Handpumps for Rural Water Supply

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After reading this you should know/be able to:

- **Understand the purpose of a handpump,**
- **Understand how a handpump works, and**
- **Understand the necessary operation and maintenance for a handpump to be successful.**

Over one billion people lack access to safe drinking water. In the developing world, many people gain access to water for drinking, hygiene, and cooking by using groundwater. Because the water is located underground, the water must be lifted from the ground to the surface, and a handpump is often the technology of choice to accomplish this task (WaterAid, 2006). Therefore, the purpose of a handpump is to manually lift water from some depth below ground to the surface where it can be used. As such, handpumps can provide a reliable source of water to those in the developing world, which is essential for community development (Elson & Franceys, 1992). Further, groundwater provides a relatively clean, unpolluted water source due to natural filtration from the movement of the groundwater through the sediments and soils.

Introduction

Handpumps, which have been around for centuries, can provide a cost-effective solution to allow the rural poor to gain access to clean water for drinking and other purposes. They are widely used in places where access to water is scarce and where financial resources for investment, operation, and maintenance are limited. Handpumps are capable of lifting small amounts of water from depths of up to 100 meters and allow the water source to be sealed, reducing the risk for potential source contamination during water collection. These characteristics make the inexpensive handpump an attractive option for rural water supply (Olley, 2008).

There are many different groundwater handpumps; however, many of these handpumps are positive displacement pumps. This means they have reciprocating pistons or plungers. A positive displacement pump moves the water by trapping a fixed amount of water and then forcing (or displacing) the trapped water to the outlet pipe. The focus of this technical brief is on reciprocating handpumps, which are the most common type of handpump found throughout the world.

To understand how a handpump works, one must first understand the different components of the handpump. The main components are depicted on **Figure 1** and include the operating rod (also called the piston or plunger), the cylinder, the piston valve, the piston seal, and the foot valve or suction valve (Morgan, 1989).

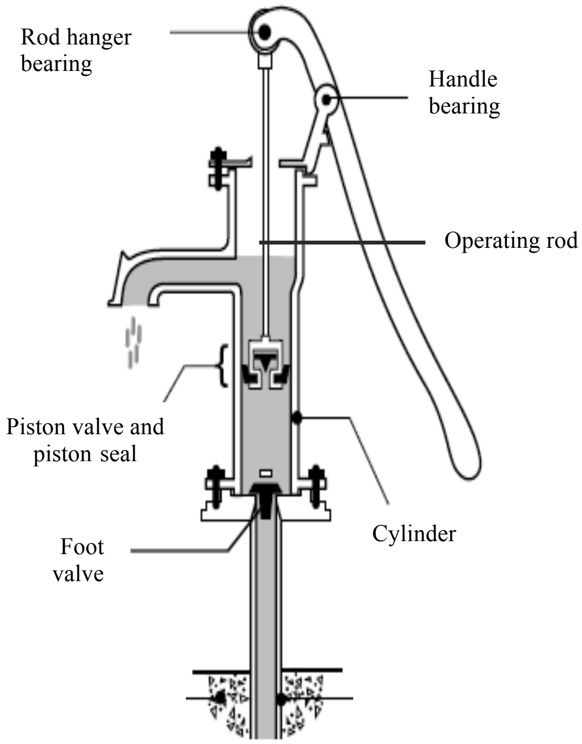

Figure 0: Main Components of the Handpump
Image Courtesy of WEDC

Fundamentals

Handpumps operate on the principles of fluid mechanics. Mechanical energy is used to lift the water from some depth below ground to the surface, and the water is moved by taking advantage of pressure differences. The fluid moves from an area of higher pressure to lower pressure when the piston is moved up and down. When the piston is moved upwards, there is a decrease in pressure within the cylinder. This causes the water to flow into the cylinder through the foot valve. When the piston moves down, the water is forced downwards, increasing the pressure. The foot valve closes, the piston valve opens, and the high pressure water exits through the outlet pipe. Therefore, the pressure within the cylinder automatically controls the operations of the foot valve and piston valve.

The amount of energy needed to lift the water depends on the depth to the static water level, h_s (static head), the back pressure, h_b (such as the water elevation in a storage tank), the drawdown caused from well pumping, s, and the frictional losses in the system. See **Figure 2** below. The term head refers to the water energy per unit weight. This is equal to the water elevation above a referenced point. The total dynamic head (TDH) is often used to describe the energy required to pump water at a constant flow rate, Q. It is the total equivalent height that water can be pumped when accounting for friction losses within the system. The TDH is the sum of the static lift head, the back pressure head, the drawdown head, and the frictional head losses (Mihelcic et al, 2009).

The energy of the water can be represented by the following equation:

$$h = \quad = \qquad 1$$

where γ_w is the unit weight of water (9,810 N/m^3), ρ_w is the density of water (1,000 kg/m^3), and g is gravitational acceleration (9.81m/s^2). Equation 1 can be used to determine the theoretical height the water can be lifted (which depends on the difference between the atmospheric pressure and vapor pressure of water). This theoretical height is reduced due to friction losses in the pipes and fittings and efficiencies. Frictional losses can be estimated using the Darcy-Weissbach and Hazen-Williams equations. As the TDH increases, the flow rate decreases. As seen in the sections below, this demonstrates why the pumping rates decrease as the depth of the water table below ground increases. An advantage to positive displacement pumps is that they are able to produce a relatively constant rate regardless of the TDH (Mihelcic et al, 2009).

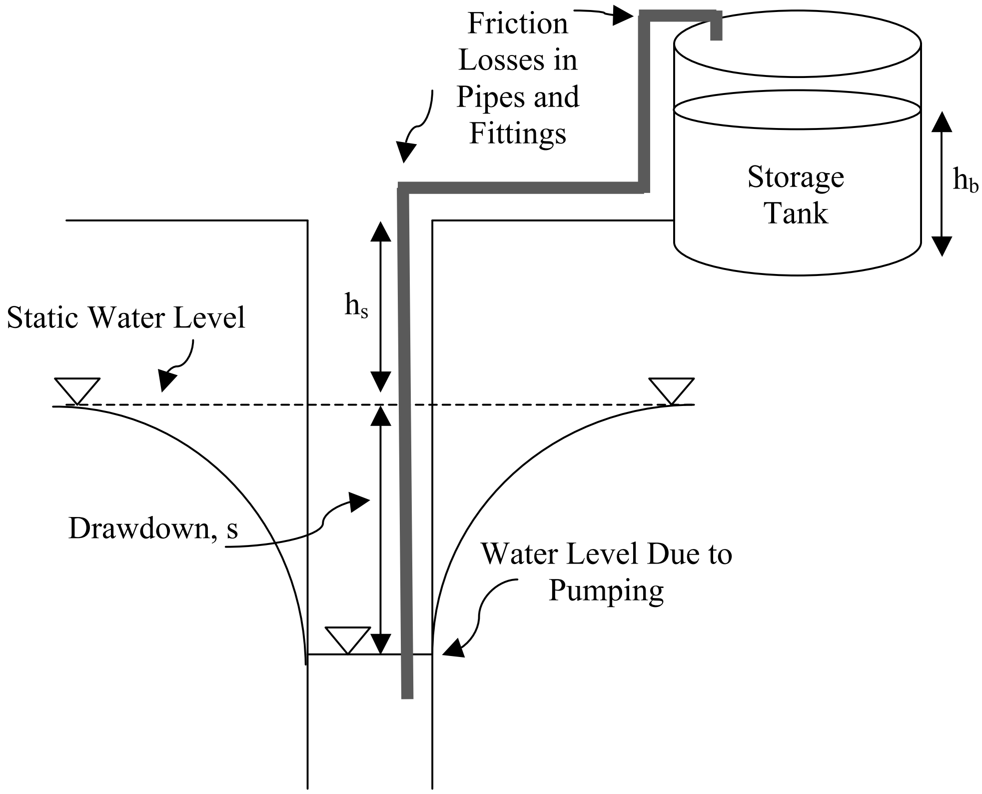

Figure 1: Components Affecting the Energy Needed to Lift Water
Image drawn by Jenna Martin

How a Handpump Works

The three types of reciprocating handpumps this technical brief will cover include the suction pump, the direct action pump, and the deep well pump. All three operate on similar principles. In general, the piston (or operating rod) slides vertically up and down within a cylinder and is fitted with a non-return valve (the piston valve). The cylinder is also fitted with a non-return valve (the foot-valve) (WaterAid, 2006). **Figure 1** showed the locations of the valves. The ranges over which water can be lifted are grouped into the following categories as depicted in **Table 1**:

Table 1: Categories of Handpumps

Pump Type	Pumping Depths (meters)	Pumping Yields (L/min)	Location of Cylinder
Suction Pump	0-7	24-26	Above Ground
Direct Action Pump	0 to15-25	26	Underground
Deep Well Pump	Up to 100	11-17	Underground

The Reciprocating Suction Pump

Reciprocating suction pumps are the most numerous handpumps in the world because they are cheap and suitable for household pumps (WaterAid, 2006). As seen in Table 1, the cylinder is located above ground. **Figure 3** provides an illustration of how the pump works. When the handle of the handpump is raised and lowered, the operating rod, which is connected to the piston, moves up and down. As the handle is lowered and the piston moves upward, the atmospheric pressure within the cylinder is lowered, creating suction and causing the atmospheric pressure outside the cylinder to push the water upwards. The piston valve closes due to the weight of the water above the piston. The water above the piston is displaced upwards with the piston and discharged through the outlet. This creates a vacuum (reduced pressure) below the moving piston, which causes the water to be drawn into the cylinder through the foot valve which opens. As the piston moves downward, the foot valve closes due to increased pressure and to prevent backflow. The pressure of the water below the piston opens the piston valve, allowing water to pass through the piston as it moves downward. Moving the piston down brings the pump back to the starting location (Skinner & Shaw, 1999). The main limitation of the suction pump is that the pressure difference between the inside and outside of the cylinder is only large enough to raise the water a maximum of about seven meters from beneath the ground (Olley, 2008).

The advantages of the suction pump include easy access to the wearing parts because they are usually located above ground and quick delivery of water due to the large cylinder diameter. The disadvantages include a limited depth of approximately seven meters, the need for priming (adding water to the cylinder before the first use or if the suction valve leaks overnight), and a limited capacity of 50 people per day unless frequent repairs and replacements are made. Further, during the process of priming the pump, the users may use polluted water, contaminating their source of water (Skinner & Shaw, 1999).

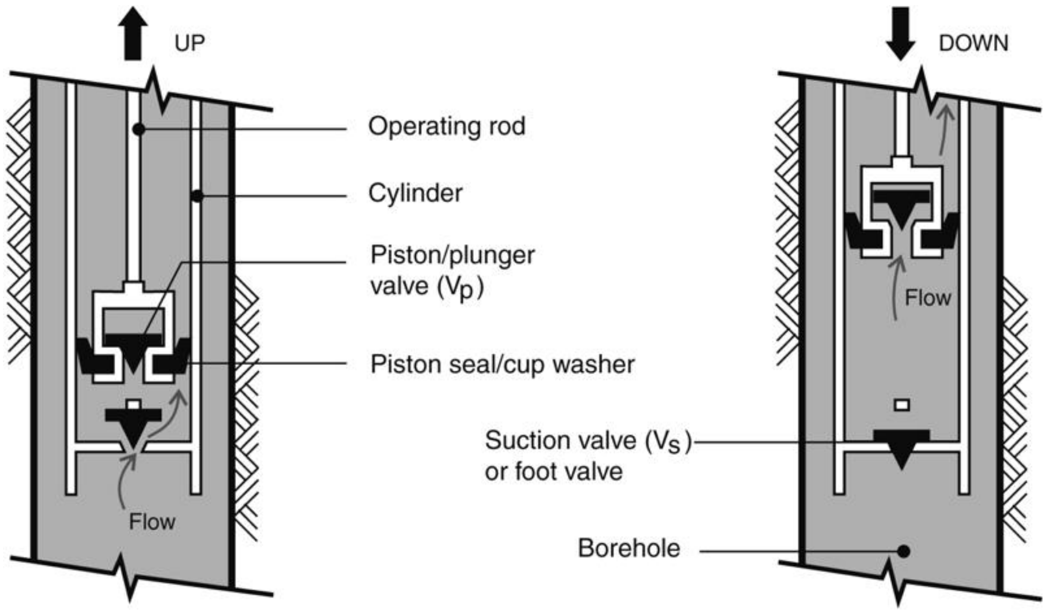

Figure 2: The Operating Cycle of a Reciprocating Handpump

During the UP cycle, the operating rod is raised and water flows through the foot valve. During the DOWN cycle, the operating rod is lowered and water flows through the piston valve.

Image Courtesy of WEDC. (c) Ken Chatterton

The Direct Action Pump

A direct action pump replaces the narrow pump rod in the suction pump with a hollow plastic pipe, and the cylinder is located below ground. This pump operates without the help of leverage, linkages, and bearings. **Figure 4** shows a direct action handpump and **Figure 5** shows the operating cycle of a direct action handpump. The piston is raised and lowered by a "T" bar handle connected to the buoyant air-filled plastic pipe rod. The rod floats in the water in the rising main. This reduces the force needed on the upstroke. On the down stroke, the rod is pushed further down into the water in the rising main, displacing an equal volume of water upwards. During the upstroke, the piston valve closes due to the weight of the water above, and the water is lifted (displaced) up. This allows water to be pushed up the rising main during both strokes (WaterAid, 2006).

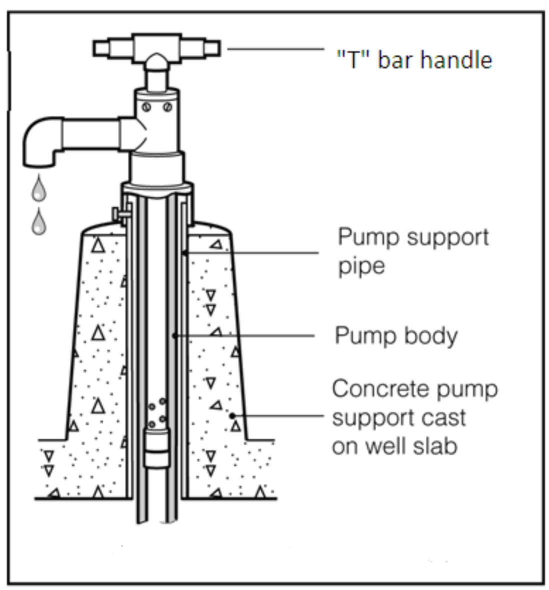

Figure 3: A Direct Action Pump

Image Courtesy of WEDC. (c) Ken Chatterton

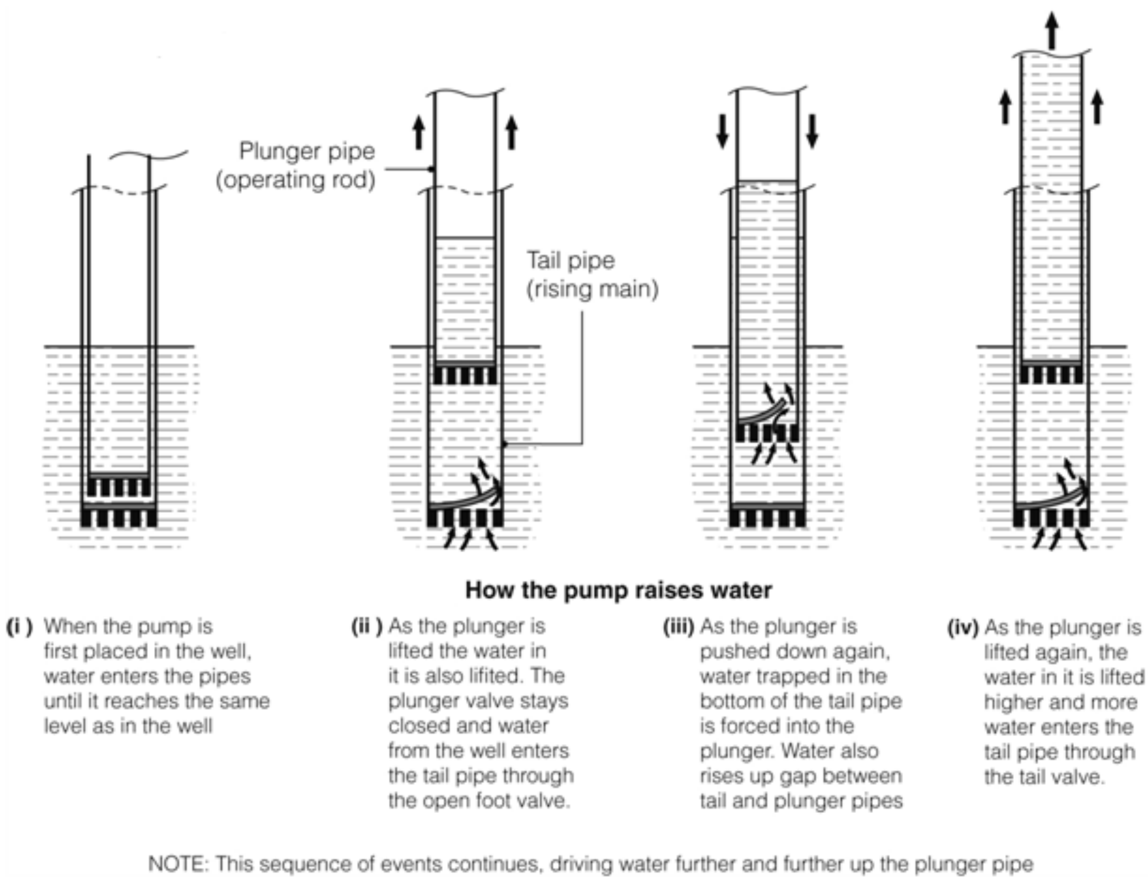

Figure 4: The Operating Cycle of a Direct Action Pump
Image Courtesy of WEDC. (c) Ken Chatterton

The advantages of a direct action pump include easy access to the piston, which can be pulled up through the rising main, the relatively low cost, and the ease of manufacturing, maintenance, and installation (Olley, 2008). Disadvantages include: a lack of a lever handle makes it difficult to operate at depth greater than 12 meters, the raising and lowering of the piston depends on the strength of the user, and the pump design is not often rugged enough for use by more than 50 people per day unless frequently repaired (Skinner & Shaw, 1999).

The Deep Well Pump
The deep well pump design is similar to that of shallow well piston pump. The main difference is that the pump cylinder is deep underground below the water table. The cylinder is connected to the pump handle via a long rod called a pump rod. This type of pump is also called a reciprocating "lift" pump and can lift water from depths of up to 100 meters. See **Figure 6** below. The typical yield at 45 meters is approximately 11-17 L/min. The maintenance is more complex because the main components are located underground. Therefore, the pump must be dismantled to remove the pump rod and access the cylinder. The rising main can be a larger diameter than the cylinder allowing the whole cylinder to be pulled out without taking it apart. This makes the pump more expensive but village level operation and maintenance (VLOM) easier (Olley, 2008).

The deep well pump is designed to reduce by means of cranks and levers the physical effort required when pumping. Therefore, this type of pump is more robust, and the parts must be capable of handling larger stresses. The Afridev pump used widely in Africa is an example of a deep well pump. The traditional deep well pumps have head levers that work similarly to the handle for suction pumps. Some have one pivot and a chain and quadrant system (India Mk II pump). The rising main is typically a galvanized steel pipe with a smaller diameter than the piston. To remove or repair the parts of the pump, the string of pipes and operating rods must be lifted so the rod joints and pipe joints can be unscrewed section by section to reach the cylinder. An advantage of the deep well pump is that it is suitable for a wide range of lifts, and the design can be strong enough to cope with intensive use. The main disadvantage is that it is difficult to access the piston and foot valve. Some designs allow the foot valve to be removed through the rising main by using a fishing tool lowered inside the rising main on piece of rope after the piston is removed (Skinner & Shaw, 1999).

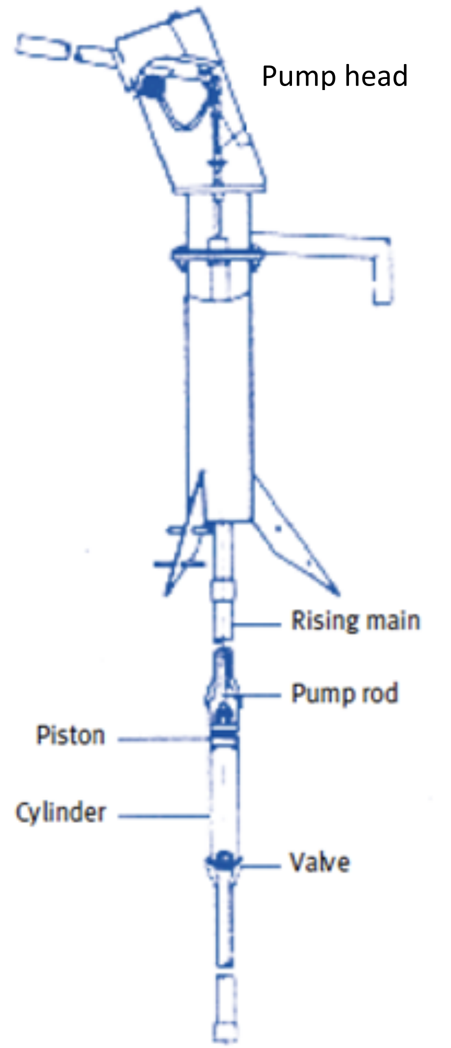

Figure 5: A Deep Well Handpump
Image Courtesy of WaterAid.org

Other Handpumps

There are many other types of handpumps. There is the Bush Pump which is designed to be robust, last 20 years, and lift water from depths up to 80 meters. The Rower Pump is a reciprocating hand pump inclined at 30 degrees above horizontal. The angle of the cylinder allows simplified construction and maintenance as energy is expended through the pumping action directly along the cylinder, requiring no pivoting motion. **Table 2** lists important considerations to take into account when selecting a handpump.

Table 2	
Items to Consider When Selecting a Handpump	**How Each Consideration Influences Decision**
Lift Height and Yield - How much water does the community need? - At what depth is the water table? - How high must the water be lifted? - Will the water table fall due to overuse? - What is the maximum flow? Does it meet the community demand?	- The suction pump provides the highest yield but is limited to shallow depths - The deep well pump can reach depths up to 100 m, but the yield is limited
Water Collection -Which group is tasked with water collection?	- A pump with a lever may be easier for women and children to use compared to a "T" bar which depends on user strength
Operation and Maintenance - Does the community have funds for capital and O&M costs? -What are the costs of the parts to replace? -Are spare parts available and affordable? -How often is maintenance or repair required?	- If the community has limited funds for O&M, it is best to choose a handpump with as few wearing parts as possible and one with parts that are affordable and available
Can the pump parts be manufactured using local skills and materials?	- This helps to support the local economy and helps ensure the availability of parts
What is the life expectancy of the pump?	- To improve life expectancy, use durable and robust materials
Is the community capable of overseeing operation and maintenance?	- O&M is simpler for suction pumps as all parts are above ground - O&M is more complex for deep well pumps which have many parts located below ground - Does the community have the technical expertise for the O&M of a deep well pump?

Operation and Maintenance

Village Level Operation and Maintenance (VLOM) can be used to maintain handpumps. There is also Village Level Operation and Management of Maintenance (VLOMM) where emphasis is placed on the user's role as manager of maintenance. Community involvement is vital for the long-term effectiveness of handpumps. Involving the community from the beginning of the planning and management of the project will promote a more sustainable handpump (Elson & Franceys, 1992). Community management also develops pride for the community. VLOM pumps aim to make all wearing parts easy to reach and replace and to reduce wear and tear on the pump. The main wearing parts of the reciprocating pump are the piston seal, which rubs against the inside face of the cylinder, the piston valve and foot valve, which are constantly opening and closing, and the bearings in the pump-head, which are subjected to constantly changing loads (refer back to **Figure 1** above) (Skinner & Shaw, 1999).

Many handpumps fail because they are overburdened and inadequately maintained. This is often due to the absence of a sustainable system of maintenance and repair. Other failures are due to pump components becoming damaged by corrosive groundwater, overuse, and lack of community involvement in planning (Morgan, 1989).

VLOM assumes the user community owns the water supply and contributes to installation, finances, and operation and maintenance. If possible, the parts should be manufactured in country to ensure the availability of spare parts. The pump should be robust and reliable under field conditions and be cost effective. Maintenance should be relatively easy and require minimal skills and tools. The community should choose when to service pumps and who will service the pumps. The most successful handpump operations include a locally chosen manager in charge of overseeing pump use and operation (WaterAid, 2006).

For maintenance to be sustainable there should be affordability and availability of spare parts. For the same reason, it is essential that there is reliable distribution of affordable spares. Standardizing one particular pump in a region or country can make this more feasible. In-country manufacturing and standardization can make in-country production more attractive due to the high level of demand. Handpumps and spares must be produced by manufacturers who have stringent quality control checks to ensure reliability. Other factors to consider include corrosion resistance (use of stainless steel/plastic pipe rods), reduction of the number of different spare parts, use of as few tools as necessary for normal maintenance work, easily replaceable bearings, and theft-resistant parts (Skinner & Shaw, 1999).

Proper maintenance includes periodically inspecting the pump and replacing parts that are worn or show signs of deterioration to prolong the life of the pump and avoid unexpected breakdowns. The pump should be inspected daily for pump operation, cleanliness, and wastewater drainage. Weekly, the parts should be lubricated and the tightness of the bolts and nuts should be checked. Monthly, the output rate should be checked as well as the condition of the concrete base. Yearly, the internal parts of the pump should be removed for inspection and parts should be replaced where necessary. As such, maintaining the suction pump is easier as all parts are located above ground compared to the deep well pump where maintenance is more complex as the parts are located deep below ground (Elson & Franceys, 1992).

Women and Handpumps

When considering the implementation of a handpump technology, it is essential to consider the role of women in the community. Providing water for the household is typically a woman's responsibility. Further, costs incurred in the collection of the household water supply are typically the woman's responsibility as well (Hoffman, 1992). Women can often have the role of operation and maintenance. For example, in a village in Africa, it is the women installing, operating, and maintaining the Afridev pumps. The women change the piston seals and replace the nylon bearings (Wood, 1993).

Figure 5: Woman Operating a Handpump
Image Courtesy of WEDC. (c) Brian Skinner

Putting the task of operation and maintenance of the handpumps into hands of women (the main users) is an effective and practical change. In a village in Kenya, the women have been trained and equipped with the necessary tools and knowledge to repair VLOM handpumps in their community. The women are highly motivated and often more reliable than the men. In this particular village, the handpumps have operated continuously since they were installed (Hoffman, 1992).

Further Reading

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Disclaimer

This document was prepared for one of the following two classes at the University of South Florida (Tampa): CGN6933 “Sustainable Development Engineering: Water, Sanitation, Indoor Air, Health” and PHC6301 “Water Pollution and Treatment”.

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