Rural Water Supply in Developing Countries

Proceedings of a workshop on held in Zomba, Malawi, August 1980
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Proceedings of a workshop on training held in Zomba, Malawi, 5–12 August 1980

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Shallow Wells and Hand Pumps

Aseged Mammo

At present, there is a general lack of potable water in rural parts of Ethiopia. There are a number of ways of supplying such water: engine-driven pumps, from boreholes, shallow wells, springs, rivers, lakes, etc.

Of the many alternatives, springs are widely regarded as the cheapest source of clean water, if they are available. Rivers and lakes are few, and streams last only during or just after the rainy season, after which time they are too turbid to be used as a source of potable water.

Another source of potable water is hand-dug wells. In rural Ethiopia, one of the local craftsmen is always the well digger. At present, however, most hand-dug wells are improperly constructed and use primitive water-lifting devices such as buckets and inner tubes that are unhealthy and time consuming. The use of hand pumps would facilitate the withdrawal of water from these wells.

In a country like Ethiopia, where there is a tremendous demand for hand pumps and a shortage of funds for importing foreign goods, a plausible hand pump has to be inexpensive and reliable to be imported.

This report, apart from a short section on wells, is essentially a comparison of some hand pumps that are in use in Ethiopia, both imported and locally designed and manufactured.

The project is financially and technically supported by the International Development Research Centre (IDRC) and the United Nations Development Programme/United Nations Industrial Development Organization (UNDP/UNIDO), and implemented through the Ethiopian Water Resources Authority (EWRA).

The designing and manufacturing were carried out in the Mechanical Engineering Department, Faculty of Technology, Addis Ababa University. This research is essentially a continuation of research on hand pumps and windmills that took place at Addis Ababa University during the “Development through Cooperation Campaign,” which spanned the years 1974–1976.

Wells

Selection of Well Sites

According to the EWRA Central Region, and presumably in general, almost all water points are established at the request of the local population. When the request arrives, a team is sent to determine what type of water-point design will satisfy the local demand, as well as be most economical to implement.

The team first considers the possibility of springs in the vicinity. If none are available, it must then consider shallow or deep hand-dug wells or perhaps boreholes with engine-driven pumps. Wind-powered water points are not, as yet, available.
**Construction**

When the most economical water-point design is a hand-dug well, a work crew is sent to camp near the site. Presently, a major problem exists with the supplying of construction and other support equipment to the work crews. As much as 50 percent of the crew's productive time can be lost trying to purchase and ship materials and handling per diem requisitions.

Technical difficulties are less of a problem. For example, if the soil is too loose, it will cave in before the casing is lowered. A temporary wooden frame, therefore, must be made as digging proceeds. Another problem with loose soil is that it keeps falling into the water, making frequent cleaning of the well necessary. In one location in Awara Melka, 200 km southeast of Addis Ababa, the aquifer material contained a lot of pumice which is much less dense than water. These rock particles were suspended in the water and were sucked into the hand pump that had been installed. After a month of operation the piston and foot valve were both stuck.

There is now a standard well design developed by the Central Region for use by the EWRA. The United Nations Children's Fund (UNICEF) and the Evangelical Church Mekane Yesus (ECMY) are two of the well "suppliers" to this project with their own standard designs. These designs are affected by the pump type to be used, the terrain, and the degree of cleanliness required of the water (e.g., UNICEF well covers have no manhole).

This particular project doesn't deal with well digging or construction directly, but requests wells to: (1) have studs cast in the concrete to match the holes in the pump stands being used and (2) be easily accessible from the main road and within a 200 km radius of Addis Ababa. In areas beyond this boundary, maintenance and follow-up are carried out by local residents. Eventually, all manufacturing (except for pistons and foot valves), installation, and maintenance of pumps will be carried out by the regions themselves. Currently, there are no hand pumps installed in boreholes in the Central Region and very few elsewhere.

**Hand Pumps**

In the EWRA Central Region (where more than two-thirds of the pumps are installed to date) there are three categories of hand pumps being used. The following list gives the category and the types of pumps used within each: (1) imported: (a) Consallen, (b) mono (myno); (2) semi-local: (a) Boswell; and (3) local (EWRA/IDRC): (a) BP, (b) BPL, (c) type C, (d) type D. This list doesn't include all hand pumps that are in use in the Central Region, but is a collection of those hand pumps which are closely connected to the EWRA and, hence, this project.

**Consallen**

These hand pumps were installed when the United Kingdom was giving aid to the EWRA Central Region. They are installed mainly in the Maki area about 130 km south of Addis Ababa, and have a 2, 2.5, or 3 in. (5.1, 6.4, or 7.6 cm) piston and cylinder (depending upon the depth of the well); a 1.25 in. (3.2 cm) riser PVC pipe; steel pump rod; and steel pump stand with lever. The piston has rings and is running in a stainless steel cylinder. The foot valve consists of a rubber sealer against a slotted or perforated steel body. Unless foreign particles are introduced, the sealer is quite effective. The riser pipe is connected with a PVC flange to the pump stand.

When operated, because of the tight fit between the piston and cylinder, the pump feels heavy, even at low pumping heads. Also, the riser pipe snakes, particularly at faster pumping speeds. Consequently, the PVC flange at the pump stand breaks and repeated failures of the 1.25 in. (3.2 cm) riser pipe at the threaded connection were experienced. Foot valve leakage was not acceptable in many cases, after some time of operation. Except for the flange connection in the stand, the part of the pump above ground stands up to a lot of mishandling.

**Mono**

This is a rotary positive-displacement pump. The piston is a solid steel helix.
running in a matching rubber cylinder. There may or may not be a foot valve because the fit of the piston and cylinder is very tight. The transmission shaft is steel and is guided by rubber bearings in the riser pipe. Pumping is accomplished by rotating the arms that are on opposite sides of the pump stand. A bevel-gear pair transmits the torque to the pump rod (transmission shaft), which has the piston attached to its other end.

This pump is normally regarded as the best type as far as reliability and ease of pumping are concerned. The only maintenance problem is oil loss at the seal of the gearbox bearings. The United Nations Children’s Fund, which is importing and installing this type of pump, leaves a quantity of oil with a person living nearby to fill up the gearbox once a month or as required. The newer version of the mono pump, the myno pump, will have double O-rings at these points in the gearbox to reduce oil leakage. If, however, there is a considerable loss in the height of the static water level (drought), parts which rely on water for lubrication, such as the starter in the mono pump, could suffer heavy wear and tear. The greatest problem with this type of pump is its cost, which is presently about U.S.$1200.

**Boswell**

In the past, this pump was imported in its entirety. Now, the only imported parts are the pump rod, piston, and cylinder. The Boswell pump is basically a piston pump with a distinctive, above-ground structure. The piston and foot valve both possess leather cup seals to minimize leakage. The cylinder is brass-lined, galvanized steel pipe. The foot valve can be withdrawn without taking up the 2 in. (5 cm) galvanized steel riser pipe by screwing the lower end of the piston into the foot valve. The pump rod is galvanized steel.

There are many varieties of this pump, but generally the pump stand is always offset from the riser pipe. The lower arm is very long (about 2 m, with a relatively small mechanical advantage of 3.3) and the pump stand is relatively high.

Installation of this pump is difficult because the stand and riser pipe are offset. As a result, alignment of the pump rod end of the lever with the “stuffing box” (the above-ground portion of the riser pipe) is never perfect. The pump rod upper end normally scrapes the wall of the riser pipe. The stops which limit the up and down strokes of the handle are frequently worn away. The piston cup seals expand when immersed in water and pumping is very heavy, even at low heads, just after installation. By the time pumping is no longer heavy, the cup seals have worn down and are almost ready for replacement. Unscrewing of the piston from the pump rod has been experienced.

The pump stand, piston, and cylinder are the major problem areas of this pump. In agreement with UNICEF and EWRA staff, it was decided that an attempt be made to modify the Boswell pump in this project. The tentative plan was to (1) have the stand screwed directly onto the riser main by using the type BPL pump stand designed by this project for this purpose (with a mechanical advantage of 4 and a maximum stroke of 20 cm); (2) redesign the leather cup seal to reduce piston-cylinder friction, but keep volumetric efficiency reasonably high; and (3) have pins drilled through parts of the piston to prevent it from working itself loose.

The pump stand is being manufactured at the Society of International Missionaries (SIM) workshops at the rate of 120 per year. It is planned to manufacture 160 per year by extending the SIM and/or the Oxfam workshop at the EWRA.

The pump rod, piston, cylinder, and foot valve are still being imported at a cost of U.S.$100 per pump. The pump stand is being made locally for Br370 (U.S.$178) and the 2 in. (5 cm) galvanized steel riser pipe is locally purchased.

**Local EWRA/IDRC Pumps**

This project is working on three types of hand pumps: types B, C, and D. Type B pumps are further subdivided into types BP and BPL. They consist of a piston, cylinder, and foot valve immersed in water. Type BP
(Fig. 1) uses plastic (PVC) riser pipe and a direct-acting handle operating in a bicycle-pump fashion. It is designed for shallow-well pumping (up to 20 m depth). Type BPL (Fig. 2) is the same as type BP below the well apron, but employs above-ground leverage and is designed for use in deeper hand-dug wells (depths up to 35–40 m). Type C (Fig. 3) is an inertia pump in which the water column and riser pipe are suspended on a spring and oscillate at the natural frequency of vibration of the system. Type D is also an inertia pump in which only the water column is oscillating.

Type C (Fig. 3)

These pumps have pipes that are suspended on a spring on the well apron. The foot valve is at the other end and pumping is accomplished by oscillating both pipe and water in the pump. The pump is self-priming, has very few parts, and has
high efficiency. It can, theoretically, be used with very high heads, and is relatively easy to pump. Collection of water is accomplished via a flexible hose attached to the discharge spout. Development of this pump has been slow due to the emphasis placed on other pump types. The main problem with this pump is that the required spring characteristics are demanding. The operating speed, i.e., the natural frequency of vibration of the system, must be 1.5-2 Hz. On wells with heads of up to 14 m, induced stress in the spring wires is 3000-5000 kg/cm². Because the springs are not readily available locally, facilities for the manufacturing of the springs will be necessary if the pump is to be used. Another problem which must be solved involves obtaining the steel needed to make the springs, because it is not available locally. It will be necessary to overcome these difficulties if the type C pump is to be successful.

**Type D**

This pump has a stationary pipe in which the water oscillates at its natural frequency. Excitation is accomplished by a piston and cylinder arrangement on the top. At the other end of the pipe is a foot valve.

Because the pipe is stationary, induced stresses are relatively low. The fact that the pump head (cylinder and actuating piston) could be arranged offset from the well makes this pump attractive as a sludge pump (dewatering pump). This pump is not self-priming, however.

Experiments on this pump were temporarily stopped due to a foot valve problem (it would not tolerate muddy water). When the foot valve problem was finally solved, priority was then given to type C pump development and later, based on a consulting report from the University of Waterloo, toward the type BP pump. The BP pump has since been used as a sludge pump as well, which led to further delay in the development of the type D pump. More information on the type D pump will become available in the future when efforts will be geared away from the type BP pump, which is now in a relatively advanced stage of development.

**Type B**

This pump consists of a pipe at the end of which is a foot valve. The lower end of the pipe serves as a cylinder. The piston is submerged in the water at the end of a pump rod. The piston has a valve incorporated in it. A type A pump, which was the same as the type B pump, except that it had no valve in the piston, was discarded early in the project in favour of the type B pump.

Experiments on the type B pump were first started using galvanized steel pipe for the riser pipe and cylinder. It was found, however, that the surface of these pipes was too rough, resulting in an inefficient system and considerable wear on the piston. It was then decided to line the bottom metre of pipe (the cylinder) with thin PVC pipe.

The type BP pump (Fig. 1) as it stands now, has a pump stand made of galvanized steel pipes that are welded and painted. The riser pipe is PVC (1.5 or 2 in. (3.8 or 5.1 cm)) and screws directly onto the stand. The joints between the pipes are made using steel couplings and at the end is a foot valve. The pump rod consists of pipes cement welded by bell ends, and at the lower end is the piston. This type of pump is designed for pumping from depths up to 10 m with the 2 in. (5.1 cm) (BP50; Fig. 4) riser pipe and from depths up to 20 m with the 1.5 in. (3.8 cm) (BP40) riser pipe. Lower heads (1-4 m) could be handled with 3 in. (7.6 cm) or 2.5 in. (6.4 cm) pipe, but these sizes are not produced locally. The handle is made of wood and is clamped onto the 0.5 in. (1.3 cm) PVC pipe/pump rod. There is no mechanical advantage on the BP50 and BP40 versions, which decreases pump stresses and cost while making pumping more difficult.

Installation of both the BP and BPL pumps is not time consuming; 3 h are sufficient for two technicians and a helper to completely install a BP40 or BP50 pump. In one instance, installation was completed in 1.5 h. The BPL pump would take about 5 h to install because the pump rod has to be measured exactly, and the steel rod and 0.75 in. (1.9 cm) PVC pipe/pump rod joined on-site. The following are some the problems experienced with this pump that have now been solved.
Fig. 4. BP50 pump supplying 20–25 m³/day from a depth of 3 m to the town of Assossa (pump installed in August 1979).

Pump stand. The most frequent problem with the pump stand involved the pump-rod guide, which was also serving as a crude stuffing box. The wood which was used had to be boiled in oil to make it a more durable bearing surface. When fastened with screws and/or when it was in contact with the handle during pumping, the guide would break and the pieces would go down into the riser pipe. To avoid the screws that initiated most of the cracks, the "cap" idea was started. The impact of the handle was still breaking the wood, however, so it has now been replaced with polyethylene, which has to be imported.

Another problem involved children putting material in the spout opening, which caused heavy piston and cylinder wear and eventual sticking. To eliminate the problem the spout, which was straight originally, was designed to face downward to make it more difficult for children to put material into the opening.

In one instance, the base plate cracked and the pump stand and riser fell down. To remedy this problem, ribs were welded onto the base plate to reinforce it.

Pump rod. Within 1 week of the installation of the first pump, the pump rod was broken about 30 cm below the handle. Although thin-walled steel tubing was added to reinforce the pump rod, this too was breaking, just below the lower bolt that attaches the pump rod to the handle. As a result, present pumps have at least 1 m of pump rod reinforced with a solid steel bar. To avoid drilling holes in the pump rod it is now clamped to the handle by friction only. A better solution to this problem, however, would be to use a solid nylon bar which is strong enough, but is lighter and can be welded to the PVC pipe. Nylon of this nature will be manufactured locally some time in the future. The pump rod stop (which prevents the rod from being pulled out all the way) was frequently becoming detached. Now, a bell-end joint on the pump rod about 50 cm below the handle also serves as a stop.

Riser pipe/cylinder. This is the major problem at present. Because the 2 in. and 1.5 in. (5.1 cm and 3.8 cm) pipes received from the local factory were not consistent in their dimensions, had wavy internal surfaces, a high out of roundness rate, and an uneven wall thickness, longitudinal cracks in the pipe developed after a few weeks of operation. After being approached on the matter, the management of the factory that had been providing the pipes pledged to supply pipes of better quality.

In a couple of instances, the riser pipe failed at the root of the thread coupling it to the pump stand. Currently, a design change is under way that avoids threaded connections (stress concentration). Because plastic couplings are not locally available, standard steel pipe couplings are used for the other connection.

Because the largest high pressure pipe produced by the factory is 2 in. (5.1 cm) in diameter, it is used in the lower head pumps
(1–4 m) (2.5 or 3 in. (6.4 or 7.6 cm) pipes would give higher discharges).

Cylinder. The last metre or so of riser pipe also serves as the cylinder. Field tests have shown that loss of volumetric efficiency has been mainly due to wear on the PVC cylinder rather than on the polyethylene piston. Thus, it is now envisaged to have the last metre of the riser pipe consist of a detachable unit, which can be replaced when it wears down (every 6–12 months, depending on the amount of usage and type of pump). It is more critical on the BPL type pump with its short (20 cm) stroke.

Piston. The piston also becomes a serious problem on the BPL type pump. Longer pistons (two coupled together) were unsuccessful in decreasing the rapid loss of volumetric efficiency. A design change to a piston with rings, after the preliminary IDRC (University of Waterloo) design, and which can easily be installed and withdrawn in the riser/cylinder, is under way. No changes in design are immediately planned on the pistons of the BP50 and BP40 pumps. However, there may be slight changes when the units go into mass production.

Foot valves. The centrally-pinned type design was abandoned early in the project in favour of the present design, in which the sealing rubber flapper is free to move up and down on a central stem (brass bushing). Because the steel washers adjacent to the brass have shown a tendency to corrode, the bushing is made of steel. The 1.5 in. (3.8 cm) foot valve was troublesome because it had little sealing area. Now, all foot valves are of the 2 in. (5.1 cm) type, with an adaptor/coupling for use on 1.5 in. (3.8 cm) pipes. This foot valve is now very effective in sealing and highly tolerant to foreign particles. There have been no further foot valve problems since the last modification, except once, when excessive amounts of floating pumice were sucked into the pump.

Table 1. Price breakdown of various pump types.

<table>
<thead>
<tr>
<th>Pump type</th>
<th>Price (Br)</th>
<th>Approximate amount of foreign currency in price (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consallen</td>
<td>900¹</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Mono (myno)</td>
<td>2480¹</td>
<td>100</td>
<td>Myno with double oil seal will be slightly more expensive than mono</td>
</tr>
<tr>
<td>Boswell</td>
<td>860²</td>
<td>40</td>
<td>25 m head</td>
</tr>
<tr>
<td>BP50</td>
<td>185³</td>
<td>20</td>
<td>8 m head</td>
</tr>
<tr>
<td>BP40</td>
<td>220</td>
<td>20</td>
<td>16 m head</td>
</tr>
<tr>
<td>BPL</td>
<td>450</td>
<td>20</td>
<td>25 m head, with similar piston as in BP50</td>
</tr>
</tbody>
</table>

¹Consallen and mono pump prices are for the pump stand, piston/cylinder assembly, and pump rod only.
²Stand, BR370; riser (5.1 cm × 25 m), Br300; piston, foot valve, and pump rod, Br207.
³Labour cost for type BP pumps assumed at Br5/h.
pump requires further development. It has also been shown from field tests, however, that no hand pump is maintenance free. Routine inspection and maintenance cannot be done by the EWRA because it does not have the manpower, organization, or sufficient funds.

Therefore, in order for any hand-pump program to be successful, the participation of the community is imperative! Maintenance should be carried out at the village level, with only marginal involvement from a central government body.