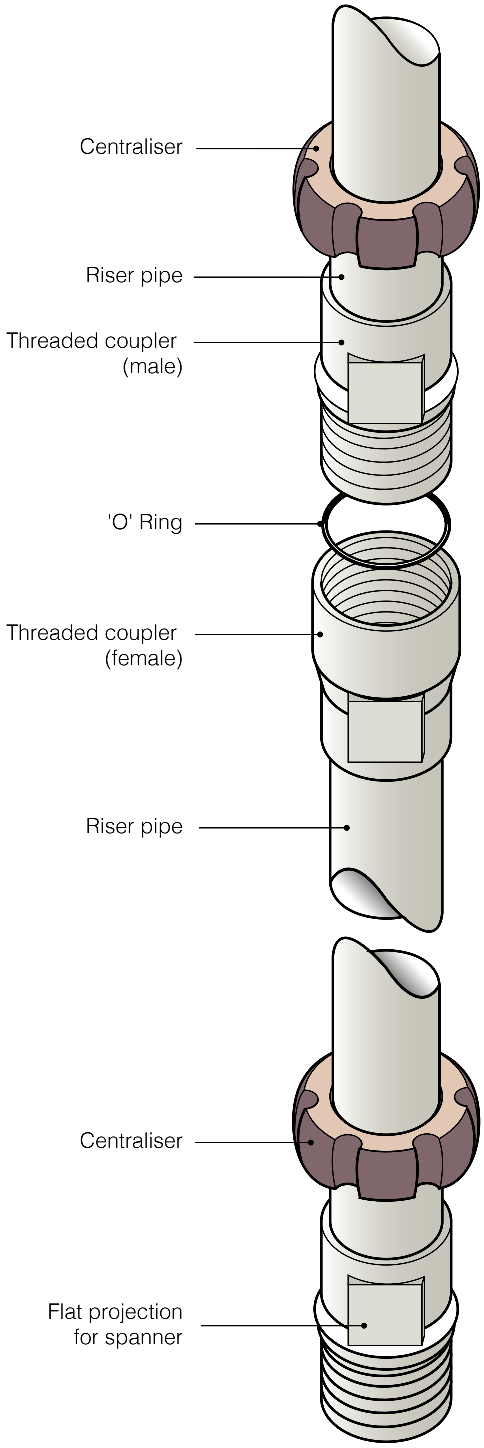

Figure 7.9 An example of PVCu rising main with threaded couplings

Source WEDC. Adapted from: Ajay (no date)

7.4.5.3 Open-top cylinders

If, instead of using the traditional design of cylinder, an 'open-top cylinder' (OTC) is used with an extractable foot valve (as used in the Tara direct action handpump, see Section 7.4.4), then there is normally no need to lift the rising main once it has been installed. The piston can simply be pulled through the rising main when the piston seal or piston valve need maintaining. Using a suitable grapple or threaded attachment on the piston, or by using a separate fishing tool on a rope connected to the rods, it is also possible to remove a suitably designed foot valve through the rising main.

The Afridev pump has an OTC that uses a fishing tool *connected to the rods* to remove the foot valve after the piston has been removed. The Aquadev pump is almost identical to the Afridev, but it uses unique rod connectors and a fishing tool *on a rope* to remove the foot valve (also after the piston had been removed). Rod connectors on both pumps were originally designed to allow the rods to be easily disconnected without the need for a spanner (most other deepwell pumps have screwed rods and connectors like that shown for the India Mark III pump in Figure 7.10). However, the hooked rods formerly used with the Afridev pump have often not performed well, so many people specify the traditional screwed rods.

The India Mark III is an OTC pump. It has a male thread projecting from the bottom of the piston, which can be screwed into a threaded female thread in the top of the foot valve, so that both the piston and the foot valve can be removed at the same time (Figure 7.11). When the foot valve needs removing, the string of rods is extended at the top, so that the piston can reach lower than when it is in normal use. The piston is then pushed down onto the foot valve and the string of rods is rotated to screw the piston and foot valve together. They can both then be pulled out through the rising main, if necessary initially using the leverage of the handle to pull the foot valve out of its tapered seating. The foot valve has a piston valve lifter, which operates when the two pieces are screwed together. This raises the valve to allow water to pass through the piston as it is pulled through the rising main. This prevents the piston seals being pushed against the inside of the rising main by water trying to pass around them as the piston is withdrawn. (The clearance around the foot valve body is sufficiently large for water to flow around it as it is raised together with the piston.)

Some versions of the Bush pump are OTC versions. Morgan (1990) provides a considerable amount of information on this interesting pump, in which the pivot points are formed by large diameter bolts that pass through an oiled hardwood block.

Clearly, the use of an open-top cylinder is a very good feature of a deepwell pump, since it makes village-level operation and maintenance a possibility.

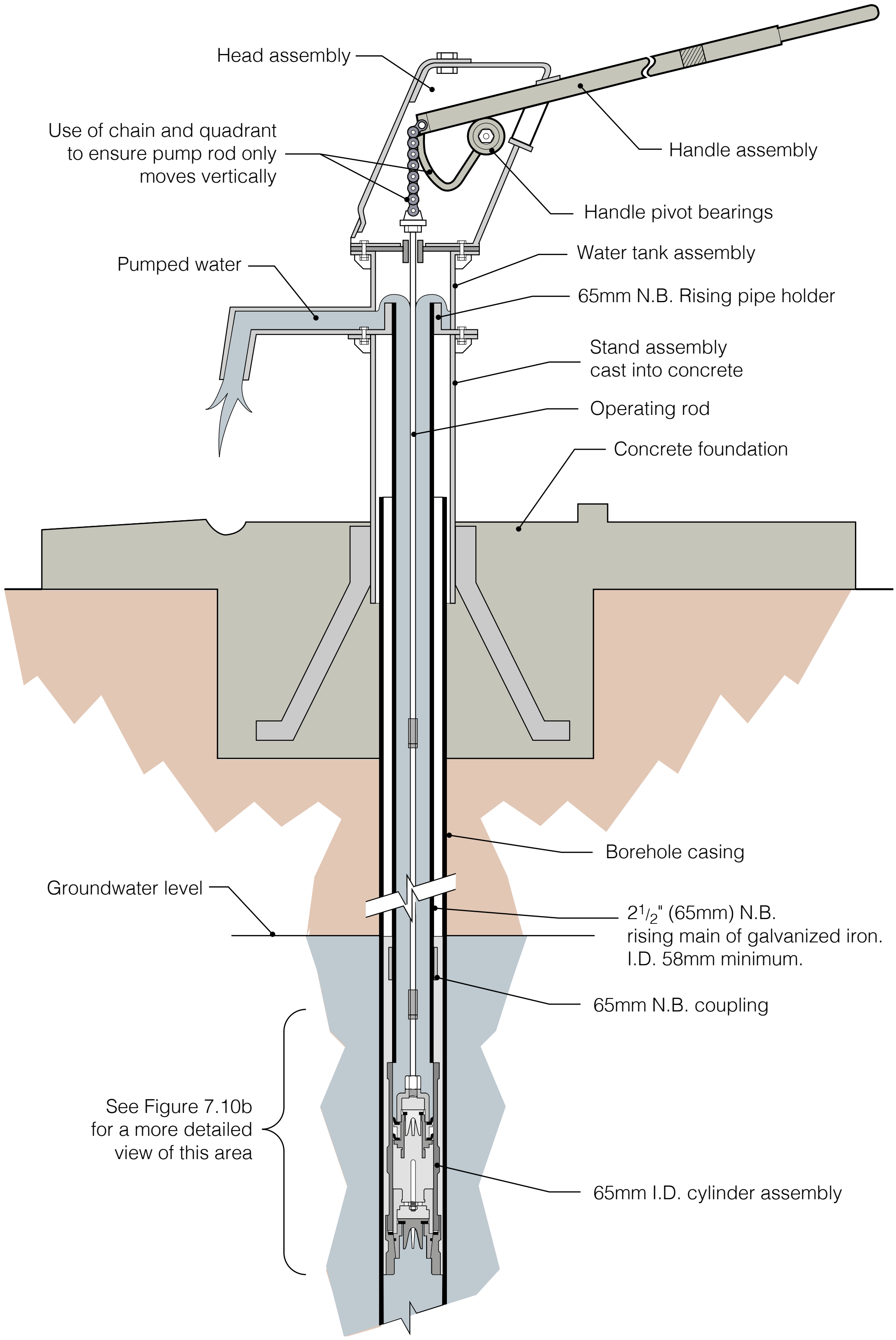

Figure 7.10 Installation details of India Mark III deepwell pump

Source: WEDC

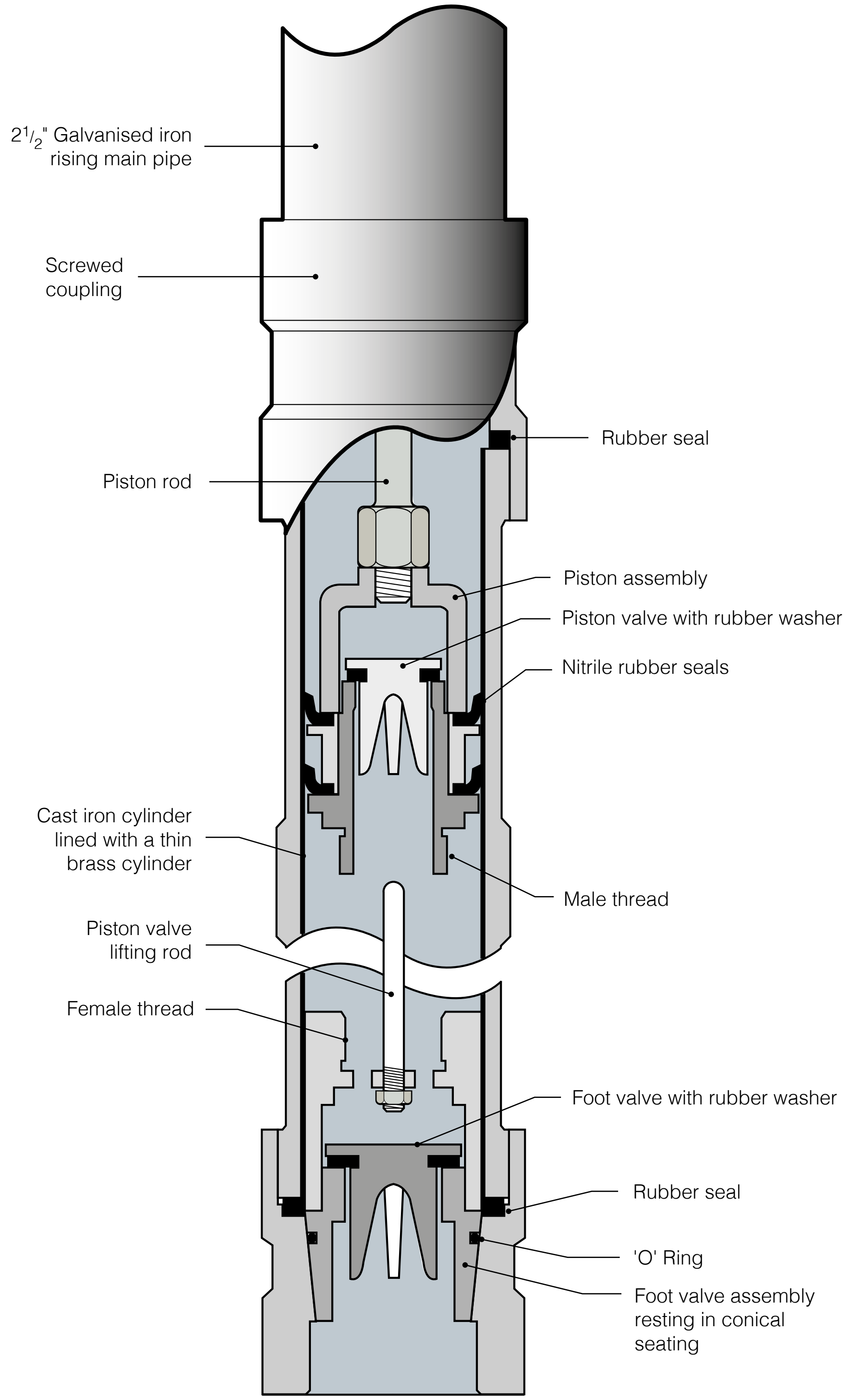

Figure 7.11 Cylinder of India Mark III deepwell pump

Source WEDC. Adapted from: UNICEF (1991)

7.4.6 Force pumps

Some authors differ on the use of the term 'force pump'. Like Smet and van Wijk (2002, pp.183-184), we use it to describe a reciprocating piston pump that is able to raise water above the level of the pumphead. With many types of pump, this is not possible because the pumphead is not designed to withstand water pressure: if the spout were connected to a pipe leading to an overhead tank, water would escape from the head rather than rise up the pipe. Force pumps can be suction pumps or deepwell pumps. They are useful for raising water to elevated tanks.

As you will see from Figure 7.3c and Figure 7.3d), reciprocating force pumps have a seal around the operating rod, which allows it to slide vertically up and down without water leaking out at that point. The feature is often known as a 'stuffing box' and is in the form of a gland which can be compressed to give a good seal around the rod. As you will see from Figure 7.3c and Figure 7.3d), a three-pivot mechanism is usually used for the handle to enable the rod to only move vertically in the gland. As mentioned earlier, if only two pivots are used with the handle, because of the arc followed by the rod hanger pivot, the top of the rod will move from side to side as well as up and down; with such a movement, it is hard to make a watertight joint.

The air trapped in the pumphead of some force pumps, as shown in the figures just mentioned, smooths out the discharge from the pumps. The height to which force pumps can raise water is limited only by the strength of the pump and the operator, and the ability of the gland to resist the water pressure resulting from the height to which the water is being lifted.

7.4.7 Miscellaneous matters

7.4.7.1 The chain suspension used for the rods on the India Mark II and III pumps

You will see from Figure 7.10 that with the India Mark III pump, the top of the pump rod moves only vertically and not along an arc. This is possible because of the use of a suspension chain, which moves against a quadrant chain guide on the rod end of the handle. The India Mark II pump is similar. This mechanism avoids the cyclical and rapid change from compression in the rod (when the handle is quickly lifted, pushing down the rod) to tension (when the handle is pushed down, lifting the rod), which is experienced in the rod joints of normal deepwell pumps.

On the India Mark II and III pumps, there is no watertight gland provided around the rod at the point where it passes through the pumphead. This means that neither of the standard versions can be used as a force pump. If a gland were added around the rod at this point, the pump is unlikely to work well. This is because unless the string of rods is heavy enough to overcome the friction in the gland. When the handle is raised the pump rod will not move down fast enough and the chain will buckle away from the chain guide. This is because, unlike with a direct rod connection to the handle, raising the handle of these Indian pumps cannot push the rod down. Instead, the downward movement of the piston and rods depends only on the force of gravity acting on the rods. Indeed, with the normal India Mark II and III, at shallow depths (e.g. less than about 10m) extra heavy rods are needed to ensure that the downstroke of the rod, during which there is some resistance from the piston seals, is fast enough. To overcome this problem, some suppliers also supply a 'fixed link' version of these pumps which, like most deepwell pumps, has a fixed connection between the rod and handle instead of the chain used with the standard version.

7.4.7.2 The VLOM features of the Afridev pump

The last page of Technical Brief No.41 lists typical VLOM features of pumps. The Aquadev has many identical features to the Afridev, but has unique rod joints and a different fishing tool (see Section 7.4.5.3).

7.4.7.3 Spout design

The way water is discharged from the spout of some handpumps makes it hard to fill water vessels with small openings. (This may be true of any type of handpump, not only reciprocating piston pumps). To prevent water being wasted, poorly designed spouts should be adapted. Sometimes providing a plinth below the spout to raise the opening of the vessel nearer to the spout also helps. Some communities cut the bottom off an old plastic bottle and use this as a funnel, but the funnel can be a source of contamination if it is left lying around on the apron slab.

7.5 Other types of pump

As previously mentioned, most types of suction, direct action and deepwell handpump have a rod-operated, reciprocating piston. However, there are some well-known hand/footpumps that use different operating principles, and this section introduces you to these. We are going to look at five types of handpump that work in different ways to the reciprocating piston pump:

- cylindrical **diaphragm pump** (e.g. Vergnet), which is *hydraulically* operated;
- **progressive cavity pump** (e.g. Monolift), in which the water is lifted by a rotor that is driven by a rotating rod positioned in the rising main;
- **oscillating water column pump** (e.g. Pulsa), in which dynamic oscillations of a water column allow water to be pumped through a rising main;
- **rope and washer pump**, in which a loop of rope carrying washers is continually pulled through a rising main; and
- **Blair bucket pump**, which is a development of the bucket and windlass method used for drawing water from open wells, but – because of the narrow-valved bucket – can be used in boreholes.

7.5.1 Cylindrical diaphragm pump

This pump is often called a 'diaphragm pump', but we prefer to prefix this with 'cylindrical' to distinguish it from another type of diaphragm pump that uses a rubber disc rather than a rubber hose.

The most common version of the cylindrical diaphragm pump is known as the Vergnet pump or more correctly the 'Vergnet hydropump'. This pump uses an elastic rubber hose (cylindrical diaphragm) as the pumping element, and this is positioned below the water level (Figure 7.12). As you will see from the diagram, the hose is located in a stainless-steel cylinder, which is equipped with two main valves. There are two separate hydraulic systems in this pump, the *drive system* and the *discharge system*.

Instead of using hydraulic operation, the Atlas Copco 111 pump uses volume changes in a rubber hose caused by alternately stretching and releasing it to pump water. There is no space in this unit to describe this pump, which is not common, and we will instead concentrate on the Vergnet hydropump, which is found in many Francophone counties.

7.5.1.1 Mode of operation of the Vergnet hydropump

The rubber hose in the main cylinder in the borehole is closed one end and connected at the other end to the polyethylene *drive pipe*, which travels up the borehole to the 'primary cylinder' at the surface which contains a small piston. The rubber hose and drive pipe are filled with water, so that when the piston is pushed down, it pressurizes the water in the *drive system*, causing the rubber hose to expand and extend to displace the water held between it and the inside of the stainless-steel cylinder that surrounds it.

When the hose expands (Figure 7.12b), the resulting increase in pressure in the water trapped between the outside of the hose and the inside of the cylinder causes the foot valve to close, so that the displaced water rises through the *discharge* valve, up a second polyethylene pipe (the *discharge* pipe), to the pump spout at the surface.

When the force is removed from the piston (Figure 7.12a), the rubber hose shrinks back to its original size, and the pressure of the water in the drive circuit pushes the piston and foot pedal up ready for the next downstroke. As the volume of the hose reduces, the pressure in the main stainless steel cylinder around it also reduces, causing the discharge valve to close, which holds the water in the discharge pipe. The reduced pressure in the cylinder also causes the foot valve to open and water is sucked into the cylinder through this valve, ready to be displaced by the next stoke.

The drive and discharge systems circuits are separate, other than for a valved connection in the top of the main cylinder, which is used to ensure that any water lost from the drive circuit is automatically replaced (for clarity, this valve is not shown on Figure 7.12). This 'topping up' takes place when the foot pedal piston reaches the top of its upstroke. At this stage, the pressure in the drive circuit at the top of the main cylinder (on one side of the 'top-up valve') reduces below that in the discharge circuit (on the other side of the 'top-up valve'). This means that some water from the discharge pipe passes through the valve into the drive circuit. If, as a result of this topping-up process, excess water enters the drive system at each stroke, it is expelled into the top of the borehole through a small hole in the side of the top of the primary cylinder.

On each stroke, a little water is always lost from the drive circuit through the plastic bush around the pedal shaft at the top of the cylinder. This washes away dirt and lubricates the shaft. This bush, which centralizes the pedal shaft, cannot be a very tight fit because that would restrict the movement of the pedal. Some observers suggest that in certain circumstances, pollution can enter the primary cylinder through the loose seal around the pedal rod, and then enter the borehole through the overflow hole in the primary cylinder.

The seals on the piston in the primary cylinder are in the form of four split polyurethane rings which are easily replaced. They are not a very tight fit in the cylinder, so the foot pedal falls to its lowest position when the pump is not in use. Swiftly pulling the pedal up, tops up the drive system with water from the discharge system (via the 'top-up valve' previously mentioned) and the pump is ready to operate.

Most Vergnet pumps are foot-operated, but the manufacturer has introduced a version where the piston in the primary cylinder is operated by a vertical rod connected to a 'T' bar for operation by hand. This is preferred by some women, who find operation of the foot pedal embarrassing and think it to be harmful when they are pregnant. The pumphead for this 'T' bar version looks very similar to a direct action handpump. Below the pumphead, the smaller diameter drive pipe is hidden inside the larger diameter discharge pipe, and this pipe could be mistakenly assumed to be the rising main of a rod-operated, reciprocating piston, direct action pump (Section 7.4.4)!

At one time, a lever-operated pumphead version of the Vergnet pump, called the Abi-ASM, was available in Cote d'Ivoire.

The Vergnet pump is supplied with three different diaphragms, main cylinders and pumpheads: one set for the direct action version (for use up to 30m lift); one for the normal footpump (from 20-60m lift); and another for a footpump operated by two people (for 50-100m lift). Each diaphragm hose (called a 'baudruche' by the French manufacturer) is guaranteed for three years.

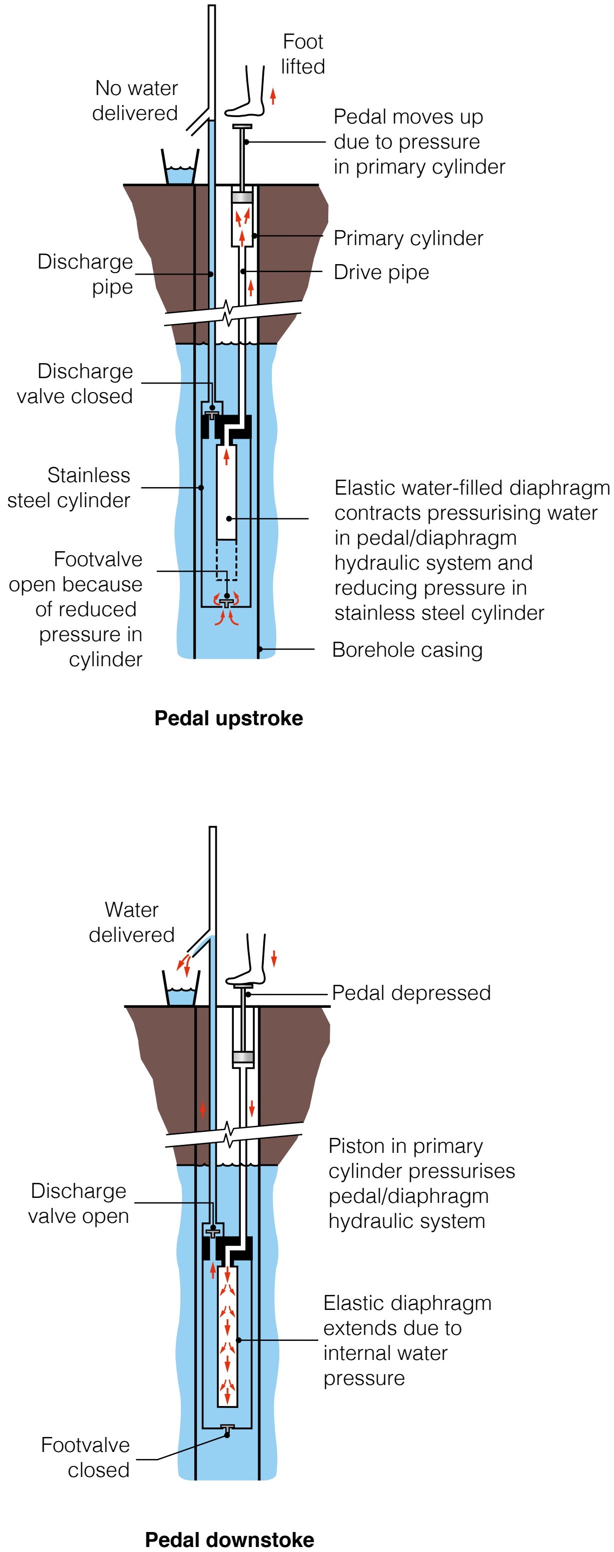

Figure 7.12 The Vergnet pump

Source: WEDC

Advantages of the Vergnet pump include:

- Corrosion resistance.
- The main wearing parts (in the primary cylinder) are easily accessible.
- When necessary, the main cylinder can be reached by pulling it up using the two long flexible pipes attached to it, without the need for heavy lifting equipment (Figure 7.12b). For shallow settings, two people can do this job, but for deeper settings it may need four people. Note that the outside of the rising main is likely to become contaminated during this operation, particularly when it is laid on the ground, so it needs to be washed clean as it is being re-installed in the borehole, and ideally (as with other pumps) the borehole should be disinfected after re-installation.
- Several Vergnet pumps can be installed in the same borehole. This is achieved by positioning the cylinders at different levels and providing a chamber at the top of the borehole, so the pipes can be routed to different pumpheads. Up to four pumps can be installed in a borehole with an internal diameter of 150mm. The uppermost cylinder has the six pipes from the cylinders below it positioned around it in the borehole.
- Unlike with rod operated deepwell pumps, the borehole does not have to be vertical or straight.
- With suitably designed headworks at the top of a borehole or well, the pump can be offset some distance away from the water source.
- The whole body weight can be used when pumping with the footpump version.
- With minimum adaptations to the pumphead, it is possible to raise water to above the level of the operator.

Disadvantages include:

- The pumping element is not suitable for manufacture in most developing countries, and may be expensive to import.
- If the raw water contains sand, this can enter the diaphragm via the automatic top-up system. This will reduce its effectiveness and may cause it to fail prematurely.
- Possible pollution risk via the pedal rod bush.

7.5.2 Progressive cavity pump

The pumping element of this pump is located below water. It consists of a very smooth metal, single (or double) helix rotor, which rotates in a double (or triple) helix elastomeric (e.g. rubber) stator (Figure 7.13c). These are positioned at the bottom of a rising main, which contains a rotating rod that drives the pump. The rod is stabilized by rubber bobbin bearings at each rod joint. Direct rotation of the rods by means of a single, horizontally rotated handle (Figure 7.13b) has been used, but it is more normal to use intermeshing bevel gears to convert vertical rotation of two handles, one each side of the pumphead (Figure 7.13a), to produce the horizontal rotation needed by the rod.

As the rotor rotates, the surface of the rotor and the flexible stator intermesh in such a way that a water-filled cavity is formed which moves up and around the stator until, at the top end of the stator, the water is ejected into the rising main. If the rods are rotated in the wrong direction, the pump will not raise water and there is a risk of the rods becoming unscrewed. To eliminate this danger, a ratchet device (or similar mechanism) is provided in the pumphead to prevent the rods being rotated in the wrong direction.

Strictly speaking, the continuous seal between the rotor and the stator means that a foot valve is not required with this pump, but often, as a precaution, one is fitted.

The best known manufacturers of this type of handpump are Mono/Dresser (the Monolift pump). Robbins and Myers (Canada) make a similar pump called the Moyno pump.

On the Monolift pump, the rod uses left-hand threads, which unlike normal threads unscrew in a clockwise direction – this can confuse some mechanics!

Advantages of a progressive cavity pump include:

- It has good abrasion resistance when pumping water containing sand.
- It can be motorized relatively easily;
- It can raise water to a level above that of the operator. (A watertight gland around the rotating rod where it leaves the water discharge reservoir in the pumphead, means that the water can be pumped to as high as 30m above the pumphead. This can be useful for filling overhead tanks [see Section 7.4.6]).
- It can cope with pumping lifts of up to 90m.

Disadvantages of a progressive cavity pump include:

- It is harder to operate than most other pumps at shallow lifts.
- As with a traditional deepwell reciprocating piston handpump, the heavy water-filled rising main and the long drive rod need to be lifted out of the borehole (Section 7.4.5.2) to gain access to the rotor/stator element.
- Although access should be needed only rarely, when this is necessary it will need heavy lifting gear and will be a task beyond the capabilities of most communities.
- It is not suitable for manufacture in most developing countries.

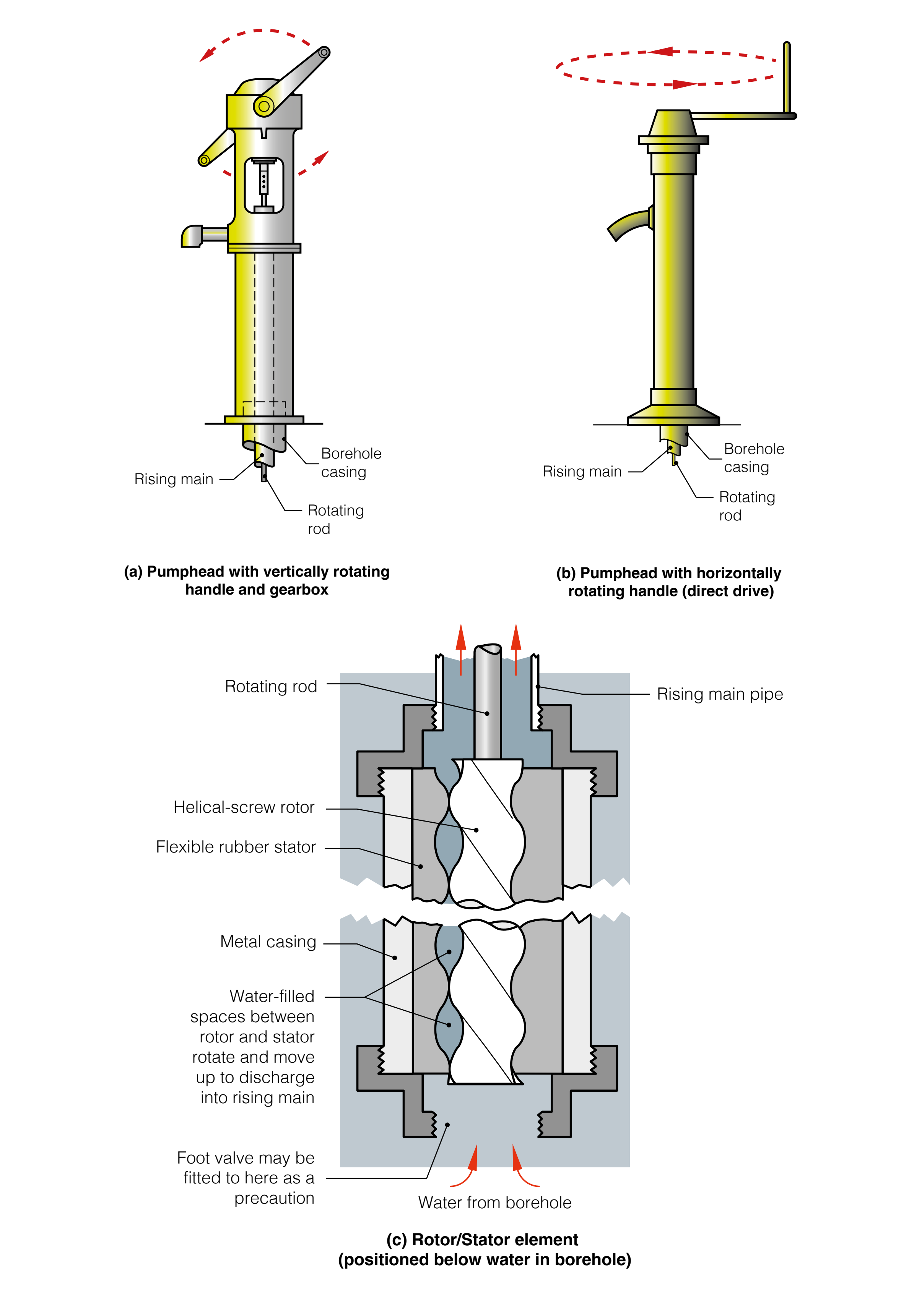

Figure 7.13 Progressive cavity pump

Source: WEDC

7.5.3 Inertia and oscillating water column pumps

There are a few pumps which depend on accelerating a mass of water and then using the momentum of the water to pump additional water. Some of these, like the 'joggle' pumps (Figure 7.14), are called reciprocating inertia pumps, but we know of no handpumps currently in production that use this principle with a single pipe.

Another type of pump that used to be in production, which also used the inertia of moving water, was the Pulsa pump. The Italian manufacturer called this an 'oscillating water column pump'.

As shown in Figure 7.15, the Pulsa pump has a large diameter piston and cylinder at the surface which is hydraulically connected, via a water-filled polyethylene pipe, to a stainless-steel cylinder below the water level. A force can be applied to the piston via a lever. This lever can be operated by two hands and one foot (via a foot pedal attachment) and it can be operated by two people simultaneously.

The way in which the Pulsa raises water is illustrated in Figure 7.15 and will now be described.

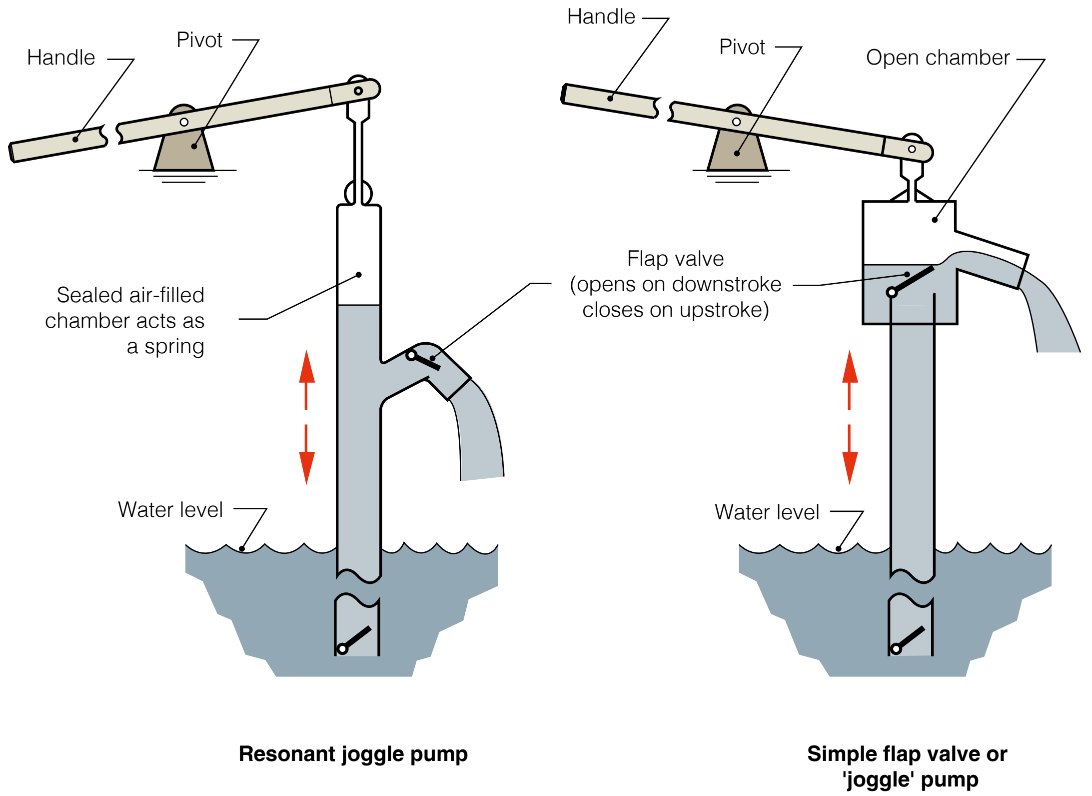

Figure 7.14 Reciprocating inertia pumps

Source WEDC. Adapted from: Fraenkel (1997)

The submerged cylinder near the bottom of the borehole has a foot valve, but instead of a piston it contains up to eight elastomeric balls. These balls are compressed by the hydraulic pressure which is transmitted to them if the piston at the surface is pushed down. At the same time, the polyethylene pipe also expands and to allow for this the manufacturer recommends using specified numbers of balls for ranges of depths to the groundwater table. When the operator stops applying a downward force on the handle/foot-pedal, the force on the piston is suddenly reduced and the water pressure applied to the balls in the cylinder therefore also reduces. This allows the balls to expand again, and their increased volume (and the contraction of the diameter of the rising main) displaces water which flows back up the pipe, causing the piston to lift again. If at the top of its stroke the piston is manually lifted above a seal, the inertia of the rising column of water causes some of it to continue to rise above its original level and some spills out of the piston cylinder into the pumphead, from where it flows to the pump spout. At the same time as the top of the water column flows out of the upper cylinder, the reduced pressure in the submerged cylinder causes the foot valve to open, and some additional water is drawn in from the borehole. The water column can now be compressed by again pushing down on the handle and the pumping cycle is repeated.

The dynamic nature of the oscillating water column means that the pump operates best at a particular frequency of strokes, which needs to be determined at each installation.

The manufacturer used to produce a solar-powered version of this pump, which used photovoltaic panels to power an electric motor which turns a large, belt-driven flywheel. When necessary, the flywheel could also be driven by hand.

We have not heard much about the field performance of the Pulsa pump, but believe that it has the following advantages and disadvantages:

Advantages (note that many of these are common to the Vergnet pump):

- the main wearing parts are easily accessible;
- it is relatively easy to remove and install;
- some of the body weight can be used on the foot pedal as well as via the handle;
- it can be installed in crooked boreholes;
- more than one handpump can be installed in a borehole (e.g. four in a 130mm internal diameter borehole);
- it has good corrosion resistance; and
- the pump can be offset from the source.

Disadvantages:

- it is harder to operate than most lever-operated pumps at shallow depths, with some skill being needed to find the right operating frequency to produce the best delivery rate; and
- considerable use of stainless steel in the design of the standard pump, although making it corrosion resistant, also makes it unsuitable and/or expensive for manufacture in most developing countries.

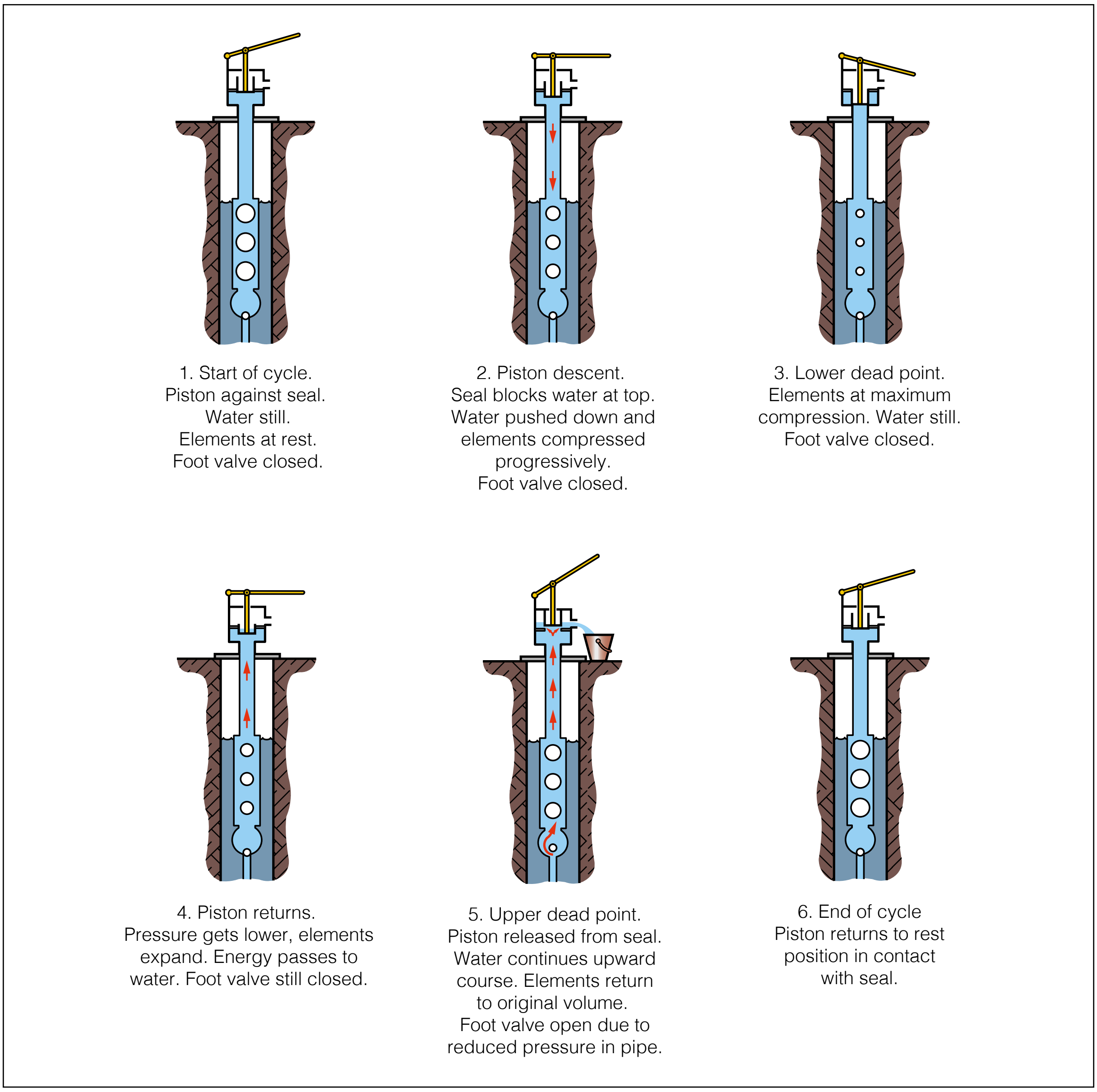

Figure 7.15 How the Pulsa pump works

Source WEDC. Adapted from: Pulsa (1988)

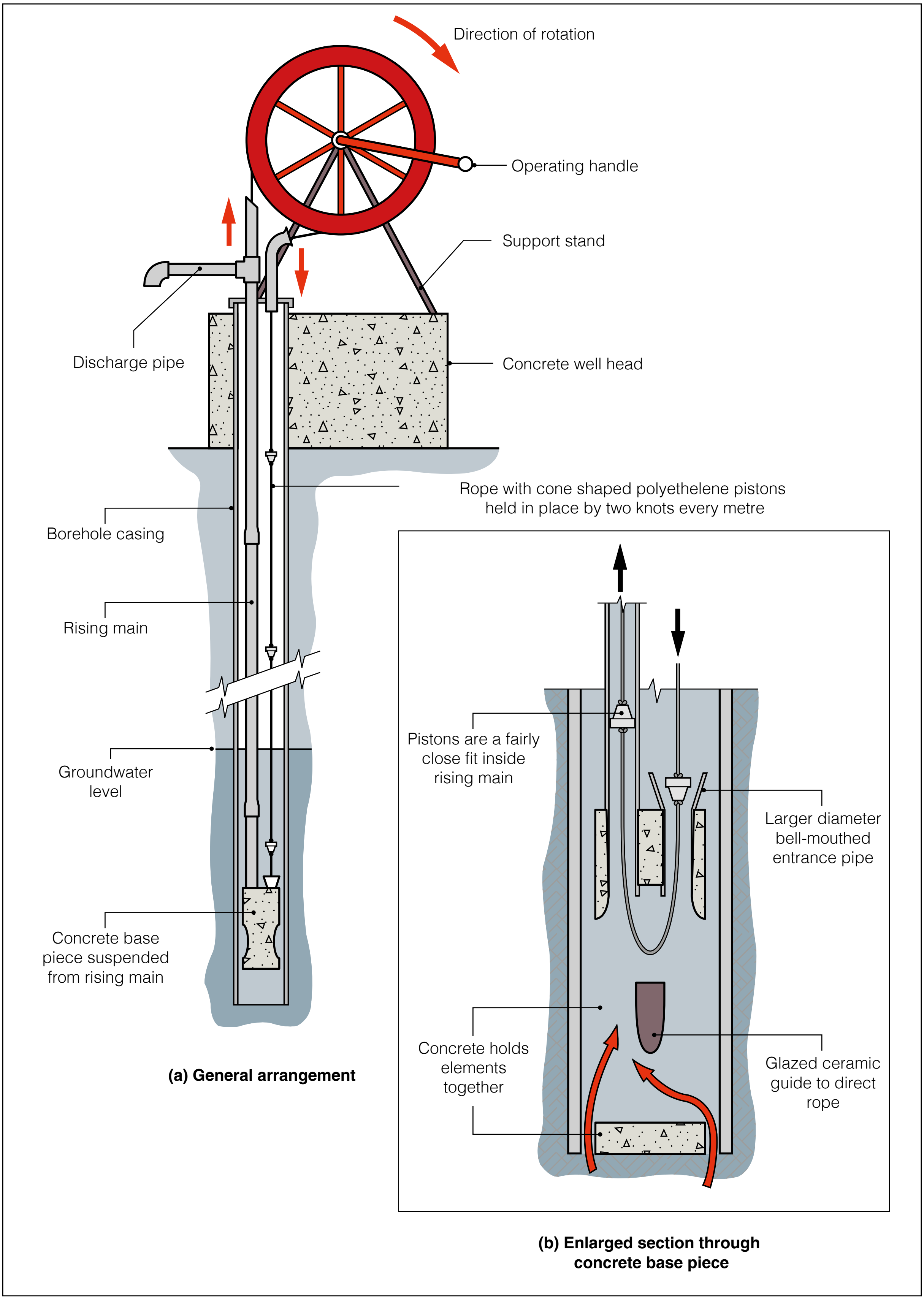

Figure 7.16 A rope and washer pump used in a borehole

Source: WEDC

7.5.4 Rope and washer pump

This is a very simple pump which can usually be made from local materials such as wood, rope and vehicle tyres (Lambert, 1989). Traditionally it has been used vertically on open wells, but inclined versions (see Technical Brief No.35) have been used to draw water from ponds or rivers. More recently, designs which allow its use on boreholes have been developed in Nicaragua (Figure 7.16).

As you will see from the diagrams mentioned above, in essence the pump works by pulling a continuous length of rope, with pistons attached to it, through a smooth pipe. The bottom of the pipe is below the water level so that it is always full of water. As each piston enters the pipe, it traps water which it then lifts it up the pipe. There is some leakage around the pistons because they are not designed to push tightly against the inside of the rising main (because this would create too much friction), but the relatively fast movement of all the pistons means that the pump can usually still deliver water at a good rate. In the home-made versions, the pistons can be discs cut out of the side-wall of lorry tyres. In Nicaragua, cone-shaped moulded polypropylene or polyethylene pistons are used (Figure 7.16).

Use of the rope and washer pump is widespread in Nicaragua and had been documented in Alberts et al. (1993) and Sandiford et al. (1993). Longer-lasting designs produced in basic workshops have been developed and a comprehensive technology dissemination programme has sought to pass on the lessons learned (e.g. RPC, 1997a and b).

In Nicaragua, a version using a 18mm diameter pipe can lift water at a rate of 8.3 litres/minute from 42m depth. A 30mm pipe at 17m depth is able to deliver 18.9 litres/minute (Alberts et al., 1993).

The rope and washer pump is sometimes called the 'rope pump' and a version for an open well is illustrated in Figure 9.12 of Smet and van Wijk (2002, p.186). When the pump is used for drinking water supply from large diameter wells, the well should be covered to reduce the risk of pollution. The delivery pipe above the rising main and the pipe that takes the rope returning into the well can both be extended to finish close to the operating wheel, so debris (e.g. from children dropping things down the pipes) is less likely to enter them. The top of the operating wheel can also be covered with a shroud (Figure 7.17). Alternatively the whole pump can be boxed in, with only a hole for the operating handle and the discharge pipe (Pump Aid, undated).

The great advantage we see with the rope and washer pump is that as long as plastic pipes for the rising main are available, the pump can usually be locally manufactured. Simple versions can be made by a skilled worker, such as a carpenter. Sturdier versions can be made in a fairly basic workshop with metal cutting, bending and welding facilities. Once it is installed, it can be repaired by the community or by craftspeople in the nearest town.

Rope and washer pumps can be motorized and can be used for de-watering hand-dug wells during construction.

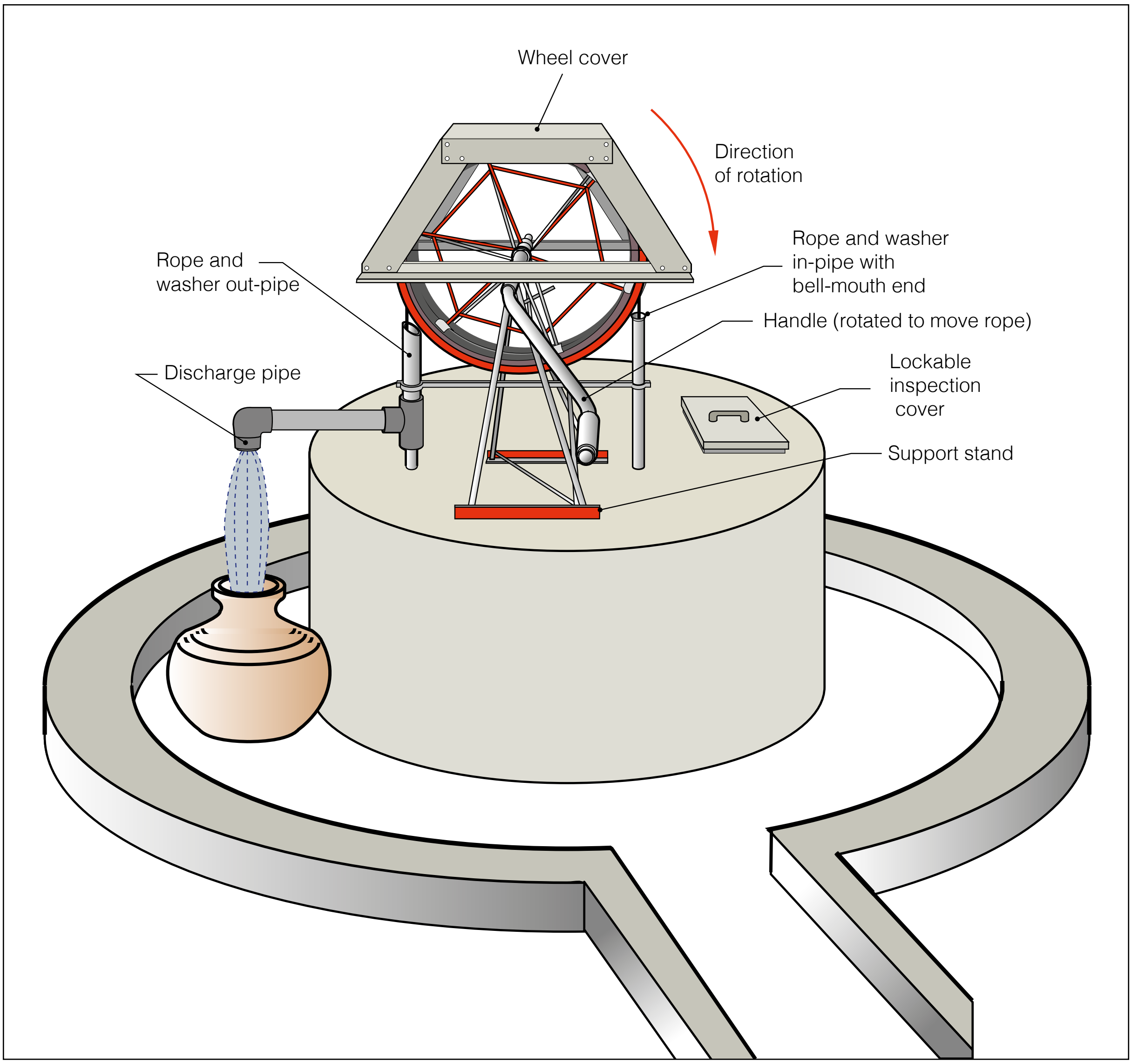

Figure 7.17 A hygienic arrangement at a wellhead for a rope and washer pump in a large diameter well

Source: WEDC

7.5.5 Blair bucket pump

The term ‘bucket pump’ is sometimes used for conventional handpumps (particularly suction pumps) and the seal on the piston of these pumps is sometimes called the ‘bucket washer’. It is also a term used for a pump which uses a rotating drive shaft and an endless chain of small buckets to lift water from a large diameter well. The ‘Blair bucket pump’ is not like either of these pumps.

The Blair bucket pump is a development of the traditional bucket and windlass system that is often used on large diameter open wells, to make it suitable for use on narrow boreholes (Figure 7.18).

The Blair bucket is different from the normal bucket in that it is of a much smaller diameter and it has a valve in the bottom of the bucket (Figure 7.19). The valve is faced with a rubber disc, which can be cut from the inner tube of a vehicle tyre. The disc is replaced by using two spanners (one a long-handled socket spanner, Figure 7.20) to remove the valve. The nut which holds the rubber between two metal washers can then be undone.

The Blair bucket pump can be used in large diameter covered wells, in which it is installed in a vertical casing pipe fitted in the well that sits in a pre-cast concrete footing resting on the base of the well. A 8mm hole in the casing near to the bottom of the well is all that is needed for water from the well to enter the casing. This small hole ensures that any contamination on the bucket (added by the user) does not easily pollute all the water in the well; instead it is soon removed from the casing pipe mixed with the water collected in the following few buckets.

The bucket has a capacity of about 5 litres and is usually suspended from a chain. The bucket is best made from steel pipe. The capacity of the bucket means that the windlass has to be operated to raise and lower the bucket three to four times to fill a normal-sized water container. This delay can frustrate users, and the total lift should not exceed 15 metres.

Morgan (1990) gives full details concerning this pump. He suggests that it is only suitable for serving between 30 and 60 individuals. Where more than 60 people require a means of lifting water, it may be better to have two or more boreholes equipped with bucket pumps that can be easily maintained by the community, rather than having one borehole with a conventional handpump which, although capable of supplying water to the people, may be less easy to maintain than the bucket pump system.

The steel windlass can have oiled wood bearings which are supported by two steel posts. On one of the posts, there is a water discharge unit which is like a funnel (Figure 7.18).

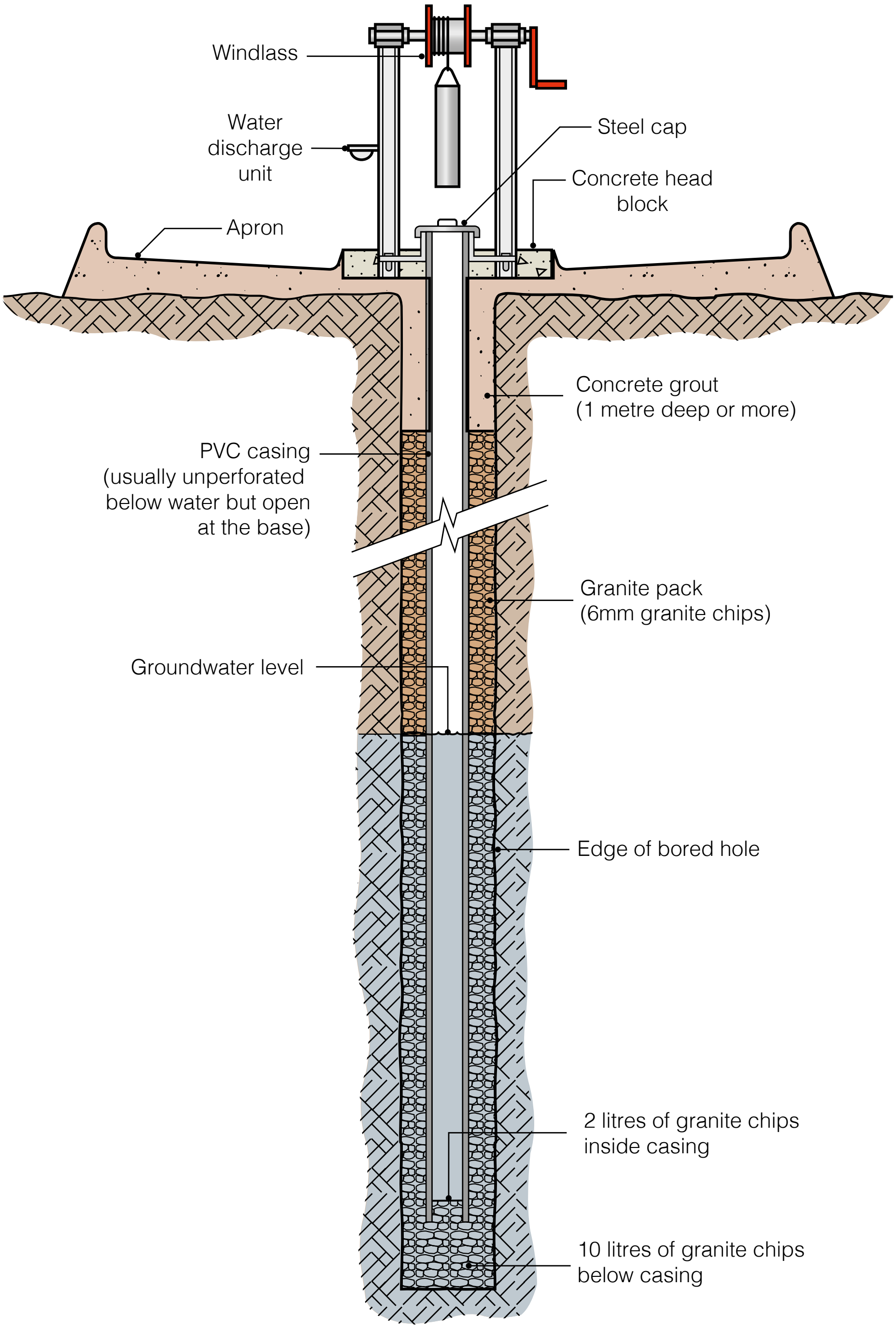

Figure 7.18 The Blair bucket pump fitted on a borehole

Source WEDC. Adapted from: Morgan (1990)

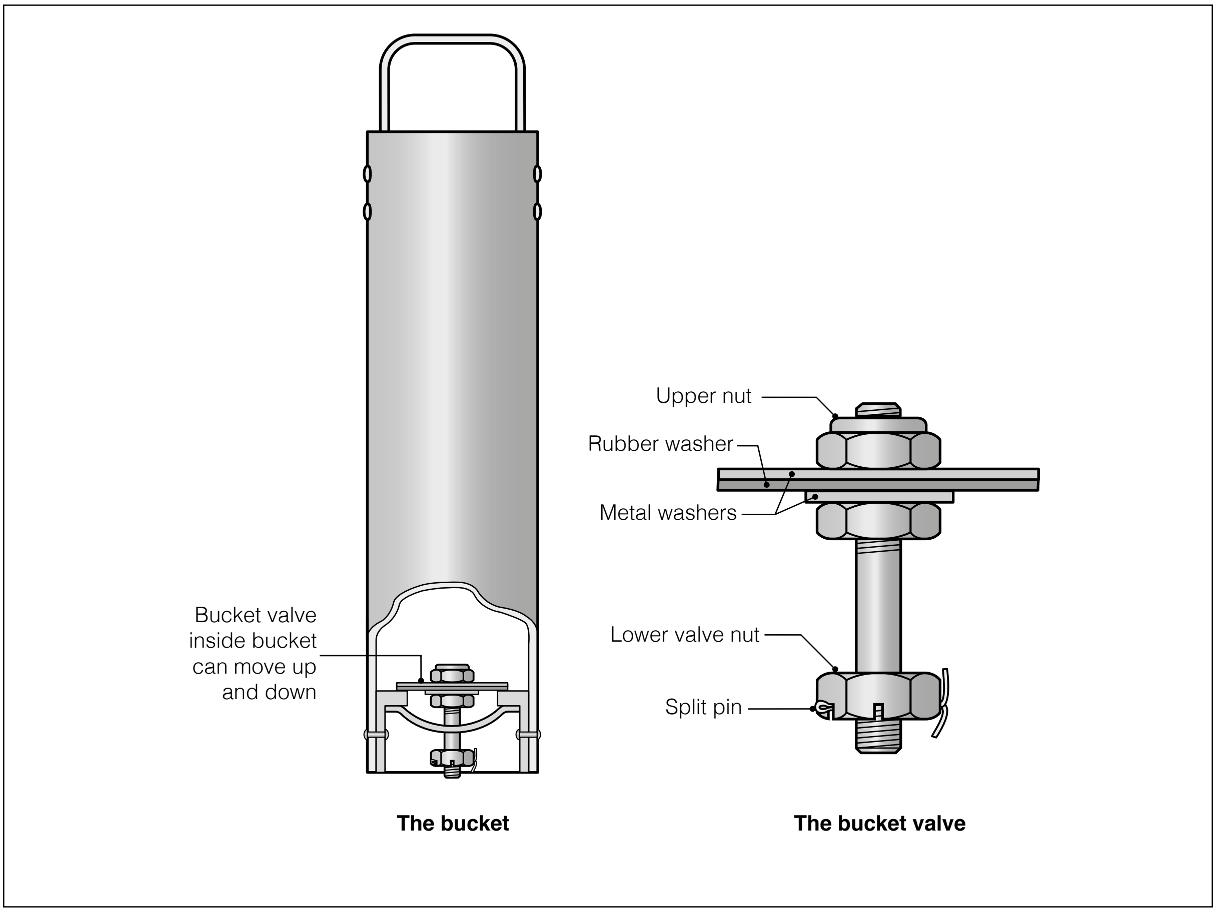

Figure 7.19 The Blair bucket and its valve

Source WEDC. Adapted from: Morgan (1990)

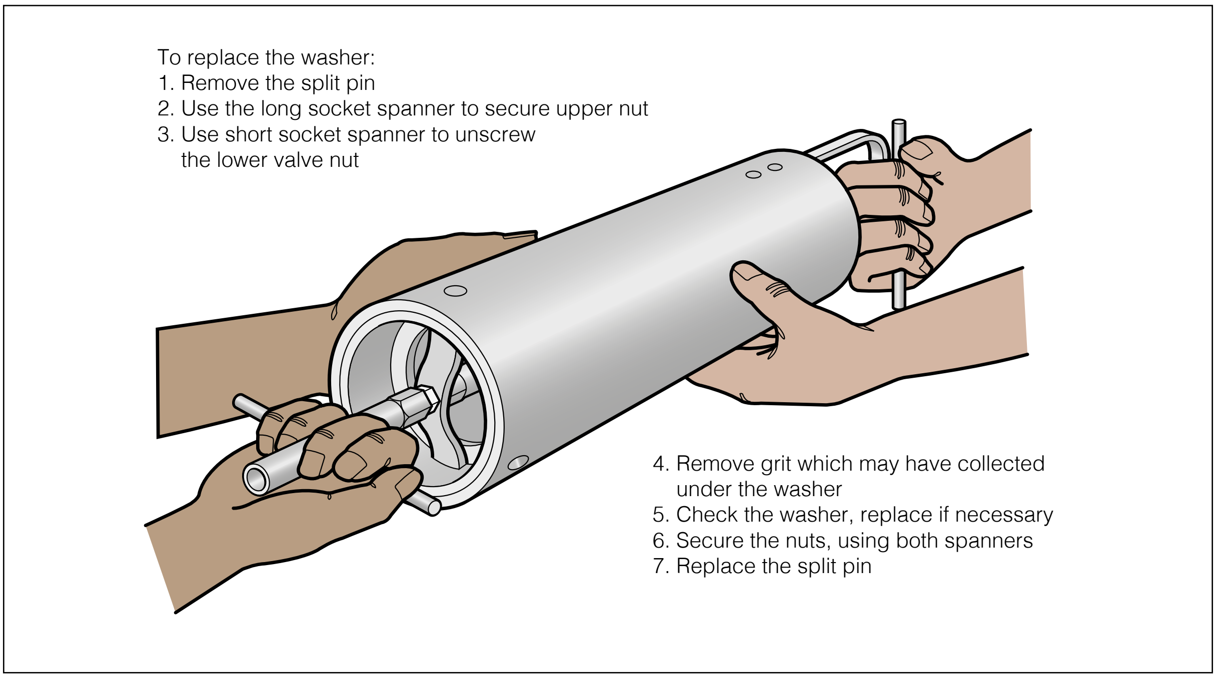

Figure 7.20 Replacing the washer of the Blair bucket

Source WEDC. Adapted from: Morgan (1990)

When the bucket is dropped into the water, it fills through the valve at its base. It is then raised using the windlass, water being held in the bucket by the valve. When the bucket reaches the surface, the operator grasps the lifting loop at the top of the bucket, lifts it out of the borehole and places it on the discharge unit. This unit has a device which pushes the valve up when the bucket is rested on it, causing the valve to open and the water to discharge into a container positioned below the funnel. Despite the need to handle the bucket, field testing in Zimbabwe has shown that the resulting level of contamination is not very high.

When the bucket is not in use, it rests inside the casing under a slotted cap which covers the casing pipe.

The Blair bucket can be used with a shaduf. A shaduf as illustrated in the previous unit.

Activity: Sometimes handpumps breakdown or, although they are working, they fall into disuse. List the physical (think wider than just about the handpump), social or institutional conditions which may lead to such a situation occurring.

7.6 Handpump choice and installation

7.6.1 Problems that may arise which are nothing to do with the handpump

Many problems can arise with a handpump which are nothing to do with the type or model of handpump. For example, problems can occur because of:

- poor borehole design and construction;
- poor borehole siting, poor choice of depth or use of an insufficient number of boreholes; and/or
- lack of community involvement.

Even when there are no problems arising from the above factors, other problems can arise from:

- bad installation.

The following subsections briefly discuss a number of problems that can arise under these four categories.

7.6.1.1 Problems from poor borehole design and construction

- A poorly designed filter pack (gravel pack) or use of the wrong size slots in the screen will allow ***sand*** or other particles to enter the borehole. This can fill it up and/or cause unnecessary wear on pump components which come into contact with the sand, particularly the valves and seals.

- Even if a borehole has a good gravel pack, ***poor development*** of the borehole will limit the amount of water that the aquifer can yield. If it cannot cope with the pump discharge, it can appear that the pump is not working.
- If a rod-operated pump is used in a ***crooked borehole***, this can lead to problems of wear of the rods against the inside of the pipes.

7.6.1.2 Problems from poor borehole siting, poor choice of depth or use of insufficient numbers of boreholes

- **Inconveniently located**. If a borehole is further away than traditional sources, it may not be used because people prefer the convenience their old source. Note that in the wet season, people may be less willing to walk to a distant handpump because of the seasonal availability of water nearer to their homes. Also if access to the borehole is physically difficult users may find alternatives. For example, users may be discouraged from using a handpump if the access is via a steep slippery path which becomes hazardous in the rainy season. They may also be discouraged by a muddy surround to the pump.
- If a borehole is ***not sited with regard to the social structure*** of the community, it may not be accessible to some users because of their low status or because it is located on private property. Its location should also take into account local taboos, such as the need to position it away from traditional graveyards.
- The position or depth of a borehole with regard to the ***hydrogeology may be wrong***, resulting in a poor yield which makes the borehole source unpopular because it is unable to cope with the peak demand. Careful siting is particularly important when the aquifer is in the form of a fractured rock.
- Sometimes the groundwater contains unacceptable levels of iron or salts, which make the water unacceptable to users because of ***taste, staining of laundry or other effects***.
- The depth of a borehole may be insufficient to cope with seasonal changes in the groundwater table. Sometimes the effect of ***drawdown due to nearby irrigation pumps*** is not allowed for. Legislation may be needed to prevent future exploitation of groundwater for irrigation in particular areas where handpumps are at risk. The additional human effort required when the water table is low or when there is a high drawdown may make the handpump unpopular. If at times the borehole dries up and people attempt to use the dry pump, then the seals and valves which are usually lubricated by the water may become damaged.
- If an insufficient number of handpumps are installed for the size of a community, then those that are installed are likely to suffer from excessive wear and early failure. Also, people may choose not to use a pump because of the long waiting time caused by the large number of people wanting to use it at peak times. It is preferable to have more than one handpump in a community. If possible, these should be positioned in different locations to minimize walking distance to the nearest pump. Increasingly the number of pumps will usually reduce the number of people using each pump, and will also allow shared use of another handpump when a major repair is being carried out on one that has broken down.

7.6.1.3 Problems from lack of community involvement

- Sometimes for various reasons (e.g. taboos, taste of the water etc.) ***people do not want a groundwater source***. They therefore need to be involved in the decision as to whether or not to use groundwater. Even if groundwater is acceptable, they may not want a handpump which they feel they cannot maintain, or which only delivers water slowly; they may instead prefer an open well with bucket(s) and rope(s). Alternatively they might want, and may be willing to pay for, a much higher level of service than a handpump, such as a powered borehole pump.
- The community may have ***poor organizational skills*** so be unable to arrange to collect money for maintenance, even though people are willing to pay.
- There may be insufficient involvement of women in the project. Women are usually the main water collectors and users in the home. Their involvement from the start is an important aspect of finding an acceptable and sustainable solutions to a water supply problem.
- The ***ownership*** of the pump may not be clearly defined, leading to misunderstandings as to the community's responsibilities. If they do not feel that they own the pump, but consider it to be owned by the government, they may not care for it as they should.
- Without prior agreements being made in the community, there may be ***disputes*** over who can use the water and for what purposes. For example, some people may wish to use the handpump extensively for cattle watering or small-scale irrigation, and this adds considerably to wear and tear on the pump and also inconveniences those who only want to use the pump for drinking water. Some communities insist that such people should pay more for their use of the pump.
- The ***wrong use of the pump may damage it***; for example, users may cause the handle to bang against the pumphead, or they may use very short and fast strokes which lead to premature pump failure. The community needs to be taught how to use the pump properly. (In some countries, two horizontal wood-en bars are installed, one above and one below the handle, to limit the handle movement so it cannot bang against the pumphead). Very few pumps are suitable for sustained daily use by more than 250 people and it is best to aim for a much lower figure. Some pumps are designed for only a limited number of users, such as just one family group.
- As mentioned above, the ***siting*** of the handpump may be considered by the community to be ***inconvenient*** or its position may be ***culturally unacceptable*** (e.g. near to a graveyard). This problem can be avoided if the community is involved at an early stage.

7.6.1.4 Problems from poor handpump installation

- If the pump inlet is ***installed too low*** in the borehole, it may become choked with sand or silt which enter from the aquifer and collect at the bottom of the borehole. Alternatively, if the inlet position in the borehole is ***too high*** to allow for the seasonal fall in the groundwater level, or for the 'drawdown' which occurs during pumping, the pump will run dry.

- A handpump may be ***damaged during installation*** by carelessness, over-tightening of bolts, use of wrong tools etc.. Likewise, a handpump can be ***damaged during maintenance*** (e.g. threads and galvanizing on the pipes and rods may be damaged by frequent maintenance operations and the steel below the protective coating may begin to corrode). A pump may also be ***incorrectly assembled***.
- The ***apron slab and holding-down bolts may be improperly constructed***, leading to the pump head coming loose, causing damage to the pump and/or allowing contaminants to enter the well or borehole.

Activity: List down the important things you think should be considered about a handpump when deciding whether or not it is suitable for adoption for a certain handpump project.

7.6.2 Problems that arise because of wrong choice of handpump

7.6.2.1 Wrong choice of pump

Problems will arise if the pump chosen does not suit the following important criteria:

- The ***maximum pumping lift***. The maximum depth from which the water is being lifted must be within the acceptable operating range for the pump.
- The ***required discharge rate***. If it has a low rate of discharge, people may reject the pump.
- The ***corrosiveness of the groundwater***. Plastic and stainless-steel components may be needed, because galvanized steel parts will deteriorate in acidic groundwater.
- The ***abrasion resistance required*** to cope with any sand pumped out of the borehole. Nitrile rubber seals on the piston can resist abrasion from sand. Oversized 'entry pipes' below the cylinder can reduce the intake of sand by reducing the velocity of the water at the inlet below the cylinder (such a pipe is used on the Afridev).
- A ***feasible maintenance system***. If the pump is too complicated for the skills needed or money available for maintenance, it will not be maintained properly.

With some pumps the following problems may also occur:

- The pump chosen has ***unforeseen design faults*** (e.g. the bearings deteriorate due to windblown dust).
- The pump is ***poorly manufactured*** (e.g. due to cost cutting and/or lack of quality control). It should be noted that the capital cost of a handpump is often only 25-30 per cent of the total lifetime costs of the installation, so the cheapest pump may not be the best choice.

Note that Section 7.6.3.1 discusses some additional important criteria to be considered when choosing a handpump.

7.6.2.2 Wrong choice of maintenance system

Several situations can contribute to a poor maintenance system:

- ***No proper system for the supply of affordable*** spares is set up in the district. Therefore maintenance is not possible, even if people are motivated and able to do it.
- There are ***too many pumps of different types*** in the district for an efficient maintenance programme and a good supply of spares. See the comments in Section 7.6.3.1 on standardization.
- The maintenance system is ***biased towards handpump repair and not the prevention of breakdown***. This approach is rarely cost-effective.
- ***Centralized maintenance*** systems have been used, which are usually not affordable. About 25 per cent of handpump maintenance jobs relate to the replacement of the piston seal. The seal may cost only $2, but to use a centralized maintenance unit, with the high attendant transport costs, for seal replacement may multiply the repair cost by a factor of at least 50. This is particularly the case if the handpumps are widely scattered.
- The ***organizational or legal changes*** necessary for a feasible maintenance system have not been implemented. Ownership of boreholes and pumps, and the legal status of water committees and their powers to collect funds to meet the cost of repairs, may need to be legally defined.
- ***Poor record keeping and/or lack of evaluation*** of the performance of the handpumps already in use. This often leads to a lack of proper planning for maintenance, both in terms of servicing and replacement.

7.6.3 Appropriate handpump choice and installation

7.6.3.1 Choosing between different types of handpump

The subsections above looked at a large number of problems, many not directly related to the type of handpump. This section considers aspects relating to the actual handpump.

There are many factors to be considered when choosing a particular type of handpump. Extensive laboratory and field tests were carried out in the 1980s and 1990s to compare pumps and the results of these can be a useful starting point

(see Arlosoroff et al. [1987] and Reynolds [1992] for a summary). In particular, one should consider:

- ***Ease of operation and discharge rate*** for the pumping lift at which the handpump will operate.
- ***Ease and cost of maintenance***. The ideal pump is usually suitable for village-level operation and maintenance (VLOM) and is to be located where spares are affordable and available.
- ***Reliability.***
- ***Corrosion resistance*** (especially where the groundwater is aggressive).
- ***Abrasion resistance*** (especially important if sand is present in the water being pumped).
- ***Safety*** (e.g. can children crush their fingers? Is the pumphead hygienically sealed?)
- ***Manufacturing needs***. It is helpful if the pump, or at least commonly used spares, are being produced in the country in which it is to be used.
- ***Cost of purchase and installation.***
- ***Standardization***. It is best if only a few types of handpump are chosen for use in a country. This makes in-country manufacturing, spares supply and maintenance all more sustainable, because there are more pumps of one type. If a country can standardize on one good pump (or two, one for low and one for high pumping lifts), the market for the pump and its spares is more likely to become large enough to attract investment for local manufacture, leading to a greater chance of sustainability. As an interim measure, a country can at least standardize on the cylinder design or cylinder size, so that identical piston seals can be used in a number of different makes of pump. (Note that it is often possible, using appropriate adapters, to swap cylinders and rods between different pumps as long as the maximum movement of the pump rod does not exceed the length of the cylinder). Standard spacing of holding-down bolts, or a standard design of pump pedestal to suit different pumpheads, are two other options which should be explored.

A compromise is often required; sometimes, although direct action handpumps might be suitable for certain installations (e.g. below 15m depth), it may be better to instead install an easily maintained deepwell lever-operated handpump if this type is already being used elsewhere in the area for deeper pump settings. Although the latter is more expensive, its choice will avoid the introduction of a second type of handpump (the direct action type) into the area.

- ***Pilferage***. The ease with which the whole pump or useful parts of the pump (such as bolts) can be stolen may need to be considered where this might be a problem. (Note that, to prevent loss, the Afridev handpump uses some 'captive' nuts and bolts which can be loosened to allow maintenance to be carried out, but cannot be easily removed.)

7.6.3.2 Good installation

Each handpump will have its own particular installation requirements and the manufacturer's recommendations should be followed. SKAT/HTN (1995) gives details for the Afridev pump and UNICEF has produced manuals for the India Mark II and Mark III pumps. All three of these pumps have designs 'in the public domain', and they are manufactured in a number of different countries to the same specification.

The following general points can be made (although some points will only relate to deepwell reciprocating piston pumps):

- Bear in mind the operating limit of suction handpumps and avoid using them if there is a risk of the groundwater falling below the suction limit.
- Do not set a deepwell pump so low in a borehole that its inlet can become blocked by sediments that may pass through the screen and settle in the borehole during use. However, do not set it too high either, but take account of seasonal variations in the groundwater level and likely drawdown in the borehole when the pump is in use. A hydrogeologist should be able to advise you on a suitable allowance for drawdown, but if this advice is not available, install the cylinder 10m below the groundwater level in the dry season. Careful records need to be made of the number and length of rising main pipes installed in the borehole to ensure the correct setting of the pump.
- Wherever possible, use rising main centralizers (e.g. Figure 7.9) to stop the pipe swinging in the borehole or rubbing against the edge of the borehole when it is use. This is particularly important with plastic pipes.
- Wherever possible, use rod centralizers on the rods of deepwell pumps so that the rod and the rod joints are less likely to rub against the inside of the rising main.
- Ensure a good sanitary seal at the wellhead. Our opinion is that compressing a rubber gasket against a concrete surface is not a very reliable method of producing a seal, because it is hard to get the concrete flat and smooth enough to make a watertight joint. It is good to use a pumphead that can be fitted over the projecting borehole casing, as shown in Figure 7.10 and Figure 7.21 (or over a short piece of pipe cast into the cover slab of a covered

well). Note that the casing pipe should project above the top of the raised edge to the apron slab, so that if the apron slab floods up to the top of the edge, water does not enter the borehole.

- With lever-operated pumps, provide an adequate concrete foundation under the pumphead to resist the overturning moment applied when the pump is in use. Where the pump is fitted to a wide diameter well, the cover slab will need to be sufficiently thick and suitably reinforced under the pumphead to resist the applied forces. The concrete should be of a good mix (e.g. 1:2:4 ratio of cement: sand:stones). With a pump on a borehole, this concrete also acts as a seal around the borehole casing; however, below the concrete the gap between the outside of the casing and the inside of the hole drilled for it should be sealed with cement grout, or clay, to a depth of at least 3m (see Figure 7.21).
- If anchor bolts are used to fix a flanged pumphead, they need to be carefully positioned using an appropriate template. Also the concrete around them needs to be very well compacted, which is difficult if the template covers much of the surface of the concrete. We think the best method of positioning bolts correctly is to weld bars between the bolts to fix them correctly in relation to each other, and to keep them vertical (Figure 7.21). The bars are positioned below the final level of the concrete. The concrete must be horizontal under the future position of the flange, and the array of bolts must be correctly positioned in relation to the borehole to ensure that the pumphead is vertical and the rising main is held centrally in the borehole. Any concrete used should be properly cured (kept damp) and should not be stressed until it has gained sufficient strength. We recommend curing the concrete for at least one week before completing the installation of a pumphead to make it ready for use.
- Do not construct the apron slab on the excavated material from the construction of the borehole, but clear this away to ensure that it is on firm ground. (See WEDC Guide No. 3 for details about apron slab design.) Make sure the apron slab is high enough to allow water to drain away from it. (The initial choice of position of the borehole should have considered how the wasted water would be disposed of.)

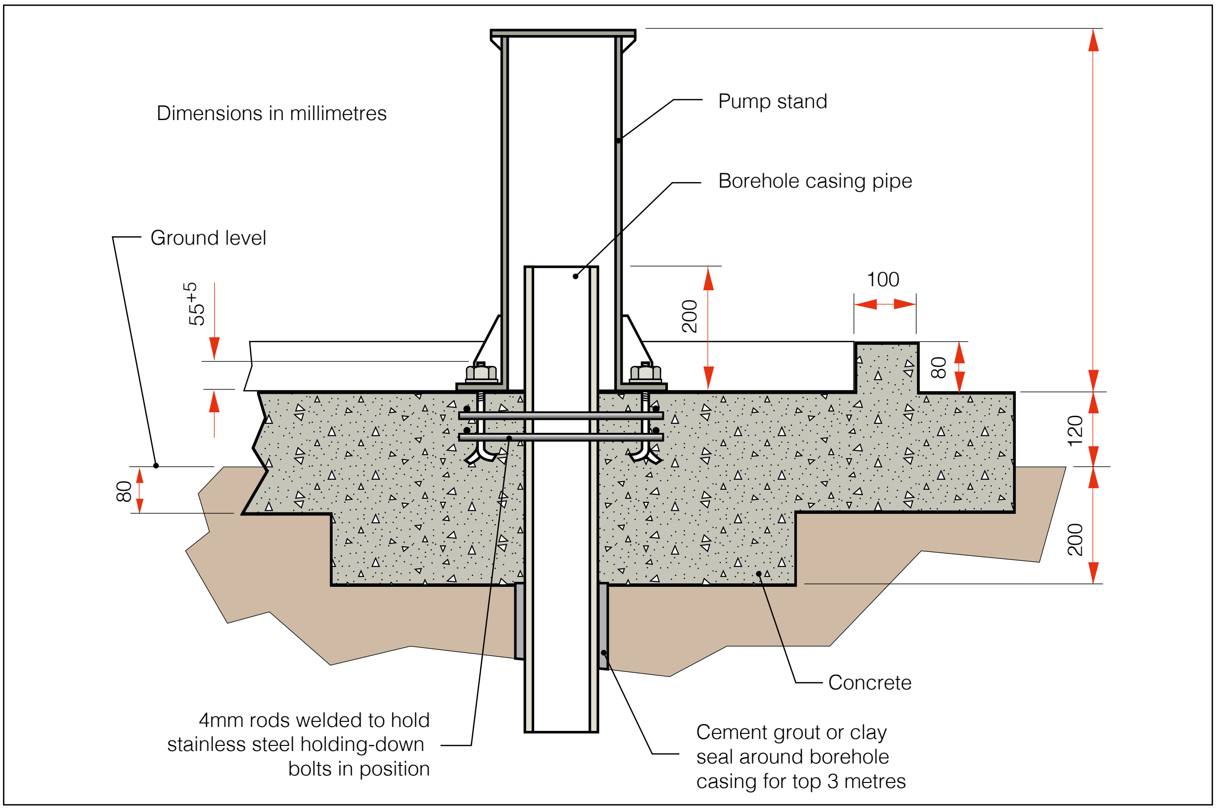

Figure 7.21 Recommended installation details for the Afridev pumpstand

Source: WEDC. Adapted from: SKAT/HTN (1995)

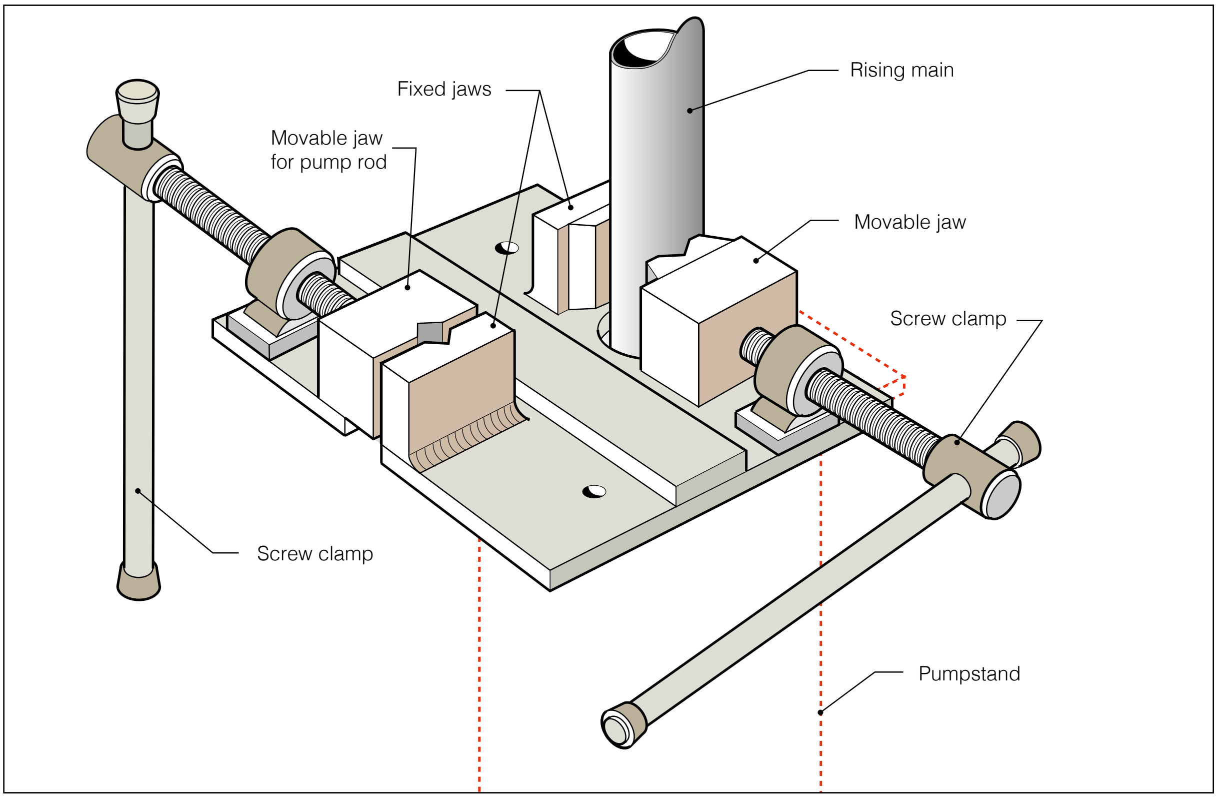

Figure 7.22 Manually closed clamp used for gripping rising main or pump rod

Source: WEDC

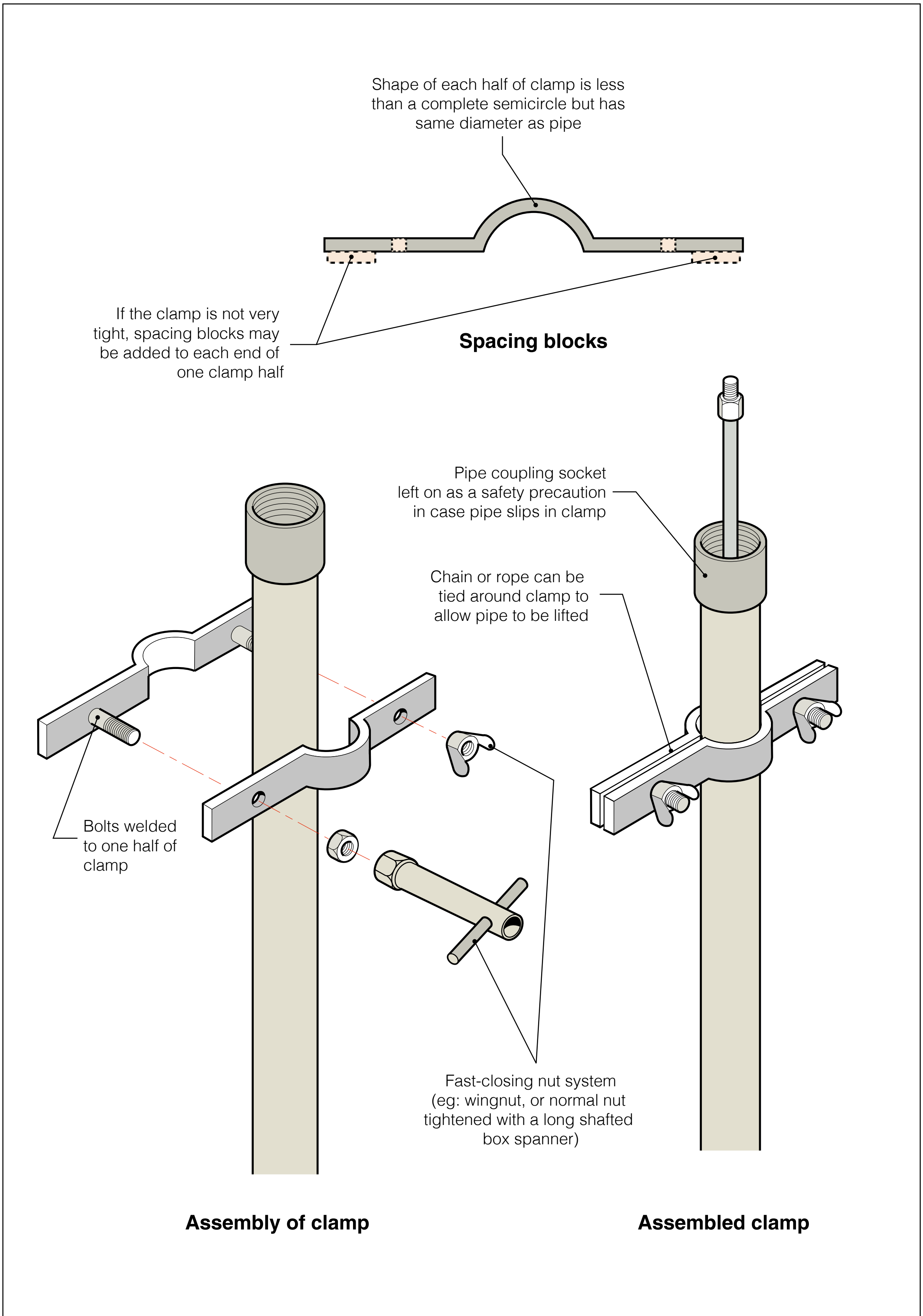

Figure 7.23 Bolted clamping system for rising mains

Source: WEDC

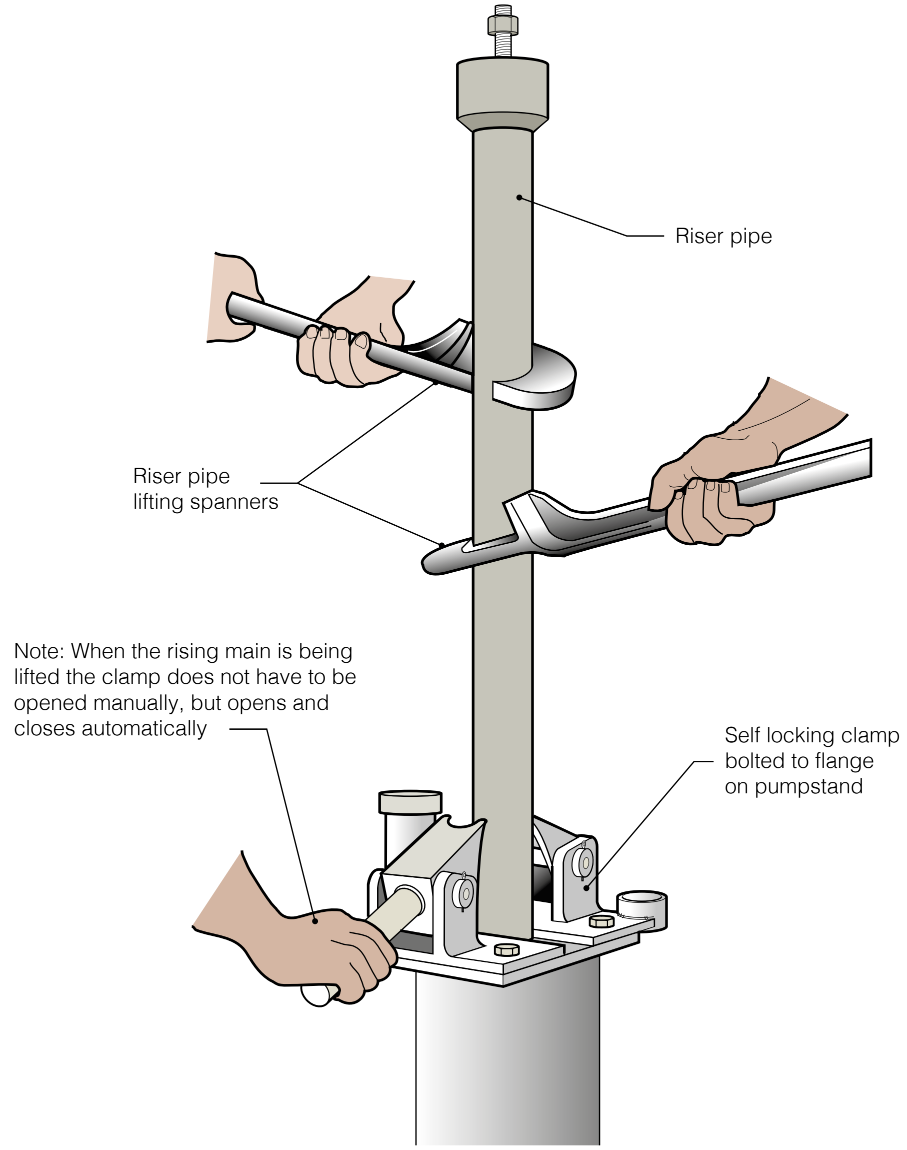

Figure 7.24 Pipe-lifting spanners and a self-closing clamp in use to lower a rising main

Source: WEDC

- Use the right tools and procedures for assembling the pump and follow the manufacturer's recommendations. Use of wrong tools and shortcuts can damage the pump and compromise the safety of the people installing the pump. Proper, well-maintained heavy-lifting equipment and clamps (Figure 7.22 and Figure 7.23) should be used when needed for pumps at deep settings. Self-closing safety clamps are recommended for steel rising mains if they are being raised manually using lifting spanners (Figure 7.24).
- Do not over-tighten or under-tighten nuts and bolts. Use of spring washers, locking adhesive, locknuts etc. is useful to stop nuts working loose.
- Store tools away from where they can fall into the borehole. Covering the opening into a borehole with a cloth during some operations can prevent spanners, nuts or bolts being accidentally dropped into it.

- Use thread filler (e.g. hemp, jointing untreated paste suitable for use with potable water, or PTFE [Teflon] tape) in the threaded pipe joints used with galvanized iron pipes to make them watertight. Do not over-tighten pipe joints; particular care is needed with threaded plastic pipes. Joints which are waterproofed using rubber 'O' rings can usually be made sufficiently tight by hand. Do not use toothed pipe wrenches on plastic pipes; if more than hand force is necessary, use strap wrenches or possibly chain wrenches.
- When first installing a pump, the correct overall length of the whole string of operating rods needs to be used. Sometimes this necessitates the last rod being cut to the correct length and it is important that the manufacturer's recommendations are followed. With traditional designs of deepwell cylinder, if the rod is too short the piston can hit the reducer at the top of the cylinder. With all direct action and deepwell pumps, if the rod is too long the piston can hit and damage the foot valve.
- To reduce the risk of contamination entering the borehole, good hygiene should be practised by the people working on installing the handpump. Workers should wash their hands before working on the pump and pipes should be laid on supports that keep them off the ground. The borehole should be disinfected after installation and the chlorinated water should be allowed to stand in the pump for at least 30 minutes to kill off faecal pathogens.

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VERGNET, 1997. Trade literature from Vergnet Hydraulic Department. Ingre, France.

7.8 Additional sources of information

UNICEF

The WASH Technology Information Packages have an excellent, well-illustrated section on 'Handpumps for Drinking Water' (TIP 1). It is very comprehensive, covering: selection criteria, photographs and data about most common types of handpump and a handpump selection tool. The reference for this publication is:

UNICEF, 2010. *WASH Technology Information Packages – for UNICEF WASH Programme and Supply Personnel*. Copenhagen, Denmark: UNICEF Supply Division. Available from: http://www.unicef.org/supply/index_54301.html [Viewed: 04/07/2019].

Rural Water Supply Network (RWSN, formerly Handpump Technology Network, HTN) has a very informative website and discussion lists. It also covers low-cost drilling and domestic wells etc. See: https://www.rural-water-supply.net/en/ [Viewed: 04/07/2019].

Lifewater Canada has a useful website with information on many types of handpumps and construction drawing for the Zimbabwe Bush Pump. It has links to many other handpump sites and handpump manufacturers. It also deals with other technologies too, such as drilling and hand-dug well construction. See: http://www.lifewater.ca/resources.htm. [Viewed: 04/07/2019].

Credits

Author: Brian Skinner
Editor: Rod Shaw
Illustrators: Ken Chatterton / Rod Shaw / Glenda McMahon
Layout: Kay Davey / Glenda McMahon / Rod Shaw

