IRC
International Water and
Sanitation Centre

WHO Collaborating Centre

The Hague, The Netherlands

Handpumps

Issues and concepts in rural water supply programmes

25

Technical Paper Series

IRC INTERNATIONAL WATER AND SANITATION CENTRE

IRC is concerned with knowledge generation and transfer and technical information exchange for water supply and sanitation improvement in developing countries. The emphasis is on innovative approaches to prevailing problems. The target groups are management and technical staff concerned with planning implementation and use of water supply and sanitation facilities in rural and urban fringe areas.

The centre works together with partners in developing countries, United Nations organizations, bilateral donors and non-governmental organizations. Its multidisciplinary staff provides support through development and demonstration projects, evaluation and advice, training and education, publications, and general information exchange.

Activities integrate technical and non-technical issues in water supply and sanitation and include community participation particularly the role of women, hygiene education, appropriate technology, operation and maintenance, community-based financial management, and development of technical information exchange.

IRC is an independent, non-profit organization. It is supported by and linked with the Netherlands Government, UNDP, UNICEF, the World Bank and WHO, for whom it acts as a Collaborating Centre for Community Water Supply and Sanitation.

For further information

IRC
P.O. Box 93190
2509 AD The Hague
The Netherlands

Telephone: + 31-70-814911
Telex: 33296 irc nl
Cable: Worldwater, The Hague

Handpumps

HANDPUMPS

Issues and concepts in rural water supply programmes

Prepared by IRC in co-operation with
International Development Research Centre, Canada

Technical Paper No. 25

IRC, International Water and Sanitation Centre
The Hague, The Netherlands
1988

Handpumps : issues and concepts in rural water supply programmes / IRC; IDRC.
The Hague : IRC International Water and Sanitation Centre. 1988. - XI, 163 p, Fig., tab. - (Technical Paper Series: no. 25). - Includes references, selected bibliography, and 4 appendices. - ISBN 90-6687-010-9

Abstract

The monograph concerns handpumps and water supply programmes based on this technology for rural communities. Discussion of the technical aspects include appropriate application of the five principle types of handpumps and the latest advances in design and manufacture with special emphasis on plastic. Specific attention is given to local maintenance, manufacture and the importance of quality control. A range of well construction techniques are considered as well as site selection. Installation requirements for the various types of handpumps are examined with attention to design of the apron. The technical issues are placed in context of planning and implementing water supply programmes aimed at sustained use of facilities. The key factor is seen as community involvement in all project phases, particularly in choice of technology, project planning and implementation, and maintenance organization. Various ways of organizing and funding maintenance of handpump water supply systems are discussed.

Keywords: hand pumps/technology/planning/decision making/community participation/ well construction/site selection/maintenance/maintenance costs/local production.

TABLE OF CONTENTS

List of tables

List of figures

Preface

Since IRC's earlier state of the art report on handpumps, Technical Paper No. 10, was published in 1977, there has been considerable progress both in handpump research and development and in the approaches to community water supply in developing countries. IRC and the International Development Research Centre (IDRC) therefore agreed to pool resources and develop a new publication, using the earlier report as a starting point.

An important source of recent information has been the major handpumps project sponsored by the United Nations Development Programme (UNDP) and executed by the World Bank. This project gathered evidence on the performance of a large range of handpumps under laboratory and field conditions. Its conclusions included guidelines on ways of selecting the right handpump for most circumstances likely to arise in developing countries. Those conclusions were published in May 1987 in the book *Community Water Supply: The Handpump Option* (World Bank, 1987). The Executive Summary of that publication is included as Appendix I of this Technical Paper. A prime conclusion is that the predominant cause of handpump failure has been inadequate provision for maintenance of handpumps once they have been installed.

The UNDP/World Bank Project coined the term VLOM (for Village Level Operation and Maintenance, later expanded to *Management* of Maintenance), to emphasize this critical role for the community in the upkeep of their handpumps. Subjects which are extensively covered in the World Bank publication are:

- the case for VLOM;
- handpump technology, including ratings for some 42 pumps and summary information about a further 27; and
- factors which affect handpump performance in the field.

In parallel with the activities of the UNDP/World Bank programme, other organizations too have been active. UNICEF, for example, has stimulated the development of local handpump production in collaboration with the government of India. Mention should also be made of the supporting efforts of several donor agencies and of IDRC, which has sponsored local researchers in developing countries to explore important issues. These include:

- use of new materials such as plastics;
- improved pump design;
- local manufacturing and maintenance; and
- community involvement and acceptance strategies.

More recently, IDRC is providing support for the establishment of a local handpump research training centre at the University of Malaya in Kuala Lumpur, Malaysia. Part of this project will be investigating various options for local handpump manufacture.

Progress in the first two phases of the IDRC-sponsored programme was reviewed at a meeting in Bangkok, Thailand, in October 1986. The proceedings, published in August 1987, summarize handpump developments in Sri Lanka, Ethiopia, Malaysia, Thailand, Indonesia, and the Philippines, and include a discussion on plastics technology (IDRC, 1987).

In this update of the IRC Technical Paper, the emphasis is on *approaches* to community water supplies involving handpumps which can help to ensure that the resulting project has the optimum chance of satisfying the needs of users, and of being successfully operated and maintained.

The main theme of the document is the planning, preparation and implementation of projects, and ways of ensuring that rural communities are fully involved from the start in decisions relating to the choice, use and maintenance of their water systems. In that sense, this publication should be seen as a companion document to the World Bank publication. IRC is most grateful for the support and collaboration of Mr. Saul Arlosoroff, Mr. David Grey and their colleagues in the UNDP/World Bank Handpumps Project, who have helped to ensure that this Technical Paper complements rather than duplicates the UNDP/World Bank work.

TP25 has been written especially for programme staff, planners and policy makers concerned with technically progressive low-cost technologies which can provide safe and adequate water to low-income communities in rural and urban-fringe areas. Its contents will also be of interest to project management staff, as it discusses the combination of technical activities with broader programme development and socio-economic progress, and the integration of "software" activities (community consultation and organization, health education, training) into the overall programme. The book's advice is necessarily general in nature, and as such it should be seen as a tool for developing implementation manuals for specific projects or programmes, not as a manual in itself.

This publication has been put together by Mr. Jan Teun Visscher and Mrs. Christine van Wijk from IRC and technical writer, Mr. Brian Appleton. Mr. Donald Sharp of IDRC has made major inputs into its preparation.

Information used in preparing TP25 has been compiled from many sources, over a number of years. In this respect, special mention should be made of the invaluable contribution of Mr. Eugene McJunkin in the preparation of TP10. Thanks are also due to former IRC staff member Mr. Ebbo Hofkes and IDRC consultant Mr. Chong Kah-Lin for their efforts. Research and editorial work has been supported by the International Development Research Centre.

IRC would also like to thank those who made valuable contributions by reviewing the document in its draft forms: Mr. M. Beyer, Ms. V. Curtis, Mr. D. Donaldson, Mr. C. Glennie, Prof. Goh Sing Yau, Mr. N. Greenacre, Ms. J. Harnmeijer, Mr. A. Karp, Ms. S. Melchior, Mr. T. Orum, Prof. E. Schiller, Mr G. Schultzberg, Mr. R. Talbot, Mr. C. Wang, Mr. M. Woodhouse, Mr. F. Wright.

Figure 1.1 Properly trained village pump caretakers can have a big impact on the cost and reliability of handpumps.

1. Introduction

It has been estimated that groundwater supplies through handpumps will be an appropriate technology choice for more than half of the 1,800 million people in rural and urban fringe areas of developing countries who need improved water supplies by the end of the century (World Bank, 1987). Yet there are many parts of the world where as many as half of the handpumps which have been installed are out of action at any particular time. If full advantage is to be taken of the potential simplicity, low-cost and dependability of handpumped groundwater, important lessons have to be learnt from past successes and failures.

One prime conclusion of handpump studies in recent years is that a predominant cause of breakdown and poor functioning has been inadequate provision for maintenance of handpumps. Other contributing factors include: poor well design and construction, which allows sand to enter pumping elements and causes premature wear of key components; choice of inappropriate pump technology; designing for the wrong service level; siting pumps in the wrong place, or at the wrong depth; and, more fundamentally, lack of community involvement in project selection and implementation.

The formula for future success includes strong emphasis on an "integrated" approach to community water supply programme planning and implementation. The community, and particularly the women, it is argued, must be encouraged and equipped to play an active part in all stages of the project cycle (IRC 1985, IDRC 1987).

The eventual aim is that the users should assume control of the upkeep of the handpump system, with central agencies offering advice and technical support, but leaving ownership and management in the hands of a properly equipped village organization. This may not always imply that villagers themselves should carry out all maintenance work, though there are increasing numbers of examples where village-level maintenance of handpump systems has proved both effective and economic. What it does mean is that, where pumps are maintained by outside mechanics, selection and payment of the mechanics remains under the control of the community. The UNDP/World Bank Project coined the term VLOM (for Village-Level Operation and Maintenance, later expanded to *Management* of Maintenance), to emphasize this critical role for the community. The new approach has important implications for project planning and implementation.

1.1 MERITS OF HANDPUMP WATER SUPPLIES

Mechanical pumping of water goes back a long way, and over the centuries a great variety of hand-operated pumping devices have been developed for different purposes.

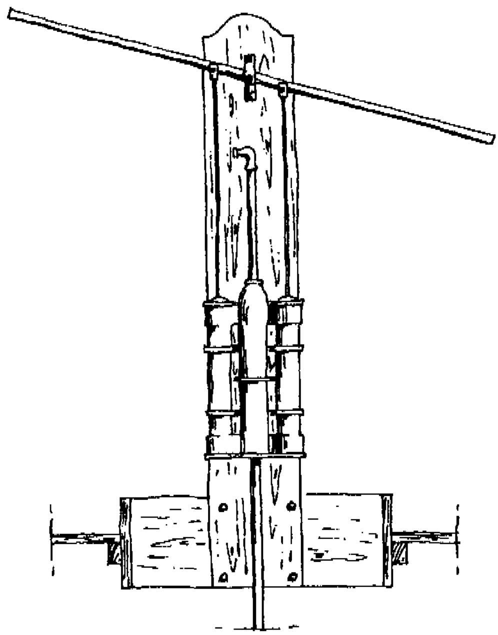


Figure 1.2 The Ctesibius pump (Source: Eubanks, 1971)

Some types of artisan-made handpumps are known to have been in use for over 2,000 years. The earliest handpump of industrial design is believed to be the one invented by Ctesibius around 275BC (Eubanks, 1971). It was mainly used to pump water from ships.

Human energy

Today, human power remains the most readily available and reliable source of energy for water pumping in many rural communities. If groundwater is available within about 45m of the surface, then one or a few handpumps will be enough to provide adequate supplies of water for drinking and domestic use for a small community.

Women and children are the main drawers of water. While they may be prepared to combine their efforts when the water table falls in the dry season, handpumps should be designed to allow comfortable operation by one woman for the main part of the year. The water discharge corresponding with an appropriate power input of 40–50W and a 50% pump efficiency would be about 12 litres/min from a depth of 10m, or about 6 litres/min from 20m depth. The number of people who can be adequately served from a single handpump depends on the discharge which can be achieved. Generally, it is advisable to keep the intended number of users per pump below 250, and preferably below 200. Much larger handpump user groups do exist, but the pumps are then very heavily worked and need frequent maintenance if they are to provide dependable supplies. Also, long waiting times drive potential users back to previous unsatisfactory water sources.

Users are often willing to use greater efforts when pumps produce a high discharge per stroke and they can therefore fill their containers quickly (World Bank 1987). The ergonomic design is very important in this regard. Pumps should be appropriate for the particular user groups — generally women and children, and should avoid the need for operators to use a stooped position or to waste energy. Leg muscles are the largest and strongest in the human body, and a healthy person can comfortably produce about 100W for several hours using a pedal drive. However, foot-operated pumps may not be acceptable in some societies, or for particular types of users, such as pregnant women, and very few reliable foot-operated pumps have been developed.

Advantages of groundwater

As a domestic water source, groundwater has a big advantage over surface water in that it has a natural protection against contamination. Most aquifers can easily provide the relatively low yields needed for handpump supplies throughout the year, avoiding the need for storage tanks or reservoirs, and wells can generally be located close to population centres, making the supplies convenient for villagers to collect. Increasing recognition of these benefits rightly leads rural water supply planners to favour groundwater-based programmes, wherever such schemes are feasible.

Unqualified promotion of groundwater is however unwise. Experience shows that groundwater is not without problems. It may, for instance contain a high level of iron, which brings taste and odour problems and leads to unsightly staining of laundry and

Figure 1.3 Foot pumping makes effective use of powerful leg muscles

cooking utensils. In some regions, chloride or fluoride may make the water unpalatable or unhealthy. In the case of shallow groundwater, bacterial contamination is always a threat, especially in urban-fringe areas, and precautions are needed to protect the water quality. And an important finding of the UNDP/World Bank project has been that corrosive groundwaters are more widespread and more damaging than previously thought, demanding greater use of corrosion-resistant materials like plastics or stainless steel. In planning handpump projects therefore, a good knowledge of groundwater quality characteristics and their implications is a prerequisite.

Simplicity and low cost

With sustainability and replicability as prime criteria, rural water supplies need to be affordable and manageable with resources available to village communities. In this category come such technologies as rainwater catchment and storage, gravity-fed standpost supplies, small-scale treatment of surface water sources, and groundwater supplies through handpumps. Each of these has a role to play where local circumstances are appropriate, and the potential for different types of technology, including pumped supplies to standposts or yardtaps, needs to be analysed and findings discussed with the community, before a final choice is made.

With an estimated per capita capital cost of between $10 and $30, handpump-based community water supplies generally offer an affordable improvement on traditional sources, while providing an acceptable level of service — 20-30 litres per head per day (World Bank 1987). With the right choice of handpump, such schemes are also well suited for maintenance by minimally trained village repairers, or by locally-based mechanics operating in the private sector. Increased user involvement in preventive maintenance and repairs makes it easier for governments to establish a maintenance support system at affordable cost, and so frees resources to continue construction in still unserved areas. A successful community-based maintenance system also means that repairs can be carried out promptly and economically, and so ensures the reliability of the new water system.

Handpumps can be used on boreholes, hand-drilled wells or dug wells, depending on the availability of groundwater and the local potential for well construction. Only when local conditions are such that even the simple maintenance needs of a VLOM handpump would be unsupportable should it be necessary to adopt the alternative of protected wells equipped with ropes and buckets.

The scope for further upgrading makes wells and handpumps a technology which is highly suitable for adaptation to growing community demands and levels of development. Taking protected dug wells as a first-stage technology, the community can add handpumps for greater protection and ease of operation, while building up skills and resources for local maintenance and management. The community may later wish to invest more resources in an improved service level, which will have a greater chance of success because of the experience gained with the handpump project.

1.2 HANDPUMP PROBLEMS AND LIMITATIONS

Results from widespread implementation of rural water supply programmes based on handpumps during the last 10-15 years have been mixed. Some countries have achieved substantial increases in the proportion of the rural population with access to safe water, and have been able to keep completed schemes in reliable operation for prolonged periods. Others have been less successful, with as many as 50 or 60% of handpumps being reported as out of order at any one time. One recurring problem is the length of time that pumps stand idle awaiting simple repairs.

Estimation of the downtime— the product of the breakdown frequency and the length of time the system stands idle awaiting repairs — is critically important when assessing the reliability of a community water supply system. Once this downtime exceeds about 5% of the total time that a pump is needed, the community may easily lose interest and return to dependence on other water sources. While breakdown should not be too frequent, it is the reduction of maintenance delays which has greatest impact on reliability, and hence on the utilization of the system (World Bank, 1987).

Maintenance needs

While the technical maintenance needs of handpumps are inherently simple, surveys have shown that achieving satisfactory long-term performance depends on careful

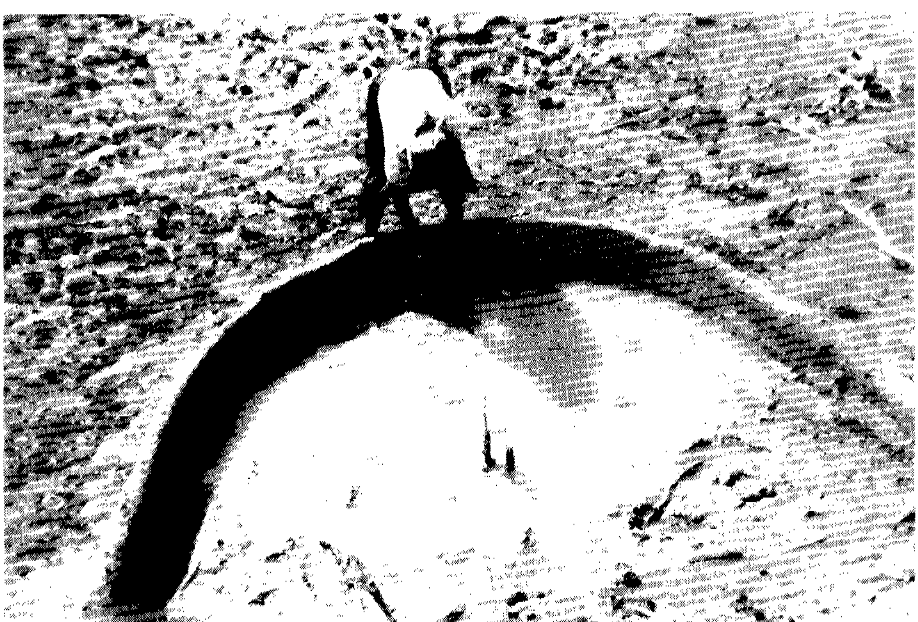


Figure 1.4 If handpumps are unreliable, users may be forced to collect water from polluted sources. All the benefits of providing safe water will then be lost

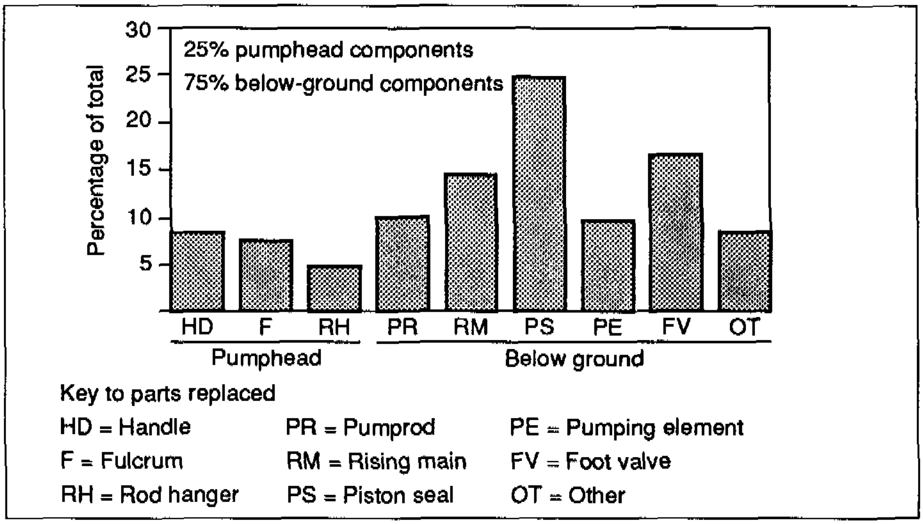


Figure 1.5 Seal replacement was the most common servicing need in the UNDP/World Bank field trials (World Bank, 1987)

attention to detail in the planning and implementation phases. In fact, maintenance is more an organizational than a technical problem. Good maintenance and timely repairs depend on a chain of tasks, resources and decision-making powers at all levels from the neighbourhood to the national authority. If one or more links in the chain are weak or absent, the whole maintenance system may be put in jeopardy. An adequate and financially viable organization for management of maintenance has to be developed in the planning stage.

Technically, the most common maintenance problem is replacement of worn or damaged plunger seals. Seal replacement accounted for 25% of the essential interventions in the World Bank field trials, and it is instructive to consider the requirements for ensuring that worn seals are replaced promptly and economically. Such servicing should not, as is often the case now, demand a special visit by a mobile team of mechanics travelling from a central depot many kilometres from the pump site. Staff, transport and fuel costs for replacement of a $2 seal make such operations unsupportable. Some projects have prepared a somewhat less costly approach in which seals and other vulnerable parts are replaced at scheduled intervals. Scheduled servicing has other advantages too. As with the regular servicing of motor cars, industrial equipment, etc, it means that pumps can be taken out of service at planned times and for only short periods, rather than having to wait for a mechanic to arrive when they break down.

Far preferable though is a system under which seal replacement is carried out by a village pump caretaker or locally-based mechanic with assistance from villagers. In the case of deep wells, that means choosing handpumps which do not require heavy lifting equipment to be available for removing pumprods and rising mains when seals need replacing. It also means training and equipping mechanics, and possibly villagers, to undertake seal replacement, and ensuring that supplies of spare seals are readily available through the mechanics or through retail outlets. The system has to be planned carefully in relation to the density of pumps and the likely number of repairs required. Unless they have enough work to do, trained mechanics may lose interest and start to lose their specialist skills.

Standardization can make a substantial difference to maintenance needs. Training and the stocking and distribution of spare parts are simplified when national procurement guidelines lead to selection of just one or only a few pump types. Compromises on initial capital cost and optimum pump performance may be needed to achieve the greater benefits of standardization. For example, it may well prove worthwhile to use a handpump type selected for deepwell applications also for shallow-well projects in nearby areas, rather than duplicate training and spare parts needs by choice of a different pump type. If there are substantial numbers of both shallow and deep wells, it will make sense to standardize on two pump types, but seeking interchangeability of parts wherever possible.

Well design and construction

Poor borehole design and/or construction has been mentioned as another factor influencing the performance of handpumps. There are many examples where inadequate placing of screens and gravel packs and poor well development has resulted in sand ingress, leading to rapid seal wear and abrasion of other key components. Good borehole alignment is also crucial to the proper functioning of many handpumps (the exception being hydraulically operated pumps with flexible hoses), as contact between pumprods and rising main means reduced performance and rapid wear. Rehabilitation of clogged wells is expensive and is generally beyond the scope of community-based repairers. This makes it even more important to construct wells with care.

Local appropriateness

There can be great differences between individual communities in a single region or project area. Some communities may be isolated, with difficult access, a subsistence economy and strong social ties, but with few technological capabilities and little experience in managing development projects. Others may be large roadside villages with a developed cash economy and experienced leadership, but with less social cohesion and widening differences in income and socio-economic status among various population groups. In the first case, even if they are technically feasible, handpumps may not be the right solution, because reliable maintenance and quick repair could be beyond the physical and economic capacity of the community. In the second case, greater financial and technical resources may mean that the community desires a higher level of service than handpumps can provide.

A single standard project is not the best solution where the range of needs is so wide.

Such local variations can however be accommodated by giving the community an informed choice from a range of groundwater technologies from open protected wells with a windlass or hygienically protected buckets, to perhaps even motorized pumps with a simple reticulation system.

Even where handpumps are the right technological solution, proper upkeep will only be achieved if villagers are convinced that the system installed meets their needs and if they have the resources and access to the necessary backstopping services to sustain it. If the community is not closely involved in planning and implementing the scheme, pumps may be rejected, left unused, or allowed to fall into disrepair. Among problems caused by inadequate community involvement in water programmes are incorrect siting of wells, designs for the wrong service level, leading to unacceptable queuing or hauling distances, and financially unsustainable projects.

Even when pump users are willing and able to pay for maintenance of their pumps, collection and management of the necessary funds can be difficult to organize. Unless cash is available when repairs are needed, pumps will stand idle and eventually be abandoned.

Local appropriateness is ultimately governed by what both communities and government can support and maintain.

1.3 RECENT DEVELOPMENTS

During the past ten years, extensive laboratory and field trials have been conducted throughout the world on a large number of handpump models. The UNDP/World Bank project alone evaluated some 2,700 handpumps of 70 different models in a five-year testing and monitoring programme. Results from these and other tests have prompted manufacturers to improve designs. Ease of maintenance has been the chief design aim, with modern materials and technologies playing an increasing part. In the past, handpump designs have frequently aggravated maintenance problems, by making plunger removal a demanding and time-consuming operation, and by creating the need to import frequently required replacement parts. In recent years, design modifications have centred on simplifying maintenance needs, and there is now a widening choice of pump models designed to be maintained and repaired at the village level.

Use of Plastics

Considerable research has gone into the development of pump components made from uPVC, polypropylene, polyethylene, and engineering plastics. More work is planned, but it is already clear that plastic or synthetic rubber seals offer great potential for reducing the frequency of seal replacement. Engineering plastics have been tested in handle bearings in handpump prototypes, and are now in full-scale production. Plastic rising mains of various types and sizes have been tested with mixed success in field

Figure 1.6 Plastic handle bearings are already being produced for some handpumps (photo UNDP/World Bank)

trials. There are grounds for confidence that uPVC rising mains can be used successfully to depths of about 30m, and that future research already under way should prove their application at greater depths.

Plastic below-ground components have two distinct advantages: they are light in weight and highly corrosion resistant. The light weight is a vital consideration for maintenance, as lifting out galvanized steel rising mains is a cumbersome operation, which generally calls for specialist skills and equipment. Corrosion can drastically shorten the life of rising mains and pumprods, and galvanizing has not proved a satisfactory remedy. Where water is known to be corrosive, maximum use of plastics has great advantages, and plastic pumprods have even been used for shallow installation depths. For deeper installations, stainless steel pumprods, though initially expensive, should be seriously considered.

Use of plastics has the additional advantage that spare parts can generally be mass produced economically, frequently in the country of use, which makes a huge difference to spares availability when pump repairs are needed.

Cylinder design

A significant step forward in simplifying maintenance has been the introduction on some pump models of open-top cylinders. The open top allows the plunger and footvalve to be withdrawn without removing the rising main, so making inspection, servicing and replacement of these wearing components very much easier. In addition, field trials have demonstrated the merits of a small-diameter long-stroke cylinder, rather than the conventional approach of increasing cylinder size as depth reduces (World

Figure 1.7 Direct action handpumps are a popular alternative to suction pumps and can be used to depths of 12m or more (photo IDRC)

Bank, 1987). This additional step towards standardization is being encouraged, and developing countries are being urged to favour pump models which adopt uniform cylinder sizes (50mm is the preferred size) for all depths. It is however likely that in the many regions with shallow water tables larger diameter cylinders will remain popular.

Direct action handpumps

The majority of handpumps in use around the world are lifting from depths of less than 15m, and many from less than 7m, beyond which suction pumps become unusable. For these applications, it is possible to dispense with the mechanical advantage of a lever handle. Direct action pumps have the merits of simplicity, lightness and high discharge potential. They also eliminate the need for bearings, and so simplify maintenance needs. In comparison with suction pumps they also have the distinct advantage of being self priming, which greatly reduces the risk of contamination. Considerable work has gone into the development of direct action handpumps in recent years, and there are now several well-proven models on the market.

Local management and financing

Important as developments in handpump technology are, they can make only small inroads into maintenance difficulties without important changes to institutional and support mechanisms. Increasing recognition of the inadequacies of central maintenance and the consequences for pump reliability is leading to widespread acceptance of the need for new approaches to community participation in water system planning and implementation.

Shared or community-managed maintenance can be one answer, but is highly dependent on the quality of agency support. Problems do not lie so much in the training of community members in technical skills, but in the social and organizational aspects. Among the issues that have to be addressed are: who to select as caretakers and mechanics; how to compensate them; what kinds of locally appropriate financing to set up; who should manage maintenance and how should the management body be trained; and how to monitor maintenance and provide the necessary support. Community-based financing of handpump maintenance is the only practical way to keep handpumps functioning reliably, but the task of organizing it should not be underestimated. It calls for skilled assistance in the initial stages, to choose the right people and establish the right collection systems, book-keeping routines, secure storage of funds, and facilities for paying for parts and services. Experience is now building up of these new approaches.

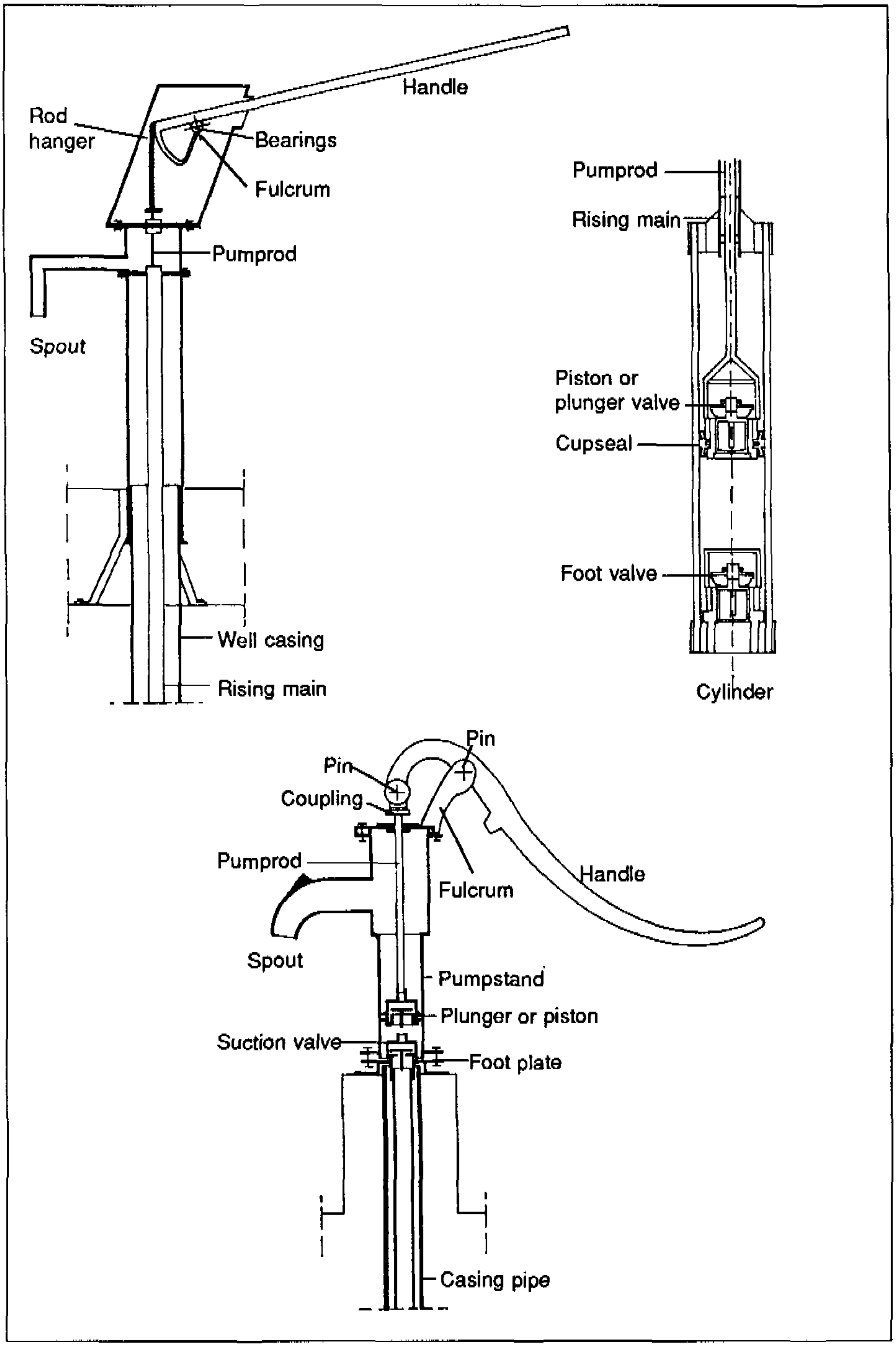


Figure 2.1 Terminology for handpump components can vary from publication to publication. The nomenclature used in this document is illustrated on the diagrams above

2. *Handpump Technology*

Reciprocating handpumps were known to the Greeks and Romans, were in widespread use in mediæval Europe, and have been mass produced since the late 18th Century. Only recently however has it been recognized that designs based primarily on single family use in Europe and North America are not adequate for user groups of 200 or more in developing countries.

Before discussing applications in detail, it is helpful to consider the different operating principles of handpumps now available on the market. Figure 2.1 opposite is a typical reciprocating lever-action handpump, included to indicate the nomenclature used in this report. Appendix III contains a discussion of the latest research and development related to individual handpump components.

2.1 HANDPUMP TYPES

Still by far the most common type of handpump in use throughout the world is the reciprocating-plunger pump. Rotary pumps and diaphragm pumps have been gaining in popularity in recent years. Other designs include bucket pumps, chain (or rope) pumps, and water oscillation pumps.

Reciprocating-plunger pumps

The name derives from the up-and-down motion of the plunger (or piston) in the cylinder. On the upstroke, the plunger lifts water into the rising main and replacement water is drawn into the cylinder through the footvalve. On the downstroke, the footvalve closes, a valve in the plunger opens, and water passes through, to be lifted on the next upstroke. Most reciprocating handpumps discharge water only during the upstroke and are termed *single acting*. Pumps discharging water on both the upstroke and downstroke involve a more complicated valving arrangement and are called *double acting*.

In the suction version of reciprocating pumps, the cylinder is located above ground and draws water up above the standing water table behind the plunger on the upstroke. Such pumps can only be used for shallow lifts — 7m is the practical limit — as at greater depths the water column cannot be supported by atmospheric pressure. In high lift reciprocating pumps, the cylinder is immersed below the water table, and the pumping limit is fixed only by the effort needed to lift water to the surface.

The operator's effort may be transmitted to the plunger in a number of different ways. The illustration shows the most common type of operation in which a lever handle gives a mechanical advantage to the operator. A simpler operation is known as *direct action*, in which lifting and lowering of a T-bar handle linked directly to the pumprods moves the plunger up and down. Other options include flywheel operation, in which rotation

Figure 2.2 Flywheel operation is an alternative to the more usual lever

of a flywheel in the vertical plane is transferred to reciprocating motion of the plunger via a cam linkage.

Wearing parts of reciprocating pumps include footvalve and plunger valve seals, and handle bearings. With all wearing components located above ground, suction pumps are comparatively easy to maintain, calling for minimal skills and only a few simple tools. They do however suffer the disadvantage that, unless the footvalve is of very good quality to prevent leakage, regular priming is needed. Use of contaminated water for this purpose can contaminate the well. Maintenance difficulties of high lift reciprocating pumps increase with depth, because of the need to withdraw the plunger and footvalve to replace seals. This has been the focus of much research and development during recent years, and removal of below-ground components has been greatly simplified on some modern pump designs.

Routine maintenance may include lubrication of pumphead linkages and bearings, though again modern designs are reducing or eliminating this requirement. Breakdowns of reciprocating pumps can also arise from pumprod breakages or rising main failure, and the choice of appropriate materials for these components is important, particularly if water is corrosive.

Rotary pumps

Hand operated rotary pumps use relatively low rotation speeds and lift water by positive displacement, not by centrifugal action. The pumping element, patented by the French engineer M. Moineau in 1924, consists of a helical rotor turning in a helical sleeve or stator, and pushing the water upwards in "progressing cavities". Drive is commonly applied through a gearbox in which rotation of two handles or a flywheel about a horizontal axis is converted into rotation of the pumprods about a vertical axis. The gear ratio can be varied to suit different depths. Precise machining is required to ensure that the rotor and stator provide their own continuous seal, so that only a footvalve is needed. This requirement complicates local manufacture.

Routine maintenance is unnecessary, as the gearbox is supplied as a sealed unit, and there are no seals to be replaced. However, when the pump does fail, repair generally means replacement of the pumping element or the gearbox, and the operation is beyond the capabilities of local mechanics. As with reciprocating pumps, the pumprods and rising main are susceptible to corrosion in aggressive water, unless corrosion-resistant materials are used.

Diaphragm pumps

The operating principle of the diaphragm pump involves alternate compression and expansion of a pump chamber by movement of a flexible diaphragm. Inlet and outlet valves cause water to flow through the pump chamber and up to the surface, through a flexible hose, rather than the conventional rigid rising main. In domestic water supply

Figure 2.3 Diaphragm pumps are relatively easy to maintain, but replacement of the diaphragm is costly

handpump applications, the diaphragm movement is caused by a secondary hydraulic circuit, also using flexible hoses, in which either pedal or lever action applies and releases pressure.

There are no moving seals in the cylinder, so that a major wear element is eliminated. Maintenance is also considerably simplified by the absence of heavy pumprods and rising main. It is possible to withdraw the pumping element from depths of 40m or more without the use of lifting tackle. Unlike pumps which depend on direct force transmission from a handle to a plunger, diaphragm pumps are insensitive to borehole misalignment. Sand particles can be pumped without damaging the diaphragm, though there have been cases of sand accumulating within the diaphragm, partially filling it and distorting its operation until it has burst open.

A disadvantage of currently available pumps is that the diaphragm requires considerable manufacturing skill and quality control and is a very expensive item. Experience has shown that diaphragm life may vary from two to five years, though there are examples of diaphragms failing within six months.

Rope or bucket pumps

Mainly used on cisterns and shallow dug wells, the bucket pump consists of a continuous chain of small buckets running over sprockets. Each bucket dips into the water at the

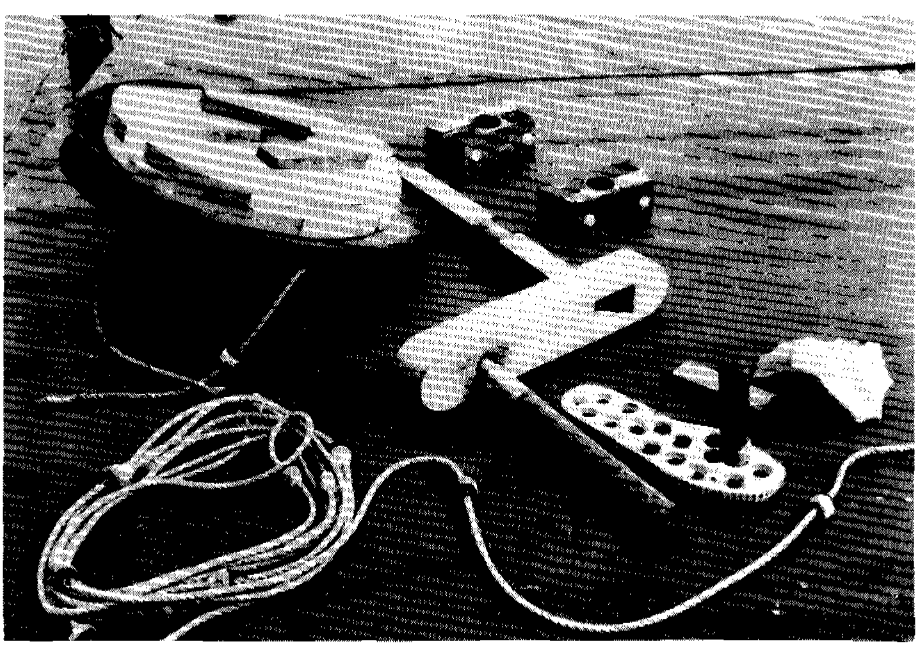


Figure 2.4 Rope pumps allow maximum use of indigenous materials. They are mostly used for low-lift applications and small user groups (photo WASTE Consultants)

bottom, carries it to the top and empties into a spout as it passes over the top sprocket. For their comparatively limited application, bucket pumps are well suited to local manufacture from indigenous materials and are consequently simple to maintain in reliable operation. However, the frequent maintenance needs involve a continual risk of contamination of the well water.

Similar in principle and application to the bucket pump, the chain or rope pump uses discs or knots of suitable local material to lift water through a pipe and discharge it via a spout at the surface. Again the pump operates as a continuous chain, running over a top sprocket.

Oscillation pumps

Water oscillation pumps work by inducing a column of water to oscillate close to its natural frequency. A plunger located in an upper cylinder is moved by means of a lever handle, and the operator matches the movement to the response of the water column felt through the handle. The column oscillates as a result of alternate compression and relaxation of a compressible medium (e.g. rubber balls or ovoids) contained in the lower cylinder. Pressure variation in the water column draws in water through a footvalve in the lower cylinder and discharges it through ports in the upper cylinder.

The pump has the advantage that no pumprods are involved and it can therefore be installed in inclined boreholes. Though the design principle is interesting, application has so far been very limited.

2.2 HANDPUMP APPLICATIONS

There is a direct relationship between the amount of effort applied by a handpump user and the discharge obtained. Discharge is also related to pumping lift, with the delivery rate of the pump falling as pumping lift increases, unless the operator can apply a compensating increase in pumping effort. Two other important variables are the mechanical and volumetric efficiencies of the pump.

Mechanical efficiency may be defined as the work done in lifting water divided by the work input. It is a measure of the waste of mechanical effort resulting from leakage, friction, and pressure resistance losses. For most handpumps, mechanical efficiency increases as the lift increases.

Volumetric efficiency is the volume of water delivered per cycle divided by the volume displaced during the pump stroke. Valve delays and leakage past the piston decrease volumetric efficiency. Slip is another term used to measure volumetric efficiency and is usually defined as the percentage difference between the theoretical and actual discharges.

In choosing handpumps for a particular project or programme, the pumping lift is a critical parameter. In terms of pump performance, it is the height from the top of the

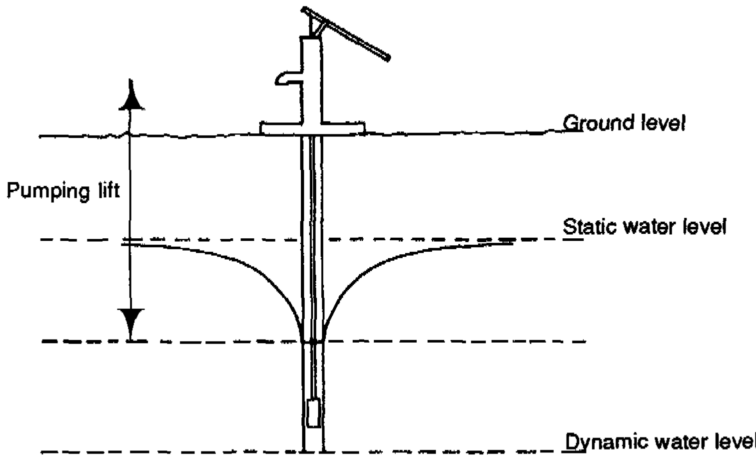


Figure 2.5 The relationship between static and dynamic water levels affects pump performance and cylinder setting

water table during pumping to the delivery point which represents the pumping lift — not the depth to the cylinder or intake point (when considering maintenance needs however, the cylinder installation depth is important as it will affect the weight of components which have to be lifted out for servicing or repair). Pumps must be selected and cylinder settings chosen to suit the maximum anticipated pumping lift. That means taking account of seasonal variations in the water table, and any drawdown in the well caused by use of the handpump. Nearby motorized pumps used for irrigation or large-scale domestic water supply may also lower the water table locally. The theoretical background to estimation of reciprocating handpump discharge, including energy requirements and the effects of drawdown, is given in Annex 2.

The characteristics of individual handpumps vary, and those designed specifically for high lift applications may be unsuited for use in shallow wells, just as suction or direct action pumps cannot be considered for high lifts.

Handles

The ergonomics of pump operation will be important to women and children. The height, length and travel distance of the handle or flywheel affect the convenience, comfort and efficiency of pump operation. A long handle provides a high mechanical advantage, but also has a large travel arc. Some users may be unable to move the handle far enough to achieve the full stroke length, and the pump will be cumbersome to operate. For example, a handle with a mechanical advantage of 5:1 moves through a distance of 1m to produce a plunger stroke of 200mm.

A handle height of 1m in the rest position (midway through the travel arc) has been found to be convenient for most users. Pumping efficiency in a stooped position is less than half of that in an upright position, so too low a handle position should be avoided. Optimum efficiency of human power output is likely to be achieved when the pump operating force is about 100N (10kg-f). For deepwell pumps it is sensible to make provision for pumping with both hands, or for more than one person to operate the pump — e.g. by use of a T-bar handle or two handles on a flywheel. Two-handed operation raises human power output by a third or a half compared with single-handed operation.

Designers should recognize that pump operators' hands may often be wet or soapy. A simple stop or grip on the handle to prevent hands from slipping off is a sensible safety precaution.

In general, there are distinct differences between pumps suited for low lifts (up to 15m) and those for high lifts. The merits of direct action pumps in eliminating wearing parts in the pumphead become less advantageous as depth increases and the lack of mechanical advantage makes operator effort excessive. Increasingly, it is becoming

Figure 2.6 In the top picture, the pump handle is too low for comfortable operation, while in the lower picture, it is clearly too high. A height of about one metre above ground level has been found to suit most users. (Source: WHO/SEARO: 1976)

possible to standardize on below-ground components of pumps, while varying the mechanical advantage in the pumphead to suit different lifts. The concept of a "pump family" in which the same cylinder, seals and valves are used in high and low lift versions has considerable merit.

Low lift pumps

When the pumping lift is low (0-15m), there are many pumps on the market which can achieve a high discharge — 20 litres/min or more. Given the choice, handpump users will opt for pumps which fill their containers more quickly, even if the operating action and effort needed on competing pumps may seem more comfortable (the effort needed must not of course be excessive).

For lifts of 7m or less, suction pumps are widely used. They give a high discharge, are cheap and simple to install and maintain, and are suitable for local manufacture in many developing countries. They do however suffer from two distinct disadvantages. First, the suction limit means that if the water table falls with time the pump will be rendered useless once the lift drops below 7m (at high altitude this limit can be as low as 4m). Second, suction pumps may need priming once they have been out of continuous operation (e.g overnight), unless the footvalve is of good quality and well maintained. Clean water for priming is rarely available, and contaminated water is frequently used for the purpose. Unless users are aware of the danger and pump the contaminated water away to waste, priming introduces a serious health risk.

These shortcomings of suction pumps are leading to a growing preference for direct action pumps, where these are economicaly competitive. Also capable of delivering large quantities of water, direct action pumps have the cylinder immersed in water and so do not lose their prime or become inoperable when the water level reaches a prescribed limit. The pumping effort becomes greater as depth increases, and delivery rate progressively reduces, but there is no sudden cut off, as with suction pumps. Direct action pumps can be very simple to install and maintain, and have been the subject of extensive research in recent years.

Some present designs of deepwell reciprocating pumps offer options on cylinder size, so that larger diameter cylinders can be used for pumping from shallow depths, to produce higher discharges. In general, high lift lever action pumps, even when used for shallow lifts, are more complex to maintain. They may therefore only be selected for low lift applications for reasons of standardization. Rotary and diaphragm pumps presently available on the market have discharges too low to make them acceptable for low lift applications unless there is a strong user preference based on familiarity.

High lift pumps

Once the pumping lift exceeds 12-15m, direct action pumps are eliminated from consideration, because the effort needed to lift water from such depths demands the

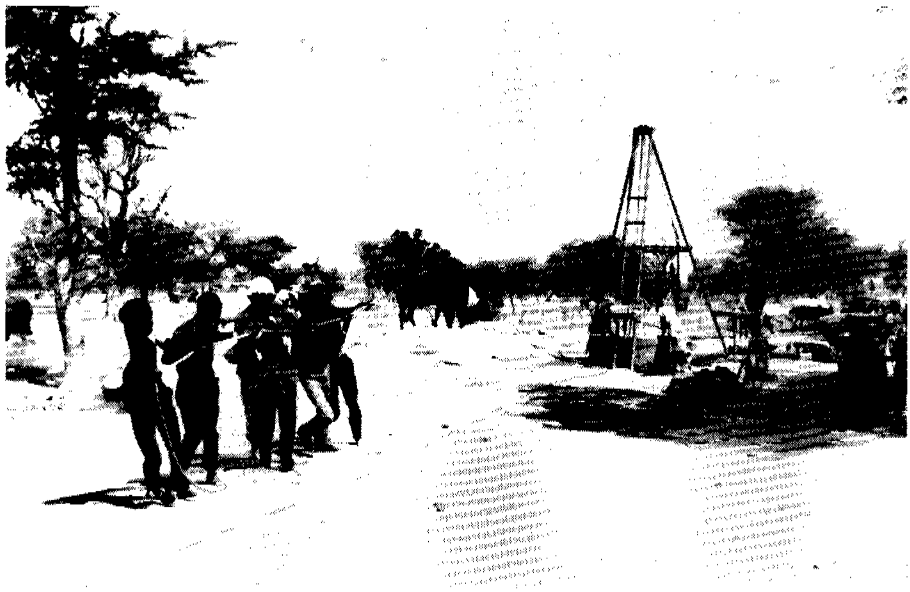


Figure 2.7 Raising a heavy pump string from a deep well may be beyond the capacity of local pump caretakers (photo UNICEF)

mechanical advantage provided by a lever or flywheel action. Increasing pumping depth also means increasing loads on all pump components, and extra weight to be lifted from the well when servicing below-ground components.

The discharge capabilities of reciprocating pumps, diaphragm pumps and rotary pumps become comparable for deepwell applications, and models of each type merit consideration. The paramount importance of matching handpump selection with the maintenance capabilities of benefitting communities may well restrict choice to only a few pumps when the depth is great. Many current designs require the use of lifting tackle for such routine repairs as plunger seal replacement, and would be ruled out of consideration unless such facilities could be provided promptly and economically when needed.

2.3 TECHNOLOGICAL PROGRESS

In the 1980s, handpump research and development has intensified, with the main goal being ease of maintenance and simplification of spare parts needs. The identification of corrosion as a major problem in several regions has spurred the introduction of plastics for valves, cylinders, seals, and rising mains, and considerable work has gone into developing the theory and application of direct action pumps with lightweight pumprods.

Latest research findings related to individual pump components are summarized in Annex 3. The general focus of recent handpump research and development is discussed below.

Ease of Maintenance

In general, it is repair and replacement of below-ground components which cause the greatest problems in handpump maintenance. There have been a number of improvements in pumphead design, among which the testing and development of plastic bearings for the Afridev pump is particularly noteworthy. This pump design was developed in Kenya during the UNDP/World Bank project, with support from the project team, research organizations and private industry. But it is modifications which make possible easier removal of plungers, seals and foot valves that can be expected to have the greatest impact on ease of maintenance and long-term pump reliability in the field.

Conventional high lift reciprocating pumps need regular replacement of worn plunger seals, the frequency of replacement increasing significantly when sand enters the well and becomes embedded in leather seals. On a typical high lift pump, seal replacement means removal of the cylinder, pumprods and rising main (full of water unless special provision is included for draining it before removal). Steel pumprods and rising mains are heavy, as are brass or gunmetal cylinders. The total weight of a deep installation may exceed 200kg and calls for special lifting equipment each time a seal needs replacing. Most programmes therefore provide for costly motorized maintenance crews, though some are trying to eliminate the use of lifting tackle by developing special types of winches or other small lifting tools.

It is the heavy demand on central organizations, plus the prohibitive cost of sending repair crews long distances to carry out routine servicing, which is mainly responsible for the poor reliability record of handpumps in a number of developing countries. The answer lies in design changes which allow semi-skilled mechanics or villagers to undertake servicing of below-ground components without the need for motorized transport or expensive tools and equipment. The economic impact of this kind of change is such that the World Bank estimates that the cost of servicing VLOM handpumps should be as low as US$0.05–0.10 per user per year, or approximately one tenth of the cost range for conventional deepwell handpumps (World Bank, 1987).

A major contribution to simplified maintenance has been the adoption by a number of manufacturers of open-top cylinders. By using a rising main with an inside diameter similar to or slightly larger than the cylinder itself, it is possible to remove the plunger and foot valve for inspection and repair without having to lift out the rising main itself or the cylinder. Simple coupling and uncoupling arrangements are also under development to facilitate rod removal and replacement. Provision for extraction of below-ground components through the rising main has a penalty associated with it, in that the rising main diameter must be larger than would otherwise be the case. That in turn means

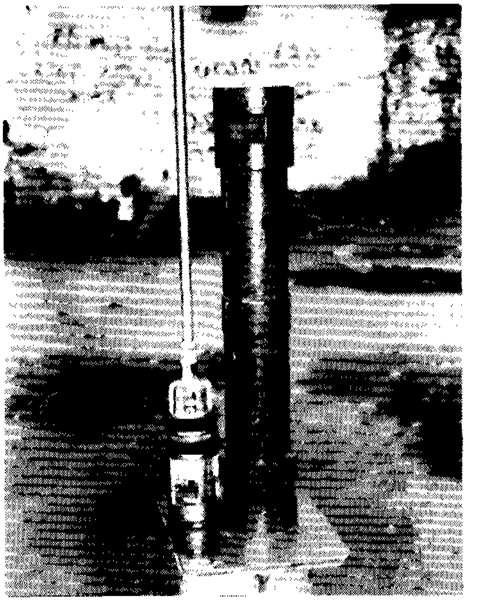


Figure 2.8 Open-top cylinders make seal replacement simpler for deepwell pumps

higher initial cost and a slightly more difficult operation when extraction of the rising main is necessary. Development of designs for large diameter plastic rising mains is already well advanced, and there is optimism that uPVC mains may be commonly employed down to 45m or more before long.

Lightweight materials

Extensive use of plastics has been strongly promoted as a desirable objective of handpump development. Plastic bearings have already been mentioned, and field trials have shown that they can be designed and mass-produced to suit the special demands of handpump operation (comparatively slow rotation speeds, cyclic reversals of direction, and potentially aggressive atmospheric conditions, including wind-blown dust). Below ground, there are now successful all-plastic plungers and foot valves (some even interchangeable); elastomeric seals are proving more resistant to sand pumping than leather ones, and can be manufactured to a more consistent quality; and plastic rising mains are extending their range of application.

For low lift applications, the use of direct action pumps offers scope for maximum use of plastic materials. An important design concept for direct action pumping involves finding ways to balance the operator's effort in the most efficient way between the upstroke and the downstroke. With heavy conventional pumprods, all the effort is expended on the upstroke, and gravity helps to return the plunger on the downstroke. However, by using hollow rods, or rods made of a buoyant material such as wood, the upward force is substantially reduced, and compensated by the need for a positive downstroke. This concept has led to the use of large-diameter low-mass pumping rods in direct action pumps. On the other hand, too large a positive downstroke may lead to buckling and subsequent pumprod failure, if the pumprod material is not stiff enough (though this effect can be countered by using rod guides).

Corrosion resistance

Increasing use of plastics helps to combat problems of corrosion, which otherwise can lead to premature failure of pump components and cause unpleasant tastes in the water as zinc and iron levels rise. The most serious effects of corrosive groundwater are failures of pumprods and rising mains. Galvanized steel is a standard material for these components in conventional handpumps, and experience has shown that galvanizing offers only short-term protection when groundwater is aggressive — galvanized rods and rising mains failed within a few months of installation in some of the field trials in West Africa (World Bank 1987).

The alternative of stainless steel is expensive initially, but may turn out to be an economic option when long-term maintenance is taken into account. So far, that is the only generally available alternative, though Duba Tropic pumps have performed successfully to considerable depths using pumprods of Oregon pine, and glass-fibre reinforced plastic (GRP) rods are offered as an option with the Monarch pump.

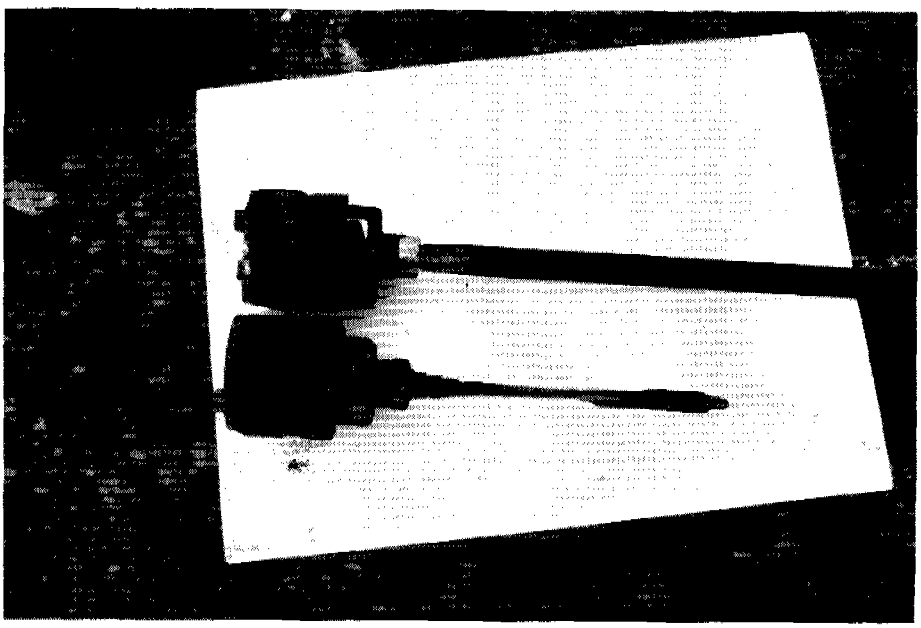


Figure 2.9 Galvanizing is not sufficient protection against corrosive groundwater (photo World Bank)

Local manufacture

Spare parts supply is vital to effective maintenance, and local manufacture of handpumps or handpump components has many attractions in this respect. Designing handpumps to be suitable for local manufacture may have limited appeal for manufacturers in industrialized countries, unless they have the opportunity to recover their research and development investment through increased markets generated by joint-venture arrangements with manufacturers in the developing countries. This approach has already been adopted by a number of western firms, and by Indian manufacturers of the India Mark II handpump.

Fostering research and development capability within developing countries and promoting collaboration and joint-venture arrangements among them is very important, as it means that designs can be based fully on local conditions and simplifies field testing in real life conditions (IDRC, 1987). A useful example is the case of the Sarvodaya SL5 and Unimade handpumps, which are locally produced, based on designs developed at the University of Waterloo, Canada, and the University of Malaya, with support from IDRC.

To be suitable for local manufacture, pumps should generally avoid specifications which demand highly skilled processes or use exotic materials. Wherever possible, manufacturing tolerances should be generous, and the need for tight quality control should be kept to a minimum. For countries with comparatively low levels of industrial development, foundry facilities may be more readily available than steel fabrication, and ideally pump designs should be adaptable to take maximum advantage of indigenous skills and materials.

These principles have been applied by some manufacturers, others have imported skills and quality control methods of their own into developing countries, with mixed success. Interest in local manufacture of handpumps is certainly growing, and research aims include maximizing the scope for local manufacture. Again, the growing use of plastics is beneficial. Plastic pipe extrusion is well established in many developing countries (though quality is variable), and injection moulding offers a low-cost method of manufacture of components which would be impossible to fabricate in metal. This process is for example used in the Unimade pumps Mark II and Mark III, which have all-plastic below-ground components.

The term *local* manufacture has a wide range of possible interpretations. The first step is to introduce manufacture of key components into the developing country. Once that has been accomplished, the potential for satisfactory production and distribution of spare parts is greatly improved. Further spread of manufacturing outlets to regional, district, or even village enterprises will depend on economic considerations, and on the diversity of industrial skills in the country concerned. Certainly there is a need to avoid any exploitation by monopoly suppliers, but there is also a danger in too much diversification, in that quality may suffer and control will be difficult.

As a general rule, manufacture at the village level is only practical for shallow lift and light duty applications, where simple designs can perform satisfactorily and be repaired

Figure 2.10 Simplicity of design and maximum use of indigenous materials means that the Sarvodaya SL5 handpump can be manufactured and assembled in regional and local workshops in Sri Lanka (photo IDRC)

easily with readily available materials. A good example here is the Sarvodaya SL5 handpump (Fig 2.10). This pump was developed by the Sarvodaya Shramadana Movement in Sri Lanka. It is based on the earlier IDRC/Waterloo pump, consisting mainly of injection-moulded plastic internal components. The simplicity and ease of installation and maintenance have made it possible for the pump to be manufactured in Sri Lanka in a network of cottage industries operated entirely by women. To help make these workshops self-sustaining, the women also carry out other income-generating activities such as the manufacture of simple tools and farm implements.

This approach to handpump manufacture and maintenance is presently being replicated in 60 communities in central and southern Sri Lanka through Sarvodaya Economic Enterprises Development Services (SEEDS), a local NGO established by the Sarvodaya Movement. With financial support from the Canadian International Development Agency (CIDA) and IDRC, SEEDS will expand three existing regional workshops and create 60 village workshops to be run by women technicians and administered by local Shramadana Societies.

Regional workshops will be responsible for the training of women technicians in well drilling and handpump manufacturing techniques, and will mass produce the Sarvodaya SL5. The village workshops will be responsible for installation and maintenance of the pumps and storage of spare parts. The proximity of the workshops to handpump sites guarantees a ready supply of spare parts. Funds from the other income-generating activities will help to sustain the community based maintenance programme. It is interesting that in Sri Lanka, the design was amended to replace the standard polyethylene plunger seals with leather seals. Though the leather seals wear more quickly, leather is less expensive than polyethylene in Sri Lanka and the villagers are more familiar with leather crafting.

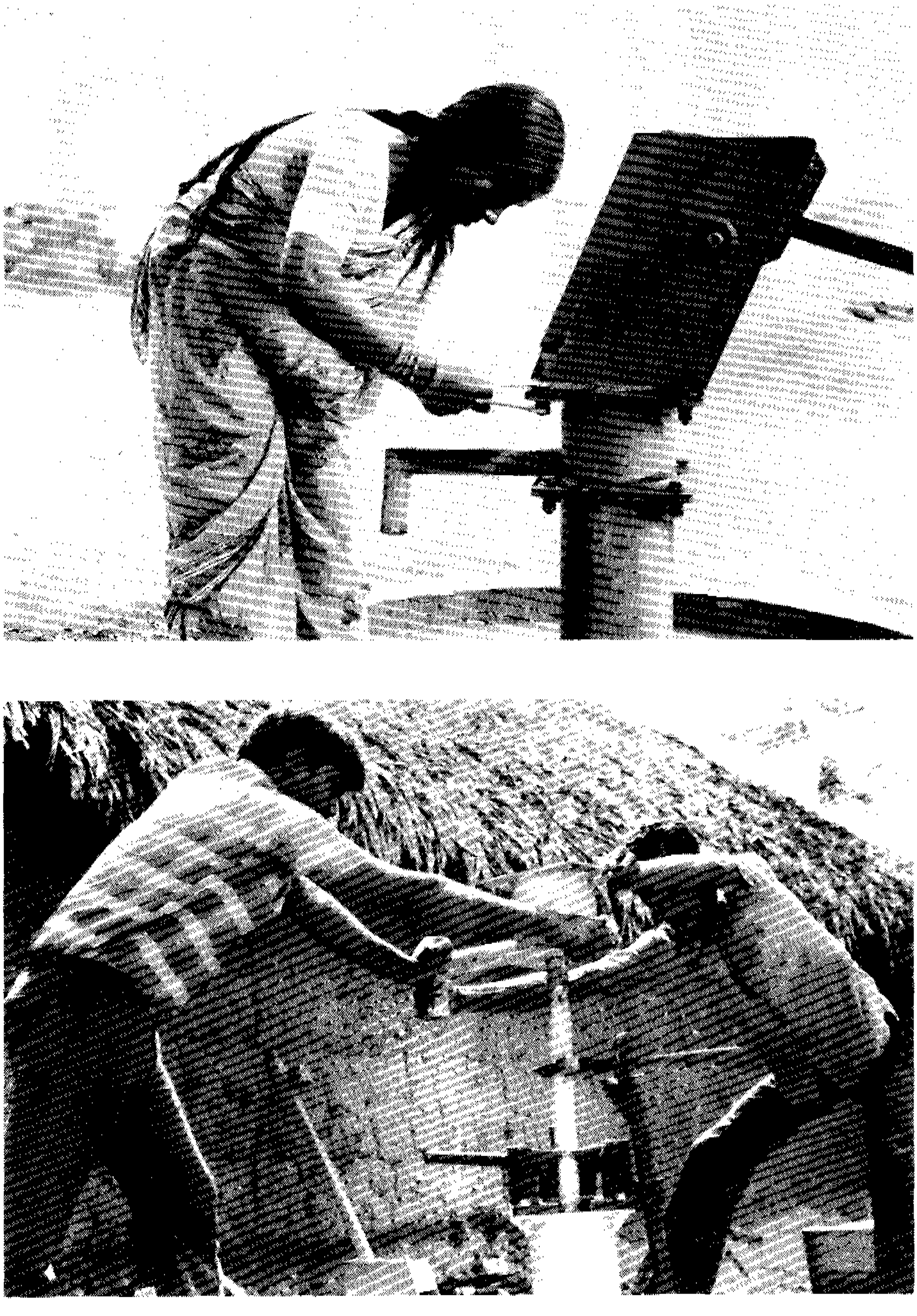


Figure 3.1 In the planning process, consideration of the eventual maintenance needs of planned water supply improvements must be included at all stages

3. *Planning for Sustainability*

Analysis of the shortcomings of existing community water supply systems carries a strong message for planners. Priority must be given to the generation of systems which will be **sustainable** and which will be **used**. Choices of technology and service level have to be based on meeting the reasonable needs and desires of communities. That means providing facilities which are affordable and which can be kept in working order with resources available to the community.

This emphasis on community involvement and maintenance capabilities calls for a different approach to project planning. The aim must be to plan each phase of proposed projects in such a way that the role of the community, including private sector industry, is taken into account, and that the resources needed for reliable functioning of completed facilities are assured.

The new approach contrasts with the common approach adopted now, in which the service level and type of technology have often been determined before the community has an opportunity to express its preferences. The implications of adopting a new approach should not be underestimated. Planners still need early information on costs and other resource requirements of proposed programmes, in order to organize sources of funding, procurement of major capital items, training programmes, etc.

Feasibility studies help to generate this information and to determine whether installation of handpumps is feasible and likely to reduce health risks in the communities. Such studies also provide insight into technical and socio-economic variations in the project area. In some cases, the circumstances and available experience mean that a fairly standardized approach to project implementation can be followed. In others, greater flexibility is needed.

Often, effective and sustainable participatory approaches need to be developed in a pilot or "learning-by-doing" stage of the project. Development of such approaches has to take account of national needs, and project experience fed back to the national level helps to influence decisions on design criteria, priority setting, manpower development and community self-reliance.

This type of approach can lead to a flexible plan which allows for any necessary adaptation to suit varying local circumstances. It must be carefully coordinated with national strategies, to prevent the type of undesirable outcome in which individual handpump programmes supported by different donors introduce widely differing technologies, social frameworks and organizations.

Donors have a key role to play, as they often have the flexibility to experiment with innovative approaches, particularly during pilot phases.

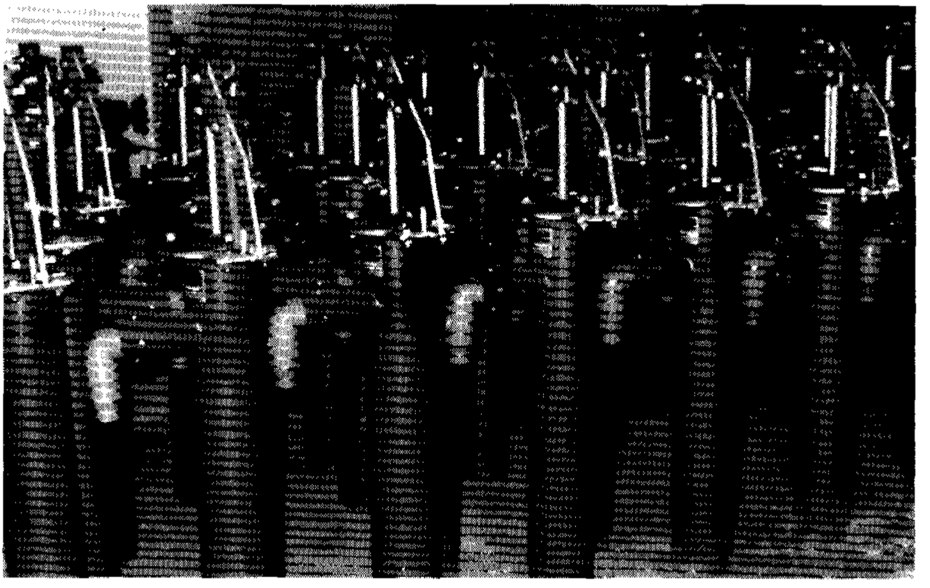


Figure 3.2 Handpumps awaiting installation. Sound planning will ensure that stocks of equipment are available in advance of construction, without committing individual communities to a particular technology (photo IDRC)

3.1 PLANNING AIMS

Advance planning of community water supply projects must provide sufficient information for the implementing agency to ensure that the necessary materials, equipment, human resources, finance, and institutional arrangements are made available on schedule and in a cost-effective way.

Programme objectives

Usually a programme will be planned for a specific time period, with targets set in accordance with available funds, manpower, management and administrative capabilities. It is important that targets should be relatively well-defined, and that they should not be over-ambitious. General objectives like "improvement of the water supply situation in small rural communities with problems of water shortage and/or quality" have little value. The objective is too general for planning qualitative or quantitative goals, and there is no basis for evaluating and adjusting the programme as experience is gained.

More detailed objectives, covering both short- and long-term development might be: "Within five years, provide 80% of all communities with a population of less than 800 with a handpump water supply, wherever such a supply is appropriate and is desired by the community; plan and implement projects so as to ensure that at least 80% of the households will continually use the new safe water supplies for their domestic needs; provide training and support to ensure that pumps are properly maintained, breakdowns are short, and alternatives are available to avoid reversion to contaminated sources; bring parallel hygiene education and sanitation programmes to benefitting villages, to eliminate other disease transmission routes and maximize health benefits; and implement water projects in ways which strengthen the capacities of the community, men and women, for problem solving and local development".

Including objectives linked to functioning, use, and hygiene behaviour, diminishes the emphasis on construction targets. The aim is to have the maximum number of pumps *used*, not the maximum number *installed*. For many, this broadening of the programme objectives will be an innovation, and progress will be dictated by experience. Targets for the early years should not therefore be set too high. Lower targets allow both programmers and communities to learn from experience and provide the opportunity for pilot approaches to be tested where appropriate. Targets and approaches may then be adjusted, without the demotivating effect of apparent failure to meet ambitious goals. Nor should initial targets be unrealistically low, however. Needs are urgent, and monitoring of progress towards achievable goals can inspire greater efforts.

Frequently, projects may have wider objectives, linking the provision of water with broader socio-economic goals. Water is not only used for drinking and hygiene, but also for economic activities in households, such as dry-season vegetable gardening, livestock watering, and raising of trees for fruit, firewood and timber. Projects may well find it beneficial to foster such uses, resources permitting, or to link the programme to another based on productive use of available water. In this way, general welfare in the area is raised, and additional income generated, which in turn helps to finance local maintenance.

Local income-generating projects are not easy to organize and demand careful study of possibilities, markets and required inputs. Evidence is growing though that successful income-generating projects, especially those focused on women, benefit not just the households concerned, but also the water projects. Extra income is commonly spent on the family's first necessities, which usually includes payment of water fees and improvements in family hygiene (Wijk, van, 1985). More research is needed at household level, to provide evidence for future planning.

3.2 FEASIBILITY STUDIES

For community water supply programmes in which handpumps will play a significant part, the pre-planning or feasibility study should provide answers to a number of key questions about the project area and available options (bold print indicates questions directly related to decisions about community participation and maintenance):

- How many individual communities come within the scope of the project, and what are their sizes and growth projections?
- What is the social structure; the role of women in traditional society; the local political setup?
- What is the health profile; are there any diseases such as schistosomiasis, onchocerciasis, or guinea worm, which have a bearing on the design of a water supply?
- What water supplies are presently available and what resources are available for improvements?
- What are existing practices in water collection, water use and hygiene, and maintenance of traditional water sources?
- How do the groundwater level and quality fluctuate over the project area, and between the wet season and the dry season?
- **Are communities interested in having handpump supplies and what are their views on community-based maintenance, maintenance financing, and the composition and role of the organization to be involved in local planning and management?**
- **Is there a history of using handpumps in the region?**
- **Is there a need for water uses additional to drinking, cooking and washing?**
- Are there environmental hygiene and sanitation constraints which may limit the potential health benefits of a handpump programme?
- What are the institutional needs of the programme, in terms of water supply policy, funding, manpower, equipment, materials, transport and communications?
- **What are the training needs to equip the communities for local maintenance, administration and management?**
- How can the programme be coordinated with activities of other government departments or agencies, such as health authorities and agencies responsible for well drilling, community development, agricultural development, housing and other related fields?
- What will be the total requirements of the programme in terms of numbers of handpumps, standposts, etc, plus spare parts and installation equipment?
- **What is the scope for cost recovery of capital and recurrent costs?**
- **What are the requirements for a viable organization to maintain the installed pumps, including establishment of dependable sources of spare parts?**
- **Are there skills in the private sector which could be applied to implementation and maintenance of the proposed schemes?**

Answers to these questions provide planners, designers and legislators with the basic information needed to begin detailed planning and implementation of community water supply programmes on a project-by-project basis. If the outcome of this pre-planning phase is to be useful, it must be presented in a way which enables strategic decisions to be taken, without pre-empting final choices, which can only be made after full community participation. In difficult areas it is prudent first to carry out a limited geohydrological survey ahead of a major feasibility study. This can avoid raising unrealistic expectations in communities, as well as perhaps saving major investment on the main study when resources are inadequate.

As a minimum, the feasibility report should contain: an **inventory** of communities, with population and growth forecasts; an indication of the **technology options** judged most appropriate for each community or area on technical and socio-economic grounds; an outline of viable **maintenance** organizations and parts distribution arrangements; **human resources** demands and training needs; **cost** estimates, cost recovery proposals, and financing details; attitudes to and scope for **community involvement** and **participation of women** in local planning, construction and management, including budget estimates for activators, promoters, etc; **targets** and objectives linked to use of facilities, water quality, and hygiene education support; and arrangements for **monitoring and evaluation.** Again the emphasis is on sustainability, and planners must recognize the way that this influences collection and presentation of data in the feasibility report.

Selection of technology options will, at this stage, be dictated primarily by broad technical and socio-economic variations in the project area. Selected surveys, investigating technical and community factors in a limited number of sample villages, can enable planners to make statistical projections without taking irreversible decisions. A strategic plan might in this way forecast that 70% of villages will be provided with handpump-based supplies, 20% with rope and bucket systems, and 10% with gravity-fed standposts. This is enough information for costing, and for more detailed planning of legislative, managerial and institutional needs. It may also be accurate enough for preliminary inquiries about procurement. It does not however remove the opportunity for individual communities to participate fully in the final decision about their improved supply, and for their wishes to be reflected in the final technology choice. At this stage too, warning signs may be identified and corrective measures initiated in connection with the future upkeep of completed systems. If transport is difficult or skills are scarce, for instance, provision of facilities for distributing spare parts and developing training centres need to get under way in advance of full programme implementation.

Few community water supply planners start from nothing. Existing projects, perhaps even existing Master Plans can provide valuable data on community sizes, existing resources, and on successful and less successful approaches in the past. Note that the most valuable information for future planning comes from monitoring and evaluation of completed and ongoing projects. This is a powerful case for *planning* regular monitoring and evaluation into new projects, which in turn can help to influence national decision making.

Hydrogeological surveys

Inadequate knowledge of groundwater characteristics can lead to the wrong technology selection and ultimately to unsatisfactory performance of completed schemes. Knowing the seasonal variations in the water table, including any drawdown caused by nearby motorized irrigation pumps, allows wells to be drilled deep enough to make water available throughout the year. Without such knowledge, either the wells may dry up, or designers may "play safe" and incur extra expense by drilling too deep and buying more expensive pumps than necessary.

Detailed hydrogeological surveys require specialist skills and can be expensive. It is prudent to make maximum use of available sources of information first. **Existing wells** provide an obvious source of data on both quality and depth of groundwater. Depth should be measured at the end of the dry season, and users can give more information about any problems that have arisen in previous years. Any pumps already in place should be examined for signs of corrosion. Otherwise, tests of pH and electrical conductivity are needed to indicate whether the water is corrosive. Naturally, full use should be made of data in existing **Master Plans** for domestic water supply or irrigation. Over large areas, **geological maps** provide a guide to the likely location of large aquifers, but are not detailed enough to pinpoint the local small aquifers which often provide enough water for community water supplies. **Aerial photographs and satellite imagery**, using specialist techniques to identify surface and subsurface features, can also highlight potentially useful water lenses. Such data may be available from specialist agencies, without the need for specific surveys.

Site-specific surveys covering a programme area need to be carefully planned, to obtain maximum information without inordinate expense. Among the techniques available for mapping groundwater and assessing its quality are **electrical resistivity measurements, seismic refraction measurements, and geophysical well logging.** A direct method, which requires less sophisticated equipment and less analytical expertise, is **test drilling and pumping** using hand-drilling equipment. Given appropriate geological conditions, hand drilling is cheap and effective, giving precise indication of water quality, depth and quantity (using a hand-operated test pump and timing bucket filling while monitoring well water depth). Useful detail of the procedure for carrying out this kind of test, based on experiences in Tanzania, is given in the book *Hand Drilled Wells* (Blankwaardt, 1984).

The aim should be to build up as complete a picture as possible of existing and potential future water sources, with a profile of the main aquifers, denoting likely minimum water levels and quality parameters. This data can then be added to the village inventory (interpolation will be needed in many cases in the pre-planning stage), to assist in technology selection. The survey may indicate a need to control water withdrawals by legislation, so as not to endanger existing or proposed handpump supplies, or to create salinity problems.

Village surveys

While it is rarely economic or practical to carry out detailed surveys in every village at the pre-planning stage, selection of the right sample villages can help to build up an accurate picture of the programme area. Bearing in mind that the planner wants to take strategic decisions on technology selection, maintenance needs, cost recovery, hygiene education, etc, village surveys can be structured to provide valuable data for future community motivation activities as well.

In selecting sample villages (about 5% of a relatively uniform programme area may be expected to yield a statistically valid sample), the objective should be to include the full range of socio-economic groupings, tribal differences, and existing water supplies.

The survey in the sample villages provides additional technical data to support hydrogeological investigations and gives a general overview of existing conditions, problems and options for improvement. It can also, if so designed, provide a baseline for future impact evaluation. Socio-economic surveys are best carried out by specialists, and may take the form of household surveys with pre-tested questions or more qualitative forms of research. Practical guidelines specifically designed for water supply and sanitation projects have been published by the UNDP/World Bank Technology Advisory Group (Simpson-Hébert, 1983). The temptation to collect too much data should be resisted. For rapid assessments a simple checklist is usually sufficient. Recently, more participatory types of social study have been used, and these are discussed in Chapter 4.

Figure 3.3 Surveys in sample villages help to build up a picture of the project area

The socio-economic survey can be very revealing. Intended users may well not see domestic water supply improvements as a top priority. Men and women may express different priorities, as may different income groups. Sometimes communities are wary because of earlier negative experiences with handpumps or other types of water supply. Some may favour piped water supplies for their higher status or convenience. Rarely will there be any appreciation of the implications for the community of the different types of technology, in terms of costs, water quality, reliability, or maintenance commitments.

Communities may also differ in their willingness and capacity to contribute to capital and/or recurrent costs of handpump wells. In Chapter 4, we look at ways in which communities can be assisted in reaching the right joint decisions about the most appropriate technology and service level. The purpose of the initial socio-economic survey is to provide the basis for later community participation activities in each village, and to enable planners to estimate the likely mixture of attitudes over the programme area as a whole. To avoid raising undue expectations, communities may need to be warned that actual implementation can take a long time, and that they will be asked to participate in further decision making and construction activities as the programme is formulated.

Existing patterns of water use and hygiene habits will influence the community's perceived needs and preferences for water supply improvements. Surveys and rapid assessments should therefore include discussions and observations to help determine the ways in which water is collected and used, and the type of improvements in convenience, quality and quantity which might be most appropriate. It will be important, for example, to identify the criteria women apply in selecting traditional sources for different purposes, as this will affect their acceptance of new facilities, and form a starting point for health discussions.

A study in selected Fula and Balanta villages in south Guinea Bissau showed great differences in source selection criteria and water use patterns. The Balanta women had no shortage of water and used the nearest water source for all purposes, including cattle watering.

Water use and drainage conditions were observed to be unhygienic. The Fula women used different water sources for drinking, clothes washing, and bathing. In the one case, they would walk a greater distance to collect drinking water from a source they considered to be cleaner. In the other case, greatest effort was made for clothes washing, using the running waters of a river-fed pond.

Most Fula women also filtered drinking water through a cloth and had regulations on water use and drainage arrangements.

Coordination with other agencies

To achieve the desired community involvement in local maintenance and financing, and to accomplish the beneficial complementary improvements in hygiene and sanitation, water agencies need to collaborate closely with other departments of government. The water agency often does not have the mandate or skills needed for community participation, involvement of women, local management training and hygiene education. These skills may well be found in other departments or services. Though the need for cooperation is increasingly recognized, establishing it means overcoming numerous constraints. Other departments have their own programmes and must establish priorities and assign staff if they are to carry out social activities in technical programmes. There will not usually be a separate budget, work plan or targets for the social and health activities. Water agencies cannot expect to be able to delegate all "social and health" activities to other departments, but must themselves work together with those departments and with the community.

Similarly, much of the data needed for community water supply planning is also useful for developments in other sectors. Collaboration with ministries and agencies responsible for community development, health, agriculture, and other activities is therefore mutually beneficial. Rural water supply agencies can obtain much demographic, socio-economic, health and technical data from these other agencies, and, by jointly collecting missing information, can encourage long-term coordination and avoid unnecessary duplication of effort.

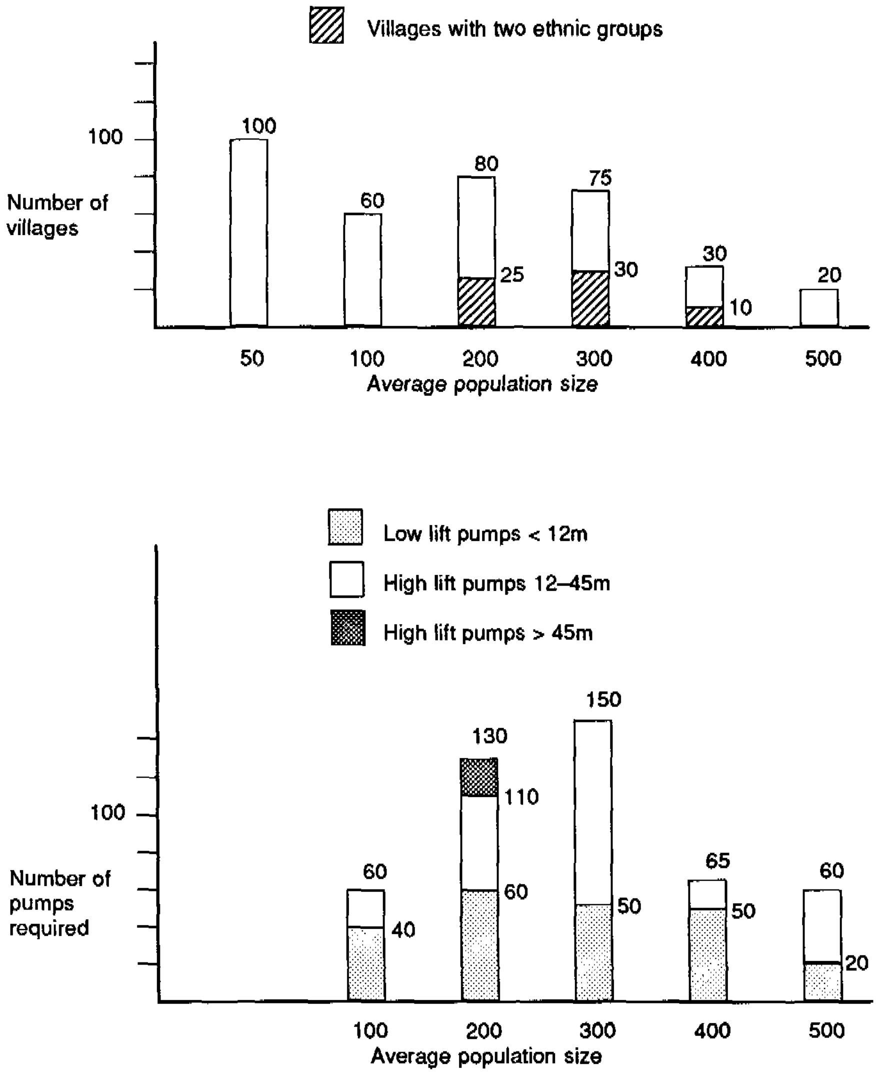
Collaboration is often lacking simply because there are no funds for outside agencies to seek data needed for water programmes. Proper planning can eliminate this difficulty by assigning project funds for data collection from and by collaborating agencies.

Data presentation

As well as providing a basis for strategic decisions on programme implementation, the pre-planning report may well be an important element in requests for funding support. Its argumentation must therefore be logical and concise, recognizing the need for judgements to be flexible at the village level, but sufficiently detailed over the whole programme to permit reliable estimation of costs and other resource implications. Simplified graphical presentations are an effective way of illustrating demographic data (Figure 3.4). Easier to assimilate than the tables on which they are based, such graphs can also provide visual support for forecasts on numbers of handpumps required, training needs, and project scheduling. Qualitative and behavioural aspects of community life, such as types of water use and latrine use can also be understood more readily from simple graphs than from tables.

3.3 PROGRAMME PRIORITIES

One important purpose of the pre-planning exercise is to establish programme targets on a year-by-year basis. That involves not only dividing up the total amount of work into achievable activities, but also establishing and adhering to project criteria and procedures for selecting villages to receive improved supplies, to avoid later suggestions of bias, political influence or manipulation.



Notes:

1. Villages with two ethnic groups of significant size will get two pumps
2. Maximum number of users per low lift pump = 250; per high lift pump = 150
3. Villages with a population average of 50 people will be assigned protected open wells

Figure 3.4 Graphical presentation of survey data can make it easier to understand

In many countries, national guidelines exist to establish which communities are entitled to government-supported water projects. With the help of such guidelines, target villages can be identified in the project area. National guidelines commonly involve some measure of water shortage or serious quality problems, and may also include division by socio-economic groupings, with the poor getting priority for financial subsidies or soft loans. Priority may also be given to crowded areas, or areas with high incidences of diseases which are readily reduced by improved supplies (such as guinea worm).

Having identified the communities or areas to be served, project priorities have to be set and again criteria are needed. These project criteria may include issues like motivation, willingness to contribute, scarcity, or high disease incidence. It is possible, from the feasibility study data, to establish these criteria and to get an impression of which areas or types of community should be served first. The criteria selected will have a significant influence on the implementation programme. For example, if the project only intervenes on request, implementation may be somewhat scattered..

In other cases, it may be possible to classify communities into a number of categories with high and low priority based on the clearly defined criteria. Sometimes, for logistic reasons, implementation may have to proceed on an area basis, starting with areas containing the biggest proportion of high priority villages, but also serving lower priority villages in the same area. Alternatively, the programme will cover all villages ranked as top priority, before moving to those rated priority 2, and so on.

Target communities must be made aware of the criteria by which they may achieve a priority rating. There is a danger that poor villages with low influence may be excluded from priority classifications which depend on village applications, particularly if a user contribution is required. Special care is needed to see that programme information reaches all villages, and that real needs criteria are applied fairly. This last point is especially important, as commitment to upkeep of the completed project will be highest in those communities with the greatest perceived needs.

3.4 SERVICE LEVEL AND TECHNOLOGY CHOICE

The pre-planning report will be the most important tool for initiating programme activities, including procurement, training and community motivation. It follows that planning "decisions" will have to be taken on the types of technology which will be appropriate over the programme area as a whole, before more than a few communities have been able to express their views. Statistically, it may be valid to extrapolate from the sample and produce inventories and schedules accurate enough for this more detailed planning phase. But, the basis of decisions on the appropriate level of service for particular physical and socio-economic conditions needs to be clearly understood.

One general rule, around which more project-specific guidelines can be developed, is: "The technology chosen should give the community the highest service level that it is willing to pay for, will benefit from, and has the institutional capacity to sustain." (World Bank, 1987).

Communities, in other words, should be allowed to vary more in their choice of technology and service level than is usual at present. A more developed community, able to meet all the extra costs of construction and maintenance, would be encouraged to opt for a piped system with a mixture of private connections and standposts, rather than settling for mandatory handpumps, provided only that the scheme was technically feasible, affordable and sustainable.

The wishes of the community remain paramount, but the implementing agency has a critical role in establishing that the desire for as high a service level as possible is matched by the necessary resource commitments. This task should not be underestimated. It must end with the community convinced that the supply improvement adopted is both valuable and sustainable. If, after hearing all the arguments, and recognizing the responsibilities, risks and benefits, the community opts for a practical solution different from that favoured by the promoters, then the community's will should prevail, as long as adequate measures are taken to protect public health. In Guinea-Bissau, for example, approximately half of the wells provided on a rural water supply project were in the end equipped with rope and bucket systems, after communities considered the maintenance needs of handpumps to be a threat to the reliability of the new supplies.

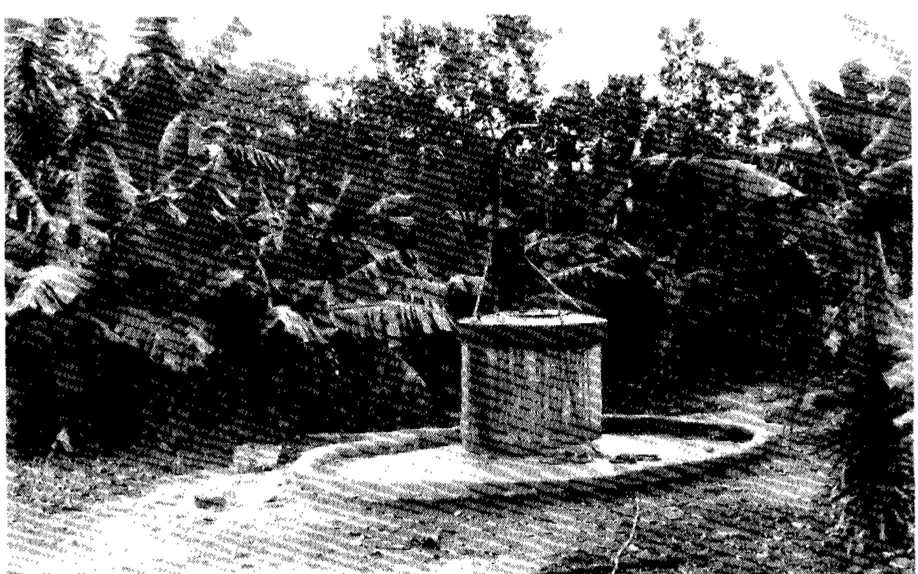


Figure 3.5 About half of the wells in a Guinea-Bissau programme were equipped with rope and bucket systems, because the villagers thought handpump maintenance might be too unreliable (IRC, 1982)

Reviewing the options

Before community representatives can express preferences for one technology or another, they must be given a complete picture of costs, benefits, maintenance commitments, and hygiene behaviour implications. Technicians from the implementing agency need to spell out how the options (e.g. rope and bucket, handpump, standpost) offer different service levels, what that means in terms of convenience, water quality, health implications, etc, and any changes made possible by the provision of extra water (small-plot irrigation, raising of small animals, and so on). The options are not always easy to envisage, and some projects have used case histories, demonstration models, visits to pilot communities, and other similar information techniques, to facilitate informed discussions (Jackson, 1979). Villagers may then use their own judgement to decide whether the extra cost and human resources commitments justify opting for a higher service level. Some projects arrange for community members to visit other villages where facilities have already been installed, so that they can correctly understand the implications.

Though the higher service levels may have superficial attractions, with appropriate guidance it is likely that more than half of the population in need of improved supplies, will see handpumps as the appropriate choice (World Bank, 1987).

A wells project supported by the European Development Fund in Burkina Faso offers a choice between a protected dug well and a borehole with a handpump. The dug well demands more village labour (700 man-days for an average type, or about 60% of total construction costs). It has greater risk of contamination, but is cheaper to maintain, has a high recharge and storage capacity, can be fitted with a pulley or handpump, and does not become unuseable when its pump breaks down. The borehole demands much less labour and material for construction of the apron, drainage and cattle trough. But, the community has to bear its higher maintenance costs and must establish and administer a water fund to pay for spare parts, the fees of the local mechanic who repairs the pumps, and the installation of a new pump after an estimated ten years. The decision on the type of system is usually made after two village meetings. So far, 24% of the villages have opted for a dug well and 76% for a borehole with a handpump.

Handpump evaluation

The hydrogeological surveys will allow the programme area to be divided according to the range of depths to the water table. Pumping lift is one of the crucial technical parameters which subdivides different types of handpump (see Chapter 2). Other important variables affecting selection of the right pump include: user group size; per capita consumption; maintenance needs; the potential for standardization; cost; and, sometimes, groundwater corrosivity. The weight attached to each variable depends very much on local conditions, and each programme will develop its own criteria.

Table 3.1 shows how extrapolated data from the hydrogeological survey can be presented in a way which simplifies evaluation of handpump models under consideration.

Table 3.1 Example of pump requirements for a handpump programme

Pumping head (m)	*Number of people served per pump*			*Number of pumps*
	100	*200*	*250*	
5	65	190	26	282
12	78	90	30	198
30	39	23	9	71
45	—	12	10	22
60	—	5	2	7
Total	182	320	77	580

This programme calls for 282 pumps with a maximum lift of 5m, 198 pumps for which the lift may be as high as 12m, and a total of 100 pumps for which the maximum lift ranges from 30m to 60m. There is a very wide choice of available pumps for low-lift applications. At higher lifts, the choice is more restricted, but there may be as many as 30 pump models available capable of meeting the lift requirements.

The most critical factor in reducing the list to manageable proportions will be the choice of an appropriate maintenance system for the pumps. The availability of local skills and equipment will determine how practical it is to envisage full village-level maintenance. The next best choice will be employment of area mechanics to service pumps for a number of communities. Only if it appears impractical to institute community-managed maintenance should the final option of centralized maintenance be considered. For example, if only a few pumps are being installed in one region, area mechanics may have too little work to maintain their skills, or their interest.

In *Community Water Supply: The Handpump Option*, each of the field- or laboratory-tested pumps is rated "good", "adequate" or "unsuitable" for the three categories of maintenance. The ratings vary with the pumping lift, but enable a direct comparison to be made among all the pumps which meet pumping lift requirements. While the pump ratings in the UNDP/World Bank publication are based on performance in field or laboratory trials, it is comparatively easy to make preliminary judgements on the maintainability of pumps not included in the rating tables, on the basis of the pump design and the materials used in its construction. The importance of standardization should not be forgotten, and other local considerations may also affect final selection. Above all, the type of pump to be used must be discussed with and accepted by the community, before a final decision is taken.

For high lift applications, for instance, no pump which must have steel rising main and pumprods removed to replace plunger seals can generally be considered for village-level maintenance below about 15m, or for area mechanic maintenance either once the depth reaches beyond about 25-30m (there are specific exceptions to this rule, such as the Sudan, where an area mechanic equipped with a derrick which can be carried on a motor cycle is able to service high lift pumps).

In planning for sustainability, planners will wish to select pumps and initiate maintenance structures which leave as much as possible of the upkeep of handpumps under community control. Pump selection will therefore be rightly biased towards pumps best suited for village maintenance, provided that such maintenance is within the capacity of village resources, supported through training and spare parts distribution by the sponsoring agency.

Returning then to the example in Table 3.1, the 15 separate applications listed (5 depths x 3 user group sizes) can be merged, to permit standardization on just a few pump models. For the 5m lift sites, it would be possible to consider suction pumps, and in many countries familiarity with such pumps makes them well-suited for village maintenance. Even for the intensive use by 250 users, in which frequent servicing will be needed to keep the pump functioning, there are situations where villagers would prefer to accept this responsibility rather than opt for an unknown pump. If there is no such tradition of suction pumping, the merits of direct action handpumps can be introduced. In this example, direct action pumps could prove suitable for both the 5m and the 12m pumping lifts, though the intensive use of 250 users would certainly mean frequent maintenance needs.

Pumps for 30m, 45m and 60m depths will be high lift designs, and the number suitable for even area-mechanic maintenance reduces with increasing depth. Standardization remains desirable, and some pumps would be suitable for the full depth range, using different cylinder sizes at different depths, or, in the case of more modern pump designs, using a standard cylinder diameter and varying the stroke by changing the mechanical advantage of the handle. Inevitably, however a pump supplying 250 users from a depth of 60m is going to be very heavily worked and suffer repeated breakdowns (with an optimistic discharge rate of 4 litres/min, the pump would have to be working continuously for more than 10 hours a day even to provide the basic minimum of 10 litres per head per day). Unless the 60m pump was also best on merit for the 30m applications, it would be unwise to standardize on it for all the high lift applications, when a lighter, more easily maintained pump could be provided for the majority of the programmed wells.

Scrutiny of pump types according to their suitability for the anticipated operating conditions should also take into account discharge rate, pump reliability, corrosion and abrasion resistance, and the potential for local manufacturing of wearing parts. With this type of analysis, the list of potentially suitable pumps can be reduced to perhaps five or six for the high lift applications and a somewhat longer list for the low lift pumps. More detailed information on development of a shortlist of acceptable pumps can be found in

Figure 3.6 Too many users per pump can mean long waiting times and users may revert to unsatisfactory alternative sources

the Pump Selection Guide in *Community Water Supply: The Handpump Option* (World Bank, 1987). The final choice will then depend on cost comparisons (with the ultimate test that the pump emerging from the analysis must be acceptable to the community).

Cost comparisons

For a proper cost comparison, all costs must be taken into account. It is not correct to compare only the *capital* costs of different pumps, as these may well account for no more than 25-30% of the total "lifetime" costs. *Recurrent* costs involve maintenance, repair, spare parts, and, eventually, replacement (represented in costing terms by depreciation). They are incurred at varying intervals over the life of the pumps, and have to be converted to comparable values. Two basic costing techniques are being used to compare different systems.

One method, based on the concept of the time-related value of money, is to calculate the *present value* of each cost item. So, the value of a particular cost is lower when it is incurred in the future (a cost of $100 incurred in one year's time would have a present value of about $93 at a discount rate of 8%, as that is the amount which if deposited now would become $100 in one year's time at 8% interest). The formula for calculating the present value is provided in Appendix IV.

Present values of lifetime costs calculated in this way for different pumps can be compared to indicate which would be the most cost-effective purchase (the lowest present value). The comparison is valid provided the expected lifetimes of the pumps are the same, or can be brought to the same basis.

Using a similar principle, cost comparisons can also be made using the *equivalent annual costs* method. This method has the advantage that it can be used for comparing pumps with different expected lifetimes. The initial capital cost of each pump is converted to an equivalent annual amount by multiplying it by the so-called capital recovery factor. The capital cost is thus distributed as equivalent annual costs over the expected service life of the pump. Adding the average annual recurrent costs provides a means of comparing pumps on the basis of the total equivalent annual cost.

Individual judgement may also be needed to cover circumstances in a particular community. In some communities, for example, it may be better to install a relatively expensive pump with lower maintenance costs, because one-off cash generation through local festivities or similar fund-raising activities is comparatively easy. Another community may find it easier to raise regular amounts for maintenance but have difficulty with a high initial payment, in which case a lower cost pump would be preferred, accepting the need for extra running costs.

Service life expectancy

Theoretically, a handpump could be kept in operation for a very long time, if worn out or broken parts were simply replaced as needed. The pump's lifetime might then be defined as the time until every part has been replaced at least once. Scheduled servicing, in which wearing parts are replaced at regular intervals, before their deterioration affects other components, could lead to an almost indefinite life, though such servicing is regrettably extremely rare in community water supply.

Many manufacturers claim that their pumps will last for 15 to 20 years under "normal" operating conditions. In practice, such a long service life is rare, especially when maintenance and repair are poor. For existing handpump designs, actual field performance data provide the best basis for estimating service life expectancy. Ten years is a reasonable general estimate, but periods from 5 to 8 years may be appropriate for some pumps, and the life expectancy estimate should always reflect local conditions of climate, water quality and maintenance capabilities. Service life can be enhanced by a programme of reconditioning. For example, damaged bearing housings in a handle need not result in disposal of the handle. Often it can be overhauled in a workshop at relatively low cost. This also goes for other major components such as pumpheads and cylinders.

Discharge capacity

Direct cost comparison of handpumps is only realistic if it is presumed that each pump provides essentially the same service level or economic benefit. Discharge rates vary, and some pumps will have to be operated for longer to produce the required daily output of water, but, provided the technical pre-selection has been carried out properly, it is generally a reasonable assumption that pumps which can supply the daily requirements of the users will provide approximately equivalent benefits. In some circumstances, the benefit of extra water made available by pumps with a higher discharge capacity may come into the calculation. Analysts may then have to value these benefits in such a way that a net benefit can be computed for each pump under consideration.

Real costs versus financial costs

The discussion so far has been based on *financial* cost comparisons. The real cost of using funds for any particular investment is the value of the best alternative use of the same funds. Clearly, resources used for installing handpumps are then unavailable for other purposes. This means that market prices have to be adjusted to reflect the real scarcity, and thus the real costs, of resources in the national economy.

In developing countries, the real costs of unskilled labour and of foreign exchange frequently differ significantly from the financial cost. Use of unemployed unskilled labourers generally involves little or no loss of production elsewhere in the economy and the real cost may therefore be very low. In contrast, official exchange rates in developing countries often are maintained at an unrealistically high level, meaning that currencies are overvalued. The real cost of using capital resources will then be higher than the apparent financial cost.

True cost comparisons must be based on cost data specific to the country. If the financial cost does not reflect the real cost of resources, corrections need to be made by adjusting prices (shadow prices). Adjusted, or shadow, prices may be defined as those prices which would prevail if the real opportunity costs of resources were allowed to express themselves in market prices. Data to calculate shadow prices accurately are rarely available in developing countries, but approximate adjustment can and should be made.

For example, in countries with chronic unemployment, the real cost of unskilled labour could be valued at between 25% and 50% of prevailing wage levels. Similarly, the real opportunity cost of capital may be 15% or more in some countries, despite regulated maximum interest rates of, say, 6%. Financial costs also need correcting for cost elements which are merely a transfer payment within the economy, like import duties, taxes, and subsidies, if cost comparison is to give valid results.

Cost data for maintenance and repair

Only limited data are available on maintenance costs and on the frequency of maintenance and repair interventions needed on different kinds of handpumps. The Handpump Compendium of *Community Water Supply: The Handpump Option* (World Bank, 1987) contains details of repairs needed on all the pumps which have been subjected to trials under field conditions in the UNDP/World Bank programme. From these data, it is possible to forecast the maintenance needs of the tested handpumps on a rational basis, and to estimate labour and material costs of, for example, replacing a leather cupseal twice a year, handle bearings once every two years, and so on. This is normally the most significant element of handpump costings, and it is important that the capabilities of local mechanics and the need for external assistance where appropriate are taken into account when different pumps are being compared. Estimates should also include training, monitoring and other support activities needed for reliable upkeep of the system.

3.5 MONITORING AND EVALUATION

Among the most important sets of information available to planners of community water supply programmes are records from earlier projects. Experience with different technical and sociological approaches provides crucial lessons for the future. In many ways, failures are as important as successes, as avoiding repetition of past mistakes means that new investment has a greater chance of being profitably used.

Monitoring and evaluation can be a very useful management tool, but it should not become a goal in itself. Collection of excessive amounts of data can be both time-consuming and wasteful. The point is that the information should be collected for a purpose. Projects posing ten key questions and analysing the answers achieve better results than others posing 150 questions and then being overwhelmed by the volume of data. The key questions do not only relate to technical performance. If project staff are convinced of the relevance of the data, they can collect valuable information on the operation of organizational and support systems as well.

Techniques for gleaning information in the most effective ways come from experience. Schoolchildren, for example, can be encouraged through simple games to provide data on water sources used by their households. On the other hand, assessing the quantity of water used by asking questions about the size and number of containers gives unreliable results. A better indication may come by fitting a pump stroke counter to a number of wells for which the number of users is known. However, the only accurate way is the time-consuming process of sitting and recording volumes collected by each household from a source over a period of two or more days.

Other relevant information relates to the performance of the water committee and particularly the pump caretaker. Inspection of the log book should be accompanied wherever possible by encouragement of the caretaker for any kind of record-keeping achievement. It is easy for project staff to be over-critical and demotivate caretakers through incautious remarks.

Useful planning information also comes from assessment of extra benefits coming from the provision of improved water supplies. Visible improvements such as vegetable gardens should be recorded in project evaluations, and attempts made to detect recent improvements in hygiene behaviour and sanitation practices.

In setting up a national monitoring protocol, agencies may find it useful to consider developing a standard checklist of questions to be answered through project visits or special studies, such as:

- Type, characteristics and number of wells constructed;
- Percentage of population served through new wells;
- Functioning of wells/pumps: well conditions, well surrounds (cleanliness and hygiene), pump performance, water level changes, water quality (varying from proximity of latrines and other health risks to actual chemical analyses), user satisfaction with operation, quality and quantity;
- Percentage of population actually using working wells/pumps, at least for all drinking water and throughout the year;
- Functioning of the maintenance system: frequency of inspections, frequency and duration of breakdowns, availability of spare parts;
- Functioning of the management system: regularity of water committee meetings, involvement of women, adequacy and equity of fund collection for maintenance, accountability;
- Progressive development: related improvements, sanitation and hygiene conditions, productive use of water or extra time saved, other village development projects;
- Functioning of the back-up system: training, periodic supervision/monitoring visits, distribution of spare parts.

Programme staff should be able to provide answers to most of these questions through scheduled monitoring/evaluation visits. More detailed study of water utilization and hygiene practices will usually have to be the subject of special studies in selected communities.

Systematic monitoring

Recording of data which may help with operation and maintenance of the project in hand and with planning of future projects needs to start during construction. Well depth, geological data, standing water level, cylinder setting, and details of the screen and gravel pack installed will be recorded by the installation crew, and should be retained in a standard form in the water agency office. In their periodic visits to well sites after construction, either to assist with maintenance or to monitor the community's progress in looking after pumps and wells, agency staff should record not only the general condition of the well and its surroundings, but also any changes in the standing water level. This information is important for two reasons: it enables the pump performance to be judged; and it may indicate the need for corrective action if the water table is falling year by year. The discharge of each pump should be tested and recorded, as an indicator of any imminent need for repair.

Pump caretakers clearly have the most important role in monitoring the performance and adequacy of their pumps. Chapter 7 contains a list of activities to be carried out by pump caretakers and stresses the need for operations to be recorded in a log book. The *value of this information cannot be overemphasized. Planning for maintenance depends* on assessment of the frequency of repair and replacement interventions needed for each pump, and this assessment will be more accurate, the more information there is available. Good records provide a comprehensive picture of pump maintenance needs, the degree of skill needed for each type of repair or servicing activity, and the costs.

Keeping records is not enough in itself. They must also be scrutinized periodically by someone able to judge their significance and assess whether corrective action is necessary. Annual reporting provides a useful trigger for analysis of data and preparation of summary charts for review by agency management.

Project/programme evaluation

The new emphasis on community management of completed water projects adds to the importance of regular evaluation. Evaluation goes beyond monitoring of individual projects — though good monitoring records provide important tools for any evaluation — into an assessment of the type of technology used, the community approaches employed, the type of maintenance system, the coverage achieved (water use, number of households), and the impact.

For national planners, properly conducted evaluations contain invaluable information on the merits and shortcomings of past projects or programmes. They can also have a dramatic impact on the project under study, by identifying, often simple, remedial actions which will improve the functioning or use of existing facilities. By involving agency staff and community members in the data collection and analysis, benefits come quickly and experience spreads rapidly through the programme.

Full discussion of procedures for carrying out evaluations of community water supply programmes is beyond the scope of this publication, but detailed guidelines of a *Minimum Evaluation Procedure (MEP) for Water Supply and Sanitation Projects* is available from the World Health Organization (WHO, 1983), and IRC together with UNICEF has developed a set of modules for use in workshops on evaluation (IRC, 1987).

The MEP of WHO provides a quick procedure using key indicators for evaluating the extent to which water supply and sanitation facilities are functioning and being used. It also briefly outlines the evaluation process and ways of collecting household information. The set of 15 modules on *Evaluating water supply and sanitation projects* serves as a basis and guide for practical evaluations, directed towards project management and programme improvement. Each module covers one step of the evaluation process, from programme initiation to the use of evaluation outcomes. The modules are complemented with a moderators guide for the organization of evaluation courses.

Figure 4.1 This Tanzanian pump was too far from the homes of the intended users and rapidly fell into disrepair. Users must be involved in decisions on pump siting, and on all other aspects of technology choice and service level

4. *Decision Making with the Community*

In 1981, a large handpump project constructed three wells in the small Tanzanian village of Mhenda and equipped them with sturdy handpumps. Two of the wells are rarely used; one because it is too far, the other because the people dislike the colour of the water. As a result, only 22% of the Mhenda households surveyed in 1983 used handpump water for drinking and other domestic uses throughout the year. Observations over a wider area showed that of 259 water points, 49% were out of order at the time of the survey and that over 60% of the water collected from safe water sources was stored and handled in a way that might still cause its contamination (Tanzania, 1984).

The case for involving community members in the provision of their own water supply systems has been made many times over many years, and few contest the principle. The fact that inadequate community involvement can still be identified as a prime cause of broken down or badly functioning systems shows that recognition of the need is not enough. The extent to which community involvement is accompanied by community rights and responsibilities, the degree to which planning and design take account of community needs, preferences and capabilities, and the commitment of government agencies to provide continuing advice and support, all contribute to the success or failure of completed systems.

If community involvement is to be effective it must start early, and certainly before any irrevocable decision has been taken to provide a handpump (or standpost, or rope and bucket). Decision making with the community demands an approach to villagers different from those commonly used in the past. No longer does the government provide and maintain a pre-determined service as a gift in return for voluntary labour. In a participatory project, the handpumps belong to the community, not to the government or donor. The project must treat villagers as partners, not simply beneficiaries. It follows that if, after a thorough discussion of the options and their implications, the community's representatives make a choice different from the project's preconceived "best buy", then, provided the choice is practical and affordable, and does not conflict with accepted health practices or environmental policies, the community's wishes should prevail.

In their role as partners, villagers must have strong initiative and commitment. They must want improved water supplies, and ideally they should demonstrate their commitment by applying to participate in the project. However, they cannot be expected to make sound decisions or long-term commitments unless they are well informed.

In the past, government staff, project engineers and health workers have relied mainly on the presumption of health benefits to obtain community acceptance and support of handpump programmes. But health considerations are rarely uppermost in the minds of villagers and the intangible notion of health benefits is not sufficient motivation for community involvement.

The discussion which follows is centred on handpumps, where the inherent simplicity of the technology offers great scope for community members to play a key role in the final phase — the maintenance and management of the new system. However, many of the issues raised relate also to other forms of community water supply, and indeed it is apparent that proper planning should not be based on a predetermined technology, service level or financing system.

4.1 THE PRE-PLANNING PHASE

The first opportunity for community members to take an active part in the community water supply programme occurs during the feasibility, or pre-planning phase. As Chapter 3 makes clear, surveys in sample villages provide the raw data for many strategic decisions about the content of the programme. It is crucial therefore that this phase should seek to involve all sections of the community, and that it should answer a number of questions which will help in the planning of community motivation and participation activities in later phases, when all communities will be involved.

Potential for community participation

In judging to what extent communities are able to participate in the different project phases, planners need to assess the organizational structures, both within the communities and at government level. A paper to the Development Assistance Committee (DAC) of the Organization for Economic Cooperation and Development (OECD) in November 1986, listed nine critical questions to be addressed before a plan for maximizing community involvement can be formulated (IRC, 1986). They are:

- Is there a legal framework which permits community participation?
- What has been the background of community participation in the country and particularly in the region of the project?
- What is the likely level of "social readiness" for the changes envisaged and for the desired level of community support?
- What governmental and non-governmental organizations are concerned with water supply and sanitation, community participation and the involvement of women?
- Who can assist in preliminary designs of community participation?
- What is the variation of the country or region in terms of cultural traditions, language, felt need for improved water supply and sanitation?
- Will technology influence levels of acceptance and community participation?
- What is the political climate which supports or constrains community participation?
- How can existing social or developmental structures be best used for the project?

Answers to these questions help to establish the scope of community involvement, and it is vital that they should be analysed thoroughly. Technical planning of water supply programmes is almost invariably entrusted to professional specialists. The same approach is needed when planning community involvement. There is a growing volume of literature dealing with water use studies and other community issues. Also more social scientists are available who have the right training and experience to develop and test community participation procedures (including special measures to involve women), formulate training programmes for field workers, and anticipate possible future problems. Their participation, as part of the planning team, can have an important impact in this pre-planning phase.

It is important too that answers should not be based purely on the existing situation in the country or region, but on the potential future situation, with any necessary changes designed to stimulate better community participation in rural programmes. It may often be desirable to promote new community organizations and make institutional changes, where existing organizations are not suitable.

Anticipating the key role of women

There is now so much evidence that active involvement of women in community water supply programmes contributes to improved performance and enhanced benefits that special measures for ensuring their full participation should be high on the list of programme priorities. As principal water collectors, users and household managers, women effectively determine whether a new water supply will be used or not. They can greatly support installation, maintenance and use of handpumps, provided that they are informed about and involved in the project.

Often, village women will also select from their numbers excellent candidates for training in tasks associated with the management and maintenance of improved water supplies. They do after all have a strong interest in seeing that pumps continue to function, as they are the first victims when breakdowns occur.

To achieve women's participation, government leaders, administrators, planners and community leaders need to understand and accept the importance of the role of women and the contribution they can make, including the important task of initiating improvements in household hygiene (IDRC, 1987).

Despite widespread acceptance of this principle, women's involvement in decision-making on large-scale programmes remains very limited. From the start, special attention should be given to the potential role of women in each project phase. Special measures have been developed to increase awareness of women's potential. These include training male project staff, employing female project staff or collaborating with female workers in health and community development, mobilizing the support of local leaders, and encouraging the women themselves to speak out and become active.

Once women's roles have been identified, they need to be reflected in the objectives, budget, manpower and training sections of the programme plan.

A health programme carried out in Thailand in the 1960s and 70s installed 5,000 wells in the north eastern and southern parts of the country. As health education lagged behind, no change in health practices occurred. Nor were the locally produced handpumps bought by other villages, or maintained in the villages where they had been installed. This lack of interest was ascribed to the desire of the people in these areas for a more private type of water supply, with more convenience than a handpump well. Programmes for household rainwater storage tanks and piped systems with house connections later proved more successful in the area concerned.

bility, and the needs, expectations, payment capacities and maintenance capabilities of the users. The Guinea Bissau programme already referred to offered communities the option of upgrading traditional sources, building protected wells with rope and bucket systems, or handpumps. In other countries, such as Burkina Faso and the Philippines, villagers choose from handpumps or piped systems with different levels of service.

The required social skills may not always be easy to find, and the approach necessarily takes considerably more time. Where the choice seems to be between serving more people quickly from a limited choice or fewer people more slowly with fuller community involvement, many agencies may be expected to take the first course.

It is sometimes argued that pleas for greater community involvement are unrealistic, as the ideal form of participation is too time-consuming and too costly. While proper participation does mean extra time and effort in the pre-planning stage, good planning can minimize the effect on the starting date. Many activities can overlap with implementation, and participatory planning means less problems and delays in subsequent phases. Separate costing of community participation activities is rare, so that it is hard to find comparative data. Available figures range from 2% to 17% of total project costs to cover the community participation component (IRC, 1986). Benefits are equally difficult to quantify, though not difficult to see.

Organization of community involvement

General meetings provide the opportunity for all community members to learn about programme proposals and to discuss the implications of improvement options. Special activities are often needed to reach those who may be inhibited from participating in such a forum. Measures which have been used successfully include:

- Discussing with local leaders, the importance of the participation of both men and women at the meeting
- Holding meetings at a time and place convenient for all sections of the community
- Using as many communication channels as possible to announce the meeting and promote attendance
- Encouraging questions and comments from all groups of the audience

- Holding separate women's meetings or small informal neighbourhood meetings in situations where it is difficult for women or poor people to express their views in a general gathering.

It is critically important that questions and observations from villagers are treated seriously and used to generate discussions. Otherwise, the general meeting will merely endorse a preconceived project, but without the crucial feedback and commitment of the villagers.

More detailed local planning of design, construction, maintenance, financing, and complementary hygiene improvements is best managed through a special community organization. This may be an existing local council, health committee or development committee, or a specially formed or elected water committee. There are advantages in having a special water committee, in that its members can be chosen for their expertise and concern with water and hygiene. The committee can focus exclusively on water-related issues such as design, maintenance, financing and hygiene improvement, and on water-related developments like a communal laundry or bathing facility, or a vegetable garden near the pump.

Many projects ask the users to choose a water committee in a public meeting, or through area representation in cases where communities consist of several small hamlets. Presence of local leaders can pose a special problem. When leaders are respected, their presence on or support for water committees is a great advantage. In other cases, domination or conflict can greatly hamper the functioning of the water committee. Sometimes, the problem can be overcome by attaching the local leaders as honorary members or advisers.

For the water organization to function well, its members have to be chosen for their commitment, time and expertise for the work. They also must have the trust and support of all village groups. In particular, a community water committee should be able to represent the interests of all social groups. It will not be able to carry out its role successfully, if only the interests of one party or group are represented.

Some agencies provide guidelines on the membership and constitution of water committees, and this can be a useful way of ensuring that the interests of women and of the poorer community members are represented. Issues commonly covered in the constitution of a water users' organization are listed in Table 4.1.

Nowadays, more women are being included on water committees, which benefit from their strong personal interest in a reliable water supply, and their easier contacts with the women of the village. Success comes only with careful preparation: women's participation needs to be discussed with local leaders; village women themselves should participate in the selection of candidates; and periodic training and support is needed to assist the committee members to perform their tasks effectively. As committee members, women are often made responsible for aspects related to their specific areas of experience and concern, like hygiene and communication. Women are also frequently chosen as treasurer, for which appropriate training is vital.

Table 4.1 Some typical elements of a water users' organization constitution

General characteristics:	Name, place of residence and purpose of the organization; date of establishment; legal status.
Membership:	Qualifications and conditions for membership; procedures for application, acceptance and cancellation as members of the organization.
Income sources:	Contributions, rates, subsidies, loans and other rightful revenues.
Committee(s):	*Composition:* number and functions of committee members; composition of executive committee, and sub-committees where necessary; *Election:* occasion, procedure; length of term of office; possibility of re-election; by-elections in case of resignation, etc; *Representation:* of the interests of all user groups, including women and low-income households; *Functions:* responsibilities and authority of each function, character of work (voluntary or paid); type of remuneration.
Meetings:	*Committee(s):* frequency, purpose and authority of committee meetings; *General Assemblies:* frequency of assembly; minimum period between announcement and assembly; user information on time, place and purpose; *Purposes of meeting:* rendering an account of the preceding period; appointment of a financial control committee for the financial period; recruitment and election of committee candidates; other relevant business; *Validity of meetings:* representation of various user categories; voting rights (e.g. heads of households only, or male and female heads, or one adult vote); quorum for important decisions; conditions for a general meeting on request of users.
Changes:	Procedures for changing the statutes; procedures for winding up the organization.

Technology and service level

Preliminary planning will have restricted the options on technical grounds, so that decisions to be taken will principally relate to service level. The desire for as high a service level as possible will be tempered by costs and other resource demands, so it is important that villagers get a full picture of their commitments related to each option available. If the preliminary survey has been well conducted, agency officials will have a good idea of the most likely outcome of the decision-making process in the various types of villages, but the final decision must emerge from the participatory process, or all the benefits of community involvement will be put at risk.

Essentially that means that the villagers need both the information and the understanding of that information. Much of that understanding can come from trained motivators, promoting the water programme. It should be part of their duties to spell out not just the benefits to come from improved water, but also the liabilities which come with increasing service level. So, it must be clear that choosing a handpump in

Figure 4.3 Trained motivators must make clear the community's obligations, as well as the benefits to come from an improved water supply (photo IDRC)

preference to a rope and bucket system means that someone in the village must be trained to carry out routine maintenance, that there will have to be a structure for collecting and disbursing maintenance funds and buying and storing spare parts, and that alternative sources may be needed in the case of breakdown. Similarly, the true cost of piped supplies needs to be spelled out. For gravity flow schemes, costs may be relatively low, whereas motorized pumping to standposts will mean significant extra costs to be borne by the community, perhaps dependence on external supplies of fuel or power, and the need for outside help in maintaining and repairing the completed scheme.

The government agency's commitments are also important and should be made clear to the villagers. Supplies of spare parts need to be assured, training must be available for caretakers and committee members involved in management of the completed project, and there must be provision for government support for major operations such as well rehabilitation or complete pump breakdown.

Well siting

The lessons of the Tanzanian example quoted at the beginning of this chapter should not be lost. There are many such examples. Unless wells are sited in collaboration with the future users, there will be reasons, real or imagined, why they will not be fully used. Because convenience is the most immediate perceived benefit, pumps should, wherever possible, be located closer to population centres than traditional sources used for drinking water. Minority groups may have to be provided with their own pumps, to prevent conflicts and assure their access to safe water.

Techniques used to identify well sites acceptable from a combined technical and social point of view include:

- preparation of village maps with possible sites, indicating separate hamlets and areas of weaker groups;
- selection of potential sites during environmental walks by the survey team and the water committee or other user representatives;
- discussion of selected sites, including technical arguments and agreement on acceptability, and where necessary sharing arrangements.

The need for the community as a whole, or individual user groups to contribute towards construction and maintenance costs may complicate well siting discussions. In some cases, communities have been tempted to install fewer handpumps than necessary or to locate them in places more convenient for the chief or village leaders. Individual payments have given wealthier households the opportunity to install a public handpump in their own grounds at a price far below that of a private pump bought on the open market. This may result in a monopoly of use and scarcity for the majority of the community. These abuses of power need to be avoided, and may demand skilled interventions by project staff, to protect the interests of poorer community members and avoid jeopardizing health benefits, while respecting cultural traditions.

Physical or economic constraints may prevent construction of a central well in every neighbourhood. If sharing is needed, arrangements for maintenance and financial contributions need to be discussed and agreed in advance with all potential users.

Operating rules

Handpump programmes sometimes set rules which prohibit use of water for washing and bathing at or near the pump for fear of unhygienic conditions and contamination of the source. Also, not all pumps produce sufficient water for both human consumption and cattle watering. Ignoring these needs when planning the pump installation will lead to abuse and conflict between users, for example women and cattle owners. Water use regulations are difficult to apply and can impair health impacts if they encourage continued use of unsafe sources for washing and bathing. Insisting on washing being carried out at home when the pump is some distance away often means more work and less bathing for women and children.

In such cases, it is better to discuss the need for additional facilities at some or all of the wells for washing, bathing and cattle watering. The community may then consider it worthwhile to contribute to additional construction and extra financing costs, and devise a system for managing the extra facilities and collecting contributions from users.

In some instances, for example in bilharzia-infested areas, it may be advantageous from the national perspective to provide extra financial support for the additional facilities, because of benefits in other sectors such as medical care.

Health education

Normally, the main reason for introducing water supply improvements will be to bring better health to communities. Continuous use of safe drinking water is one important criterion for improved health. Another is the availability and use of proper sanitation facilities, and the reduction of local transmission risks of diseases related to drinking water supply and sanitation.

It is not enough for a water programme to provide health information and a list of general dos and don'ts. Householders have to be actively involved in identifying the local risks to health and working out for themselves how conditions and behaviour can be changed to safeguard health. Discussion with users about the changes which will come about when the handpump is introduced are a crucial part of any handpump programme. The principle is the same as for all other elements of the package, but the details too are important, though beyond the scope of this publication. Guidelines for planning local health action programmes can be found in *Making the Links* (Boot, 1984).

> Women and girls in southern Sudan greatly appreciate handpumps for the good water, and especially because they no longer have to trek long distances to find water in the dry season. Unwittingly though, the young girls may reduce the lifetime of the pumps. The girls like to sing while pumping, and tend to match the staccato rhythm of their songs in their pumping actions, resulting in short rapid strokes.
>
> There is also a belief that the water cannot be contaminated by their own behaviour; only outsiders can bring disease to the villages. When members of small closed communities shared the same spectrum of pathogens, this belief was quite correct. However, as better infrastructure and greater mobility increase outside contact, the risk of disease transmission increases and the need for good hygiene education becomes more urgent.

4.3 IMPLEMENTATION

The only way that many rural people can afford the costs of water supply improvements is by contributing their labour, and by collecting local materials for construction of the new facilities. This contribution is doubly important. Not only can it considerably reduce the financial cost of the project, but it also may contribute to a sense of ownership within the community.

Voluntary labour

The commitment to provide voluntary labour or to hire local contractors will have been part of the community's evaluation of alternative technological options. Organizing the community efforts then becomes a task for the Water Committee, and many communities have their own ways of ensuring that work is fairly shared and that responsibilities are met. In some areas, an adult member of each user household works one day a week in a fixed work team until the work is finished. Alternatively, a whole neighbourhood may join in the construction of its own well for a limited period. With this in mind, it is clearly advantageous if construction timing can be phased in such a way that it does not coincide with busy agricultural periods (planting or harvesting), and that work is planned well in advance.

On handpump programmes, the major construction activity involving voluntary labour is well digging. For programmes based on drilled wells, community labour can be used to assist the drill crews and for gravel sieving or packing, but the main activity in which villagers can have a substantial role is apron construction, including the building of additional facilities such as washing and bathing places and cattle troughs. As well as direct voluntary labour, the community may also support the programme by providing food and lodging for project workers.

Education and training

The construction period is a time when the community's attention is naturally focussed on the water project. It therefore provides an excellent opportunity for health educators to discuss the importance of sanitation and hygiene improvements to accompany the new water supply. Disease transmission risks and hygiene practices also need to be discussed with the construction team, as their insanitary behaviour can impair the influence of hygiene education on villagers.

Discussions with all local groups are useful in identifying hygiene problems. Cooperation should be sought with health staff and others interested in health and hygiene, such as school teachers and adult educators. Posters and other educational materials adapted to local circumstances and behaviour are useful ways of communicating the health messages, provided that they have been tested and are used actively, not just distributed. It is important that siting of the handpump, and design of the pump apron should promote hygienic conditions, proper water collection and disposal of wastewater.

Handpump installation is the ideal time for future pump caretakers to receive on-the-job training in assembling and dismantling the pumps and to practise such servicing tasks as seal replacement while skilled assistance is available. Training in the community provides a further opportunity to enable women to participate.

Handing over ceremonies at the pump provide another education opportunity. As the water supply, tools and log book are handed over, the water committee and caretakers

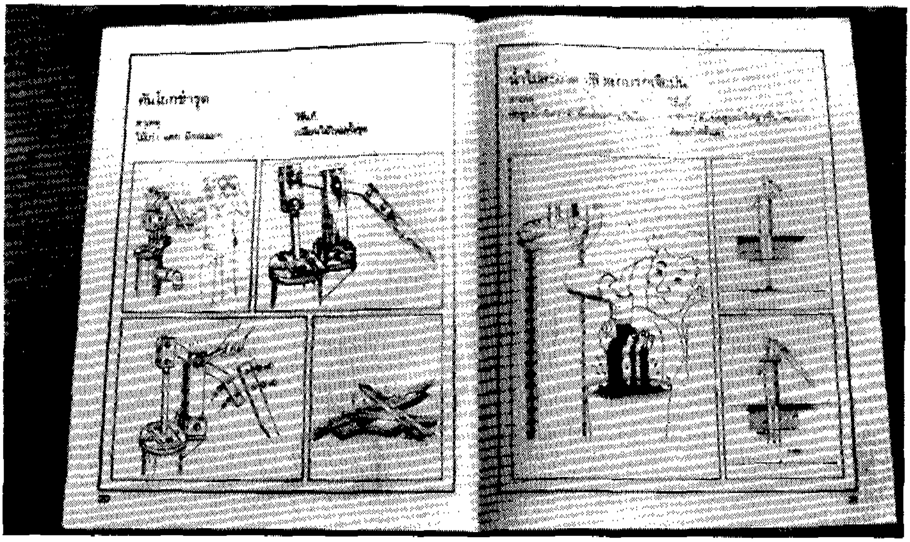


Figure 4.4 Education and training messages need to be simple and direct, making maximum use of illustrations and local language (photo IDRC)

can explain and demonstrate their work, and make themselves known to the users.

Training and employment of female pump installers proved highly sucessful in one southern African project. It was much more convincing than words in showing that women can carry out skilled work. Behaviour and hygiene practices in the construction camps improved significantly. Communication with women in the project villages became easier. Health-related topics were introduced in the villages, in close cooperation with government health staff. And communication methods like songs and drama were used with less inhibition.

4.4 PUMP MAINTENANCE

The weakest link in many community water supply programmes in the past has been the provision for maintenance of installed facilities. In the new approach, future maintenance is at the heart of decisions taken during planning and implementation of projects. The intended extent of community involvement in maintenance should therefore have been agreed even before the first well was drilled. If the concepts outlined in this publication are adopted, users will have the maximum possible involvement in pump maintenance, and the handpumps will have been chosen accordingly.

In some instances, pump caretakers with initial training and backup support from the water agency will be able to look after all pump maintenance. In other circumstances, it may be more appropriate for the community to contract the services of a local mechanic (commonly referred to as an area mechanic in handpump literature) for below ground servicing and some pumphead repairs, such as bearing replacement. Where continued use of conventional high lift pumps is envisaged, removal of below-ground components will often demand the use of special lifting tackle. There will then be a need to call on the services of a mobile maintenance team regularly.

Village level maintenance

Sustainability of the finished project depends on maintenance tasks being carried out quickly and economically. The best way of achieving that goal is to ensure that local people are trained and equipped for the task. Selection of suitable pump caretakers is a job for the village water committee or equivalent organization, but has to be based on careful consideration of all the requirements.

Women are usually more motivated than men to carry on with preventive maintenance after the first novelty of the job has worn off. A glance at the jobs list for pump caretakers in Chapter 7 will show that most of the daily tasks are either already done by women or could readily be included in their regular visits to the pump. They are also much more inclined to remain in the village, so that, once trained, they are less likely to move on and create the need to train a replacement. Involving women may require some inventiveness, to overcome cultural constraints. Other women included in planning discussions can often suggest suitable candidates and organize help in the home while the nominees are away for training. Local training for small clusters of villages greatly facilitates women's participation.

Bicycle repairers, blacksmiths, or other village craftsmen familiar with the use of simple tools, may also be able to take on the extra job of looking after handpumps. When they do, simple preventive maintenance, like lubrication and upkeep of site cleanliness are more conveniently done by others living near to individual wells. Local arrangements may involve a well committee, a roster of users taking turns, or one specially chosen individual. The important point is that users recognize the need for preventive maintenance and cleanliness, and that those responsible know what to do and why. Periodic monitoring by the water committee is a sensible precaution.

Factors relevant in the choice of a good caretaker have been listed in Table 4.2. The important criteria are that the chosen caretaker should be willing to do the job and accepted by all potential pump users as the right choice. Basic training can be conveniently given during pump installation, and should be supplemented by periodic refresher training, for example during scheduled monitoring visits. In general, pump caretakers should be responsible to the community water organization, and their work should be monitored by the organization, supported where necessary by the external water agency. It clearly helps if caretakers keep a logbook for each well and record all preventive maintenance work and repairs. Illiteracy, which is especially prevalent among women and older men, need not be an insurmountable barrier, as logbooks can be made very simple and others in the family or village can often help to fill in the logbook.

Experience with community-managed maintenance shows that, provided the pumps have been selected to suit available skills, minimally trained pump caretakers, assisted by unskilled villagers, can undertake such routine operations as lubrication and seal replacement on many types of handpumps, and even more complex operations like handle bearing replacement when modern plastic bearings are used. In some cases, pump caretakers perform their duties on a purely voluntary basis, particularly when they are women. However, some form of payment, either in cash or kind, or by including a small horticultural plot for the caretaker as part of the handpump site, is usually necessary, to provide an incentive to ensure commitment and continuity.

The limit for total village-level maintenance is generally reached when removal of below-ground components becomes too heavy a task, or starts to demand special tools or equipment. The pump caretaker system of maintenance is well suited to shallow well applications, including direct action pumping to depths of 12-15m. The range of

Table 4.2 Selection criteria for pump caretakers and area mechanics

Character of work	*Selection criteria*
Regular preventive maintenance, simple repairs and site upkeep	Daily visits to the site High motivation for all activities, including menial tasks Prepared to keep site clean and control use of site and handpump* Able to carry out small maintenance and repair jobs (after training) Easy communication with women about water use, hygiene, site upkeep, etc Living near the well site Seldom absent for long periods Likely to remain in the community Reliable and respected by fellow users Able to keep well records† Satisfactory commitment and performance during training
Periodic larger maintenance and occasional repairs	Reliable and respected person Living permanently in the area Likely to remain after training Seldom absent for long periods High personal motivation for the job Able to keep records and use simple manuals† Satisfactory commitment and performance during training

* With support from a committee and authorities when necessary
† In some cases, literacy (or a literate child) may be required

handpumps suitable for village-level maintenance is extending all the time, and it is worth noting that in Kenya minimally trained villagers are able to remove and replace the plunger and footvalve of the Afridev handpump from a depth of 40m in only half an hour, without the need for lifting equipment, and without removing a single nut.

Area mechanics

Where pump maintenance is too complex for village pump caretakers alone, or needs the use of special tools, local mechanics from the public or the private sector can usually provide the assistance needed more efficiently than a centralized system. In most rural communities, there are mechanics available to service bicycles, radios, even motorized irrigation pumps. With suitable incentives, including prompt payment from the pump users, handpump maintenance can become a worthwhile addition to their activities.

In Burkina Faso, for example, rural water supply programmes funded by the European Development Fund (EDF) have established a highly effective handpump maintenance system which it is estimated is costing only 5-10¢ per user per year. Mechanics selected during the implementation phase are given a $600 tool kit and bicycle and trained to service the standard pump (in this case the Vergnet footpump). Each mechanic looks after about 20 pumps and is paid by the villagers, who collect the small charges at harvest time and keep them in a cash box until needed. The mechanics derive a useful income from their pump maintenance activities, and are now reported to be expanding their operations to neighbouring villages where centralized maintenance is proving more expensive and less reliable. In other examples, mechanics receive an initial loan to purchase the necessary tools and equipment, which must be repaid from revenue collected for their maintenance activities.

Trained area mechanics should be capable of carrying out routine servicing of many handpumps down to considerable depths. The range of handpumps now on the market means that, in all but the most unusual circumstances, it should be possible to select handpumps suitable for this type of maintenance.

Spare parts supply

Whatever maintenance system is planned, it will only succeed if there is a ready supply of spare parts available when needed. There is a clear duty on the agency promoting a community water supply programme to establish a means for the community to obtain any spares needed quickly and affordably. Standardization and close coordination of projects supported by different donors can ensure that, as far as possible, similar pumps are selected and the range of spare parts needed is kept to a minimum.

An emphasis on the use of pumps whose wearing parts can be manufactured in the country of use removes one major obstacle to effective maintenance — the need to import spares. In addition, distribution of the spares within the country is critical. Where an effective maintenance system is established, there will often also be enough of a market for regularly needed spares for retail outlets to stock them, or for the area mechanics to hold their own stocks.

Spares supplies can be greatly simplified by adoption of a servicing schedule, by which all pumps are visited at regular intervals and specified parts are replaced, irrespective of the condition of the pump. This maintenance strategy means that mechanics need only to ensure that they carry standard spares packs, and replacements can be made available according to the servicing schedule.

4.5 COST RECOVERY

The principle of planning for sustainability of community water supply programmes includes the need for communities to contribute as much as possible towards both capital and recurrent costs. It also involves community organizations taking on the responsibility of managing completed systems. It follows that the village structure must include a mechanism for collecting money from pump users and disbursing it as necessary for maintenance operations. It may also be practical for community organizations to run financing systems such as revolving funds, which make possible future expansion or enhancement of their water supplies. In projects in Thailand, a revolving fund is established in which community members have to repay costs of materials and pumps. In Indonesia, a similar approach is followed, but a 50% subsidy is given, in view of the repayment capacity of users (IDRC, 1987). Setting up a community financing system involves quite a few practical decisions for the community (see Table 4.3).

Cost budgeting

When handpump wells are still new, few maintenance costs should arise. As the pumps get older, maintenance needs grow and progressively more parts need replacing. Also, the user population will grow and settled areas will expand, creating a need for more wells. Medium and long term planning also needs to account for depreciation and inflation. The community will depend on sound advice from project staff, to make allowance for the anticipated future costs of parts, the stocks needed, and the provisions to be made for future expansion.

Water tariffs

Handpump water systems are not suitable for metered charges and some other equitable form of charging has to be developed, preferably by the village water committee or other management organization. Clearly, the tariff needs to be enough to provide for regular repairs and to build up a contingency fund for coping with major repairs. Whether the costs of the pump and the well should also be repaid will be a political decision at national level.

Table 4.3 Main questions for village decision making on maintenance financing

Questions for discussion	*Options open to the village*
What costs to budget for?	Remuneration of Scheme Attendants Tools and spare parts for repairs Replacement of handpumps Extension of the system
What funds to use?	Village funds Voluntary contributions Regular user payments
What rates to set?	Flat rate (all pay the same) Weighted (according to benefit/payment capacity)
How to collect money?	Fund raising on breakdown Taking money from a village fund Reserving part of village funds to establish a separate water fund Regular collection of household contributions
When to collect?	Monthly At the beginning of the financial year After harvest
Who collects?	Village water committee Handpump user group Community leaders
How to keep the money?	Village account Water account Who signs?
How to administer the funds?	Receipts for book-keeping Financial control User feedback
Who to administer the funds?	Village water committee Village accountant
How to pay the caretakers and/or area mechanics?	Per job Per month Per year after harvest In cash/kind

Sometimes, the maintenance strategy selected by the community is for users to contribute funds whenever the pump needs repair, and individuals are given the responsibility of collecting money from all pump users as necessary. This system is rarely satisfactory, as it may be difficult for some users to find the necessary funds when they are needed, and this can lead to conflict. More commonly, each household is expected to contribute a calculated amount regularly (monthly, quarterly, or each harvest time). A flat contribution will work when all households have more or less the same benefits and there are no great differences in water use, or in wealth of users. If benefits or wealth do vary significantly, for instance when some users take advantage of the pump for cattle watering or where households consist of more than one family, it will usually be better to set two or three rates and categorize households accordingly.

Home visits may be used to collect the money, or the committee may organize periodic meetings at which users are expected to bring along the due amount. Women's motivation makes them good fund collectors. They have the added advantage that they can easily visit the homès of other women when the male heads of households are away.

Accounting systems

Proper accounting for village water supplies is essential for several reasons. First, the treasurer must be protected against any suspicion of mishandling of funds, and users must be convinced that their money is being used in the intended way. Second, it will be necessary from time to time to adjust contributions to account for greater or lesser need for maintenance or spare parts. Third, good management of water revenue can build up funds for additional activities within the community.

Fair application of tariffs is a prime requirement, as any suggestions that particular individuals or sections of a community are being favoured will cause others to withhold payments and result in unmanageable operations.

In some rural communities, agricultural credit banks or other private sector institutions will be willing to provide banking facilities for village water committees, and this can be a useful way of ensuring accountability and skilled management of the funds (it may also be a way of obtaining credit if cash flow difficulties arise at times of major repair). Sometimes, too, local district councils may take over the responsibility of collecting and managing handpump maintenance funds, though there are few recorded examples of this system functioning efficiently. More frequently, the temptation to divert water tariffs for other emergency uses is too strong to resist.

Periodic monitoring of the books and regular financial reports to the users, at annual assemblies for example, reduce opportunities for misuse and build up the users' trust in the water organization. Special training in simple book-keeping and budgetting helps the responsible community members to understand their responsibilities, and to avoid disputes when difficulties arise. More information on financing and financial management systems, though with an emphasis on piped water supplies, can be found in the IRC Occasional Paper *What Price Water?* (IRC, 1986).

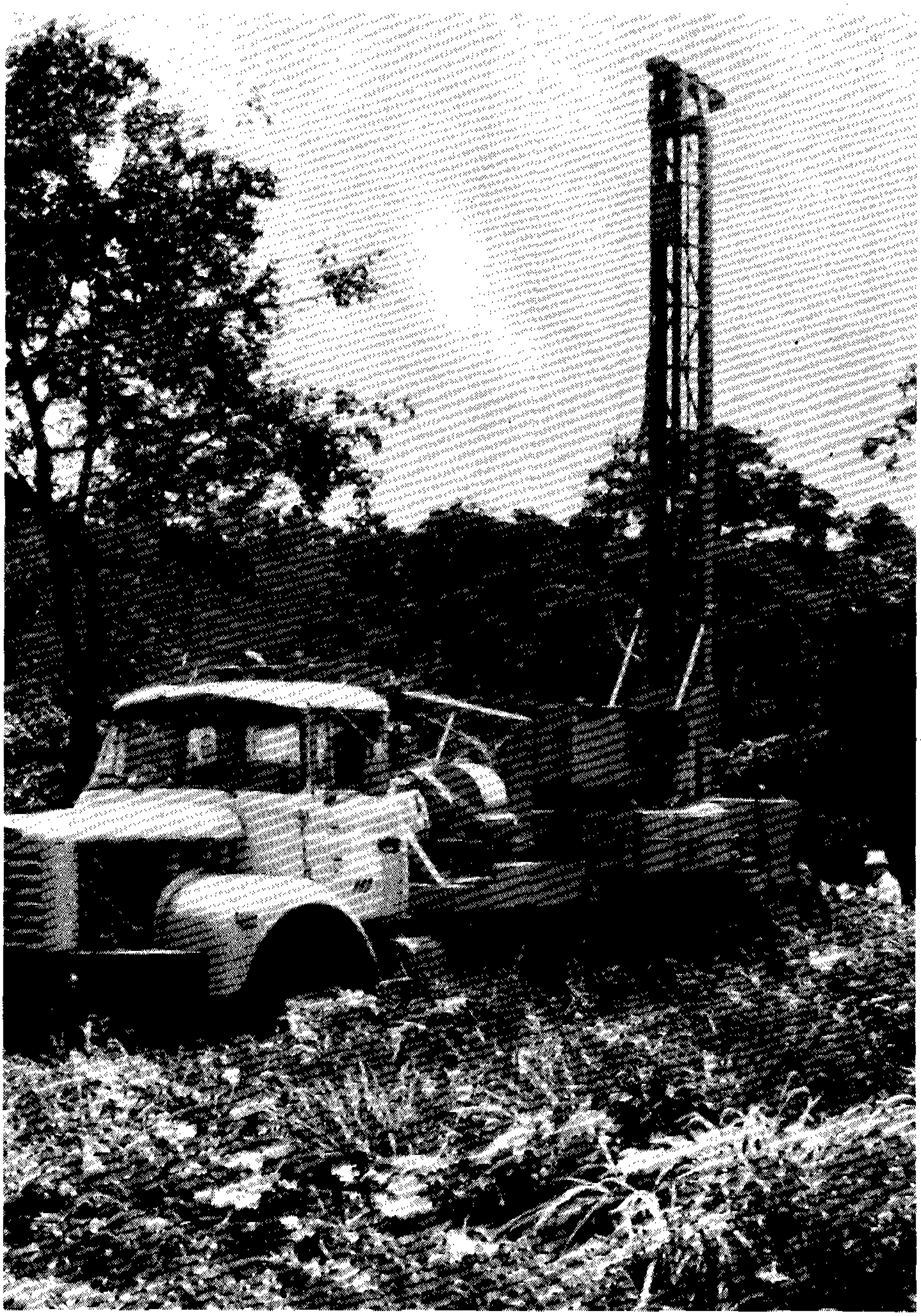


Figure 5.1 Well drilling is a very important cost component in projects

5. Siting and Construction of Wells

Even the most carefully selected handpump cannot give satisfactory performance if it is installed on a poorly designed or poorly constructed well. A major factor in the breakdown of handpumps in the field has been sand entering the well, leading to rapid wear of seals and valves, abrasion of cylinder walls, and clogging of the well itself. Badly aligned boreholes interfere with the operation of pumps which depend on the reciprocating movement of vertical pumprods. Choice of the right location for the well and judicious selection of the correct drilling depth and cylinder setting will have a major impact on the performance of any handpump. Drawing water from a well introduces a risk of contamination of the groundwater, which calls for sanitary protection of the well and its surrounds.

Well drilling and construction methods constitute a subject in their own right, and detailed discussion is beyond the scope of this publication. The basic principles however do need to be fully understood, and some essential points are therefore highlighted in this chapter. Almost invariably, the well will be a major cost item of a handpump programme, yet the attention given to minimizing that cost is typically scant. High cost, high production drill rigs are used where they cannot possibly achieve their optimum output, and where lightweight, simple rigs with lower specifications and considerably lower costs would be more appropriate.

There is an enormous range of costs associated with waterwell drilling. Even in apparently similar geological conditions, the unit cost of a 50m deep well may be as much as $60,000 in parts of Africa, or as little as $2,000 in India. A large part of the difference can be accounted for by differences in logistics and the way that drilling operations are organized in the two regions. In many African countries, public sector agencies endeavour to run drilling programmes, using rigs donated by bilateral aid agencies. Access to drilling sites is often difficult and rigs can stand idle for long periods waiting for the delivery of imported parts and equipment. In India, a flourishing private sector competes for business in a huge market, where success depends on keeping costs down and therefore on selecting the right equipment for the job. Communications and logistics are usually much better, and local production of most equipment and particularly consumables leads to a much more effective operation.

5.1 TYPES OF WELLS

A wide range of techniques is available for constructing wells. Options range from very simple digging to the use of sophisticated down-the-hole hammer rigs. Selection of the most suitable technique depends on local circumstances, geological formation, infrastructure and logistics. The right choice is important, in view of the significant cost savings which might result.

Hand dug wells

Ever since primitive man scooped water from dried up river beds, communities have been developing ways of collecting water from steadily increasing depths, without the need for mechanical assistance. Well digging has been a necessary part of community development in many countries, and villagers are generally well aware of the most suitable locations for hand digging, and of the pitfalls associated with the construction and use of unlined wells. In communities receiving assistance for the first time, though, there may well be no appreciation of the simple techniques available for making hand dug wells more reliable, and safer.

Hand dug wells have reached depths of 60m and more in some areas of the African Sahel, sometimes penetrating hard rock zones. In community water supply programmes, however, it will be rare for hand digging to be the best option when groundwater is beyond about 20m, because of the time needed to dig deep wells. A serious limitation on hand dug wells is the effort needed to dig below the water table. Even if they are pumped out while digging proceeds, the practical limit is about 2m below the water table. So, often wells can only be completed at the end of the dry season, even then leaving little margin for later water table fluctuations.

Within those limits, hand digging has its attractions. The large diameter means that well recharge should not be a problem, and it is usually possible to extend the depth of hand dug wells if drought or other seasonal factors cause drawdown — an option which is less easily achieved with drilled wells, as the drilling rig needs to be brought back. Hand digging offers the maximum possible scope for community involvement in well construction. Dug wells offer an additional security factor for handpump supplies, in that the large diameter means there is room to install more than one handpump per well to cater for high demand or possible breakdowns. Alternatively, a handpump-equipped well may also be arranged in such a way that a rope and bucket can be used if the handpump is out of use.

On the other hand, compared with drilled wells, dug wells are slower to construct; digging is especially difficult once the level extends below the water table; and dug wells are inherently less safe from pollution than drilled wells. These merits and shortcomings of hand dug wells, and the economics of alternative options, will all have to be taken into account in the preliminary planning phase.

Where dug wells are among the options offered to the community, some design and construction guidelines will be useful. The first general rule is that unlined wells should be avoided. With the possible exception of sections dug through very stable ground well below the surface and above the water table, concrete or brick lining is essential to prevent collapse of the well sides, either during construction or in operation.

The minimum diameter to permit access for a man during construction and for subsequent cleaning or extension of the well is 800mm, which means an overall size of 1m or more, allowing for insertion of the lining. In wells which require only part lining, it is often advisable to dig to a larger diameter through the softer ground near the surface

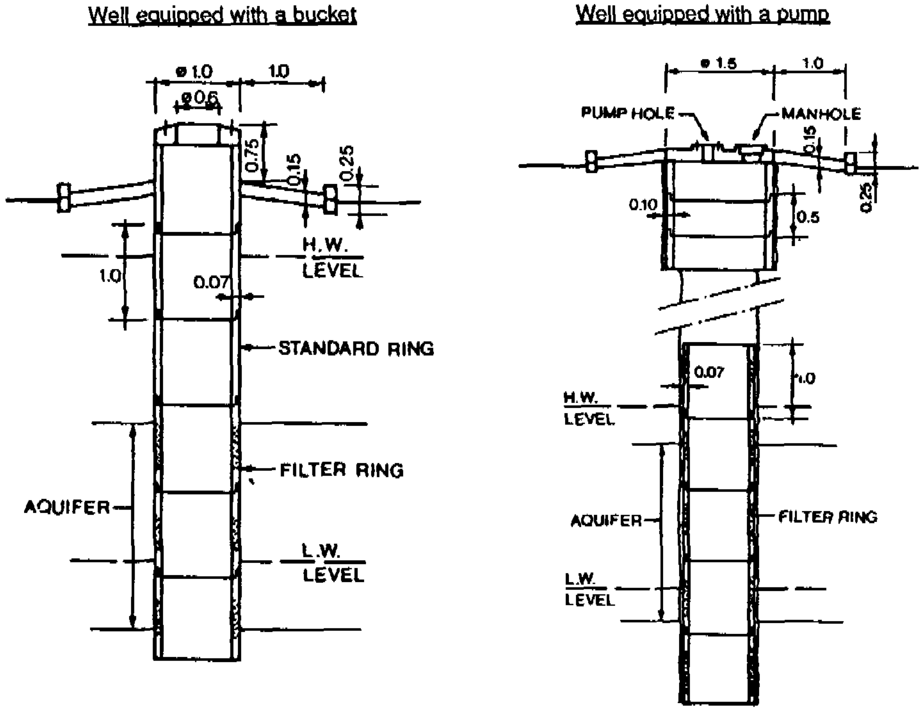


Figure 5.2 Typical dug wells on the Buba-Tombali project in Guinea Bissau

and use smaller rings for the lower section (telescope system).

A typical layout of a dug well on the Buba-Tombali water project in Guinea Bissau is shown in Figure 5.2. The upper section is 1.5m diameter and contains four precast concrete rings, each 0.5m high, which were put in place before the remaining part of the well was dug. The middle section, of 1.0m diameter, was generally dug with pick axes through hard laterite and so could be safely left unlined. From the high water level downwards, precast concrete filter rings were inserted to below the anticipated minimum water level in the well. Digging normally continued about another 0.5m into the hard clay, to provide some storage in the bottom of the well.

Lining rings were precast at a purpose-built factory, as the alternative of brick or in-situ concrete lining would have been slower and demanded extra skills and supervision at each well site. This solution did increase transport problems, and on other projects rings are made on site, which has the extra advantage that less reinforcement can be used. A tripod and pulley were used to lower the rings into place as digging proceeded, the string of lower rings progressively following the digging downwards. Once the water table was reached, an electric pump was used to keep the excavation free of water. On average, the Buba-Tombali wells were 11m deep.

More information about design and construction techniques for hand dug wells can be found in the books *Hand Dug Wells and their Construction* by S.B. Watt and W.E. Wood (Watt & Wood, 1976) and *Shallow Wells* by DHV Consulting Engineers (out of print).

Hand drilled wells

Two disadvantages of hand dug wells, the time taken to construct them and the need for dewatering in the final stages, can be overcome by using hand drilling equipment to construct a small diameter borehole instead of the large diameter dug well. In favourable geological conditions (unconsolidated materials, with no hard rock and few big boulders), a hand drilled well can be finished in less than a fifth of the time needed to dig a well of the same depth. For example, figures are quoted from Tanzania of 3 to 7 weeks to build a dug well, depending on depth and soil conditions, and 3 to 5 days for the equivalent hand drilled well (Blankwaardt, 1984).

Hand drilling equipment is light and simple, and can be used at sites with difficult access, where it may be impossible to bring in drilling rigs. A full description of hand drilling techniques is given in Blankwaardt's book, from which this summary of basic principles has been derived.

Typically, a 230mm diameter hand auger is used to drill the hole in 0.5m stages. The equipment is handled by first erecting a tripod over the planned borehole site. Large steel footplates prevent the tripod legs from sinking into the ground. A drilling crew consists of at least three skilled workers and 4 to 6 helpers from the village.

To obtain a truly vertical hole, the setting up and drilling of the first 2-3m are critical. Blankwaardt gives four practical tips:

- Fit a 3m extension rod above the crosspiece and have one man keep it centred at the top of the tripod.
- Adjust the starting position of the drill by holding a spirit level along the flight auger.
- Check the vertical position of the drill visually in two perpendicular directions.
- Drill with an even number of people, equally divided over the crosspiece handles. Depending on soil conditions, there may be four, six or eight people turning the drill.

After each 0.5m stage, the auger is winched out of the hole, swung aside and cleared of soil with a special tool (or a big screwdriver). A borehole log should be kept by noting the characteristics of each batch of soil removed (e.g. "loose grey/brown fine sand", "sticky yellow clay", etc.). Different extension rods are added below the crosspiece as drilling proceeds, to keep the crosspiece at a workable height (0.75-1.25m above ground). In harder soils, or where large stones are encountered, alternative bits are available to improve penetration.

Once drilling passes the water table and the borehole walls begin to cave in, the auger is removed and a casing has to be installed while spoil is removed by bailing (the casing may be needed above the water table if the soil is loose). The principle of this operation is that the casing must advance ahead of the bailer. If it does not sink under its own weight, rotation, using a crosspiece, will help to force it down. While one team of two or three people guides the casing others use a combination of muscle and winch power to bail out the loose gravel or sand from inside it. It is important that the bailer should not pass the bottom of the casing, as this simply results in extra caving and wasted effort. A simple marker on the bailer cable, denoting the length of the casing should prevent excessive bailing.

The casing may subsequently reach another impermeable layer, in which case auger drilling will be resumed if the potable water aquifer has not yet been reached. Typically, where drilling started with a 230mm diameter auger, the casing will be 200/220mm, and the lower drilling will be carried out with a 180mm diameter auger. The casing will normally be terminated either at some depth into the selected aquifer, or, if the aquifer is thin, with a further penetration of 200-300mm into the impermeable layer beneath it. This concept of "telescopic drilling" can be extended by inserting a second, smaller diameter casing inside the first to seal off a second aquifer, and continuing with a smaller auger into the next, as illustrated in Figure 5.3, which is taken from Blankwaardt's book.

The final stage of well construction involves installation of the well screen and gravel filter, plus any clay seal needed to seal off higher aquifers, and is vitally important if damaging sand ingress into the handpump cylinder is to be prevented.

Grain sizes for the gravel filter and slot sizes for the well screen can theoretically be matched to the aquifer material, the aim being to allow small aquifer particles to pass through during well development, but to prevent the passage of sand and silt during normal pumping. The thickness of the gravel pack is also significant here.

In practice, locally available gravel from lakes or river beds can often be sieved to give a range of sizes suitable for packing around a well screen. Typically, gravel which passes a 5mm screen and is retained on a 1mm screen can be used to produce a 50-80mm thick filter around a screen with a slot width of 0.7mm. Such a combination will allow 0.2mm grains to pass through during well development. The total slot area is also important, as it will dictate the entrance velocity of water into the well. For normal handpumping rates of less than $3m^3/h$, a total slot area of $280cm^2$ is needed to keep entry velocity down to the recommended 3cm/sec. Most commercially available screens can provide two to three times this slot area over a typical screen length of 2m.

The procedure for installing the screen and gravel filter into a hand-drilled well must be synchronized with casing removal, so that no collapsible borehole wall is exposed until the gravel pack has been installed. The other important aspect of installation is that the well screen and the pipe above it should be held centrally in the hole as the gravel is poured around the screen. Where the well penetrates more than one aquifer, contamination of the potable aquifer by water from the higher aquifer (or from the surface) can occur unless the impermeable barrier is restored when the casing is removed. This is achieved by halting withdrawal of the casing just before it leaves the clay layer and using moistened clay from the drill spoil to backfill around the filter pipe. A special clay rammer tool is available to ensure that the backfill forms a good seal.

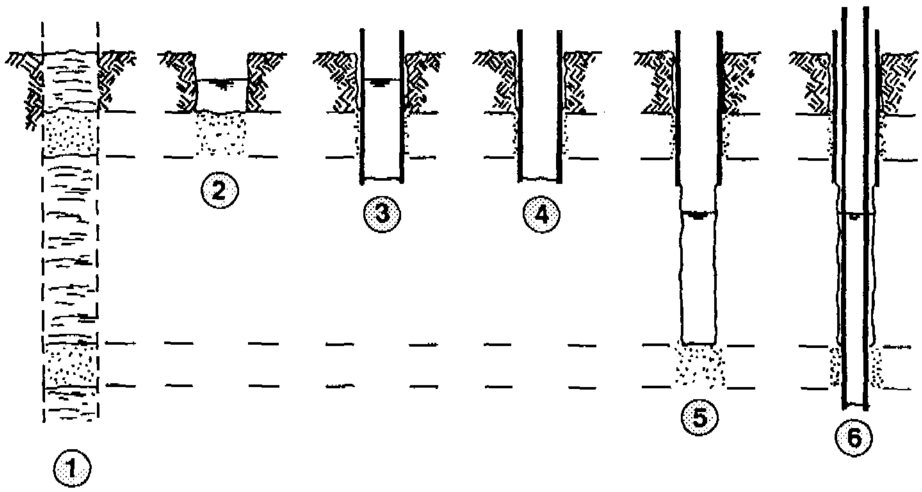


Figure 5.3 Telescopic drilling proceeds in stages:

1. The soil profile shows a thick clay layer between two aquifers. The well intake is to be constructed in the lower aquifer.
2. The first clay layer is drilled with 300mm diameter bits.
3. A 250/275mm diameter casing is inserted and bailing is carried out through the top aquifer. The casing is lowered further into the second clay layer to seal off the top aquifer completely.
4. The water is pumped out of the casing by means of a membrane pump.
5. Drilling continues with 230mm diameter drill bits through the thick clay layer.
6. A 200/220mm casing is inserted and bailing is carried out through the second aquifer. The casing is sunk into the underlying clay layer with 180mm diameter drill bits. The borehole is now complete.

Backfill may then continue with readily available sandy material as the casing is removed.

An alternative for the in-situ installation of a gravel pack is the use of double-wall prepacked screens. These have recently been applied successfully by UNICEF in Egypt and avoid the problems common with traditional systems.

Jetted wells

Well jetting, in which a jet of water fluidizes sand layers and allows a well pipe to be sunk through the fluidized material, can be an economic technique for constructing shallow wells in deltaic areas or sandy soils.

Figure 5.4, taken from a manual prepared by SWS Filtration Ltd (SWS Filtration, 1986) illustrates the installation technique, in which a mechanically driven pump forces water down a "jet probe", consisting of a $1^1/_2$ inch pipe with a jet at the lower end and an elbow and threaded fitting at the top. As the sand is fluidized by the jet, a pre-assembled plastic well pipe and screen with a steel drive point is pushed down alongside it. More rapid progress is achieved if a second pump also forces water down through the well pipe, though satisfactory installations have been achieved with only a single pump.

Resistance to the probe increases at the bottom of the sand layer, and this fixes the lowest level of the well pipe — if possible, the top elbow should be at least 0.5m below the sand surface. When the well is deep enough, the pump is throttled back, to maintain the fluidized area around the well pipe, but allow coarser sand to drop around the screen area. Imported coarse sand can be poured into this filter area, if the natural sand is too fine.

Once the filter has been established, the probe is withdrawn and the well is "developed" by pumping down the pipe at a progressively increasing rate for several minutes, then decreasing the flow rate for a short time. Extra coarse sand may also be added during this operation. The pump is then reversed and water is pumped slowly from the well, carrying with it fine sand and silt. Pumping continues until the water runs clear, pauses for a few seconds and then resumes to remove any additional silt. The cycle

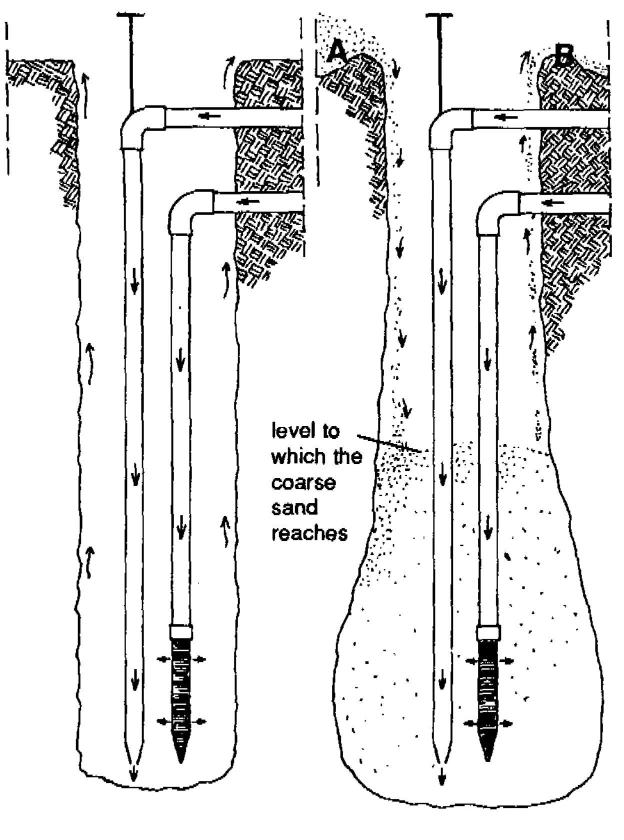


Figure 5.4 Left: Jetting down. Note that water is pumped into both the jet probe and the well pipe. Right: Gravel packing. Coarse sand (A) sinks down through the rising column of water while fine sand and silt (B) is washed to the surface

is repeated several times, until stopping and starting the pump produces no noticeable change in the water quality.

The well is then ready for connection to a suction handpump, which can be set up some distance from the drop pipe and connected to it by a horizontal suction hose buried in a trench. Fuller details of the well jetting technique are available in the manufacturer's literature (SWS Filtration, 1985). The technique is quick and effective in areas with shallow groundwater and sandy soil.

The so-called "sludger" technique, which is being used to sink up to 50,000 wells a year for community water supply in Bangladesh, uses the same principle, but without the need for a mechanical pump. The deep alluvial deposits which cover most of Bangladesh are ideally suited for well jetting with very simple equipment. As a result, large numbers of local contractors have learnt the simple skills involved and are able to sink wells to depths of 50m or more in only a few hours, at very economic rates.

The three-man drilling team's equipment consists of a bamboo scaffold, two pipe wrenches, a length of rope or chain and enough 3m lengths of 40mm galvanized iron pipe for the depth of well anticipated. A 300mm deep surface pit about 600mm square is first sealed with cow dung and filled with water. One length of pipe is held vertically in the corner of the pit and filled with water by a man at the top of the scaffold. This man then uses the pipe as a force pump, with his hand acting as a flap valve at the top. By raising and then forcing down the pipe, he creates the jetting action which fluidizes the sand. Sand and silt spurt from the top of the pipe as it sinks. The other two members of the team lift the pipe on the upstroke, using a bamboo pole pivoting on the scaffold and fixed to the pipe by a rope or chain sling (Figure 5.6).

When the first pipe sinks to the level of the pit, a second is screwed on and the process repeated. Sand samples are taken at intervals by directing the spoil spurting from the top of the pipe into a bucket and scooping out the settled sand after a few minutes. With UNICEF help, the Bangladesh drillers have been equipped with simple comparators, which enable them to judge when the sand is suitably permeable, and which screen size should be used. Drilling continues about one pipe length beyond the chosen screen setting (commonly a depth of 40-50m in Bangladesh).

The galvanized iron pipe is withdrawn by reversing the bamboo lever's sling action, and the tubewell is formed by inserting solvent-cement jointed pvc pipe with a screen and sand trap fitted at the bottom. The topmost pipe is galvanized iron and projects above the planned platform level, providing for a sanitary seal when it is subsequently concreted into place and topped by the chosen handpump.

Well development involves a temporary 3m extension of the riser pipe, which is continuously topped up with water for a few minutes. Development is completed by continuous pumping for several hours when the handpump has been fitted. This final process also serves to ensure that any contamination from the construction activities is flushed from the well.

Figure 5.5 With very simple equipment, holes can be sunk to a depth of 50m in just a few hours (Photo Richard Cansdale)

Mechanically drilled wells

If handpump wells are to be drilled mechanically, choice of the right drilling rig will have a substantial impact on overall project costs. It is generally true that the most economic waterwell drilling is in regions such as India and parts of Latin America, where local contractors compete for work and use their own rigs or hired rigs appropriate for the terrain, the available skills, and the budget of the programme. This contrasts with the experience, common in Africa and parts of Asia, in which an expensive rig is provided through bilateral aid, either through the specific handpump programme or as part of a general rural development programme. The requirements of these rigs often cannot be met sufficiently, leading to uneconomic use of equipment and high cost of wells.

The basic requirements of waterwell drilling are well within the capacity of most drilling rigs, and the choice of additional expense or complexity is generally based on either the need to drill through hard rock or an aim (often unachieved) to complete holes rapidly.

The three most common types of waterwell drilling are percussion (cable-tool) drilling, rotary drilling, and down-the-hole hammer (DTH) drilling. In terms of rated output, rotary drilling in unconsolidated or semi-consolidated formations and DTH drilling in hardrock areas show considerable time savings. The savings may however be illusory when operation and maintenance of the rigs and their manoeuvrability are taken into account. Small air-flush rotary rigs can out-manoeuvre large DTH rigs but cannot be used in hardrock areas. Large rotary air flush rigs can be equipped with heavy drill collars and used in hardrock areas, but they will ususally be less suitable and effective than a DTH rig. Similarly, the simplicity and durability of cable tool rigs may more than compensate for their comparatively slow production rate in regions where the required skills for maintenance of rotary rigs are in short supply.

Percussion (cable-tool) drilling is the oldest drilling method, and the principal features of percussion rigs have changed little over the centuries, though the equipment and tools available nowadays are much improved. The method involves raising and dropping a string of heavy drill pipe connected to a bit. Formation material is crushed and broken by the impact and forms a slurry when water is poured into the hole. At appropriate intervals, the drill string is removed and the slurry is bailed out. The machinery needed for mechanically operated (cable-tool) percussion drilling is simple and durable and easy for a minimally trained crew to operate and maintain. Much of Malawi's successful handpump programme has been accomplished using cable tool rigs dating from the 1930s.

Percussion drilling can be used in any formation, but is very slow in hard rock. Hole diameters from 100mm to 350mm are possible and wells have been drilled to depths of 250m, well beyond the normal requirements of handpump wells. The capital cost of a

Figure 5.6 A cable-tool rig(left) and a high speed rotary rig (right)

percussion rig is in the range of US$20,000-100,000, and running costs are low. Servicing needs are generally less than those of a motor vehicle, so the cable tool rig may turn out to be just as reliable as hand drilling equipment, which has to be transported from hole to hole by such a vehicle.

Rotary drilling can achieve much faster penetration rates than percussion drilling and is widely used for drilling in a variety of formations, with the size and cost of the rig dictated by the anticipated duty. The principle is that a rotating bit grinds the formation, from which cuttings are removed by a stream of drilling fluid, e.g. mud, which circulates either down the drill pipe and back through the annular space between the pipe and the borehole wall (direct circulation) or down the annular space and back through the drill pipe (reverse circulation). Foam or other additives may be used to help the drilling fluid to carry cuttings to the surface. Unlike percussion drilling, the process is continuous, and the drilling fluid also maintains a continuous pressure on the hole walls, preventing collapse. Any casing required can therefore be lowered into place after the hole has been completed (except for a short length usually needed at the surface to stabilize the overburden).

Rotary drilling is a skilled operation, in which the experience of the driller is an important factor in achieving both speed and correct alignment. A major drawback is the complexity of the equipment and the need for skills and workshop facilities when routine repairs are needed.

Down-the-hole hammer (DTH) drilling was introduced in the 1950s. It combines rotary and percussive action by adding a pneumatic hammer at the bottom of the drill pipe. A down-the-hole hammer can be fitted to any rotary rig, but this is less effective than using a specially designed DTH rig. DTH drilling is especially effective in hard rock, where penetration rates of 50-100m per day are being achieved. DTH drilling has no application in unconsolidated formations. The DTH hammer is also less effective with increasing depth under water, as the water pressure cancels out the air pressure used to activate the hammer.

5.2 LOCATION OF WELLS

We have discussed in Chapter 4 the need for the community to be closely involved in the choice of well sites. Technical considerations also play an important part in the selection of borehole locations. In some aquifers — notably the basement rocks of Africa — yields may vary substantially over quite small areas, and even the small yields necessary for a handpump well will only be obtained when the right hydrogeological conditions apply. Quality considerations may also be important. Iron-rich water is aesthetically unacceptable and will stain food and laundry; corrosive water causes major problems with many kinds of conventional handpump components; and there is an unnecessary risk of bacterial contamination if wells are sited close to latrines or waste dumps. Some salts, such as fluoride or chloride, may also make the water injurious to health or unpalatable.

In a Sri Lankan village where villagers have always dug their own wells, suitable sites are selected on the basis of the type of soil and the presence of *kumbuk* trees, which denote an abundance of groundwater. The village has ten ritual specialists, who use up to seven indicators to site a traditional well. They also determine the most auspicious time astronomically for the inauguration, and indicate the ritual offerings needed during construction to make the wells good to use. Most are shared neighbourhood wells with private ownership. There are different wells for drinking and for washing.

Maintenance is the responsibility of the owner, but in practice most of the work is done by the women and children of his household. First, all water is scooped out and the walls rubbed with a stone or coconut husk and rinsed off. Then mud is removed from the bottom with a bucket or coconut shell. Holes in the well lining are plastered and the edge is cleared of vegetation. When the clean water rises up, flowers are strewn onto it and the clean water is dedicated to the gods. (Kelles-Viitanen, 1983)

Hydrogeology and water quality

Preliminary surveys (see Chapter 3) should have given warning of any general problems of seasonal drawdown or water quality. In the detailed discussion on well siting for specific projects, the community and its advisers must be aware of the practical constraints on borehole location. In areas with alluvial formations, or those with plentiful groundwater, well siting depends almost entirely on user convenience, the main constraint being that wells should be located at least 15m from privies or septic tanks (Lewis et al, 1981), and above any danger of flooding.

At the other extreme, in dry areas over hard rock formations, a groundwater survey team may need test drillings and sophisticated techniques such as electrical resistivity

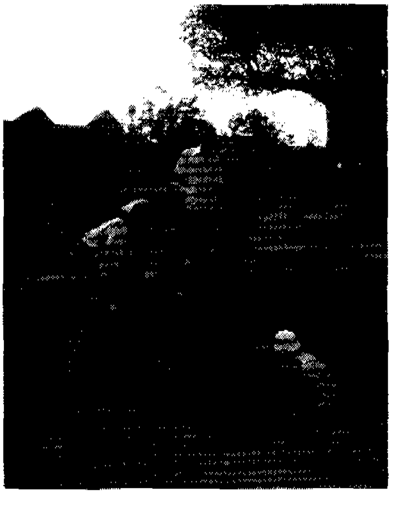


Figure 5.7 In Sri Lanka, villagers know from the presence of particular types of vegetation how to site wells where groundwater is abundant

and seismic refraction measurements, to determine a number of feasible well sites from which the community can choose the most suitable. In determining well depth, due allowance will also have to be made for drawdown, both that due to continuous operation of the handpump in low yield wells, and that due to external influences — seasonal variations and local drawdown caused by nearby motorized pumps for irrigation or industrial water supply. Community involvement in decision making is especially important when wells may have to be located in apparently inconvenient places.

In dry areas with limited availability of groundwater, shallow wells are often drilled in or near river beds. A disadvatage of this type of well, apart from flooding risks, is that the users generally live on higher ground at some distance from the river. Pumps are therefore less well protected and are at greater risk of vandalism. It also means that in the rainy season, when women are extra busy with food crops, closer water sources such as ponds are used instead of the safer pumps.

Handpump projects in drier areas of Nigeria, Kenya and Tanzania have started to discuss these implications of well siting with the communities and are planning to add safe rainwater harvesting techniques for the wet season to their technology package.

Whatever the hydrogeological conditions may be, checks need to be made on the water quality parameters before well siting is finalized. For this, samples must be analysed for chemical quality, which may include iron, manganese, fluoride, chloride, sulphate, and nitrate content. Depending on local conditions (shallow groundwater, fractured zones), bacteriological testing may also be advisable. Portable kits are now available which make on-site testing a comparatively quick and simple operation, though it does need a skilled technician to ensure proper sampling and analysis.

Test drilling and pumping

The hand-operated drilling equipment described in section 5.1 can be used for drilling test holes in a few locations. In this case, a much simplified procedure can be followed, using smaller augers (typically 100mm, reducing to 70mm if telescopic drilling is needed). Soil samples should be taken for each metre of drilling, and a note made of their appearance before they dry out in the sun. Regular water samples should also be taken for electrical conductivity measurements (a guide to the total dissolved solids in the water and hence its palatability).

When drilling reaches a potentially suitable aquifer, a simple survey pump test can be carried out much more economically than a full pump test, which depends on observation boreholes, a constant discharge pump and a lengthy pumping period. The survey test takes about two hours and employs a hand operated test pump, a water level meter, a watch or alarm clock, and a bucket (Blankwaardt, 1984).

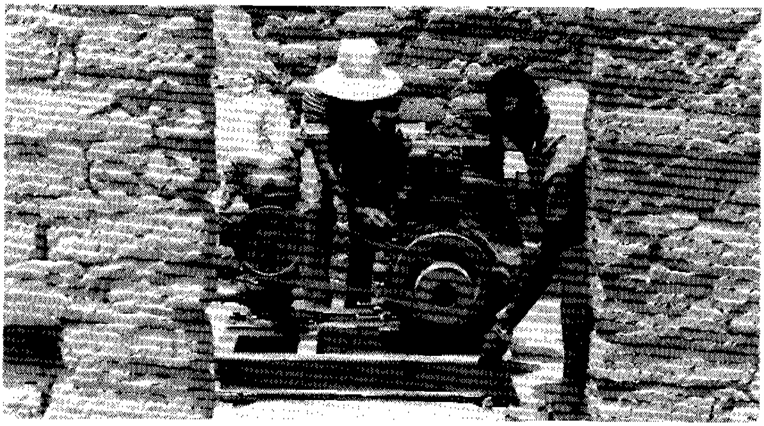


Figure 5.8 Irrigation pumps like this one in Guinea-Bissau can cause local drawdown, leaving handpump wells dry

The test well is first "developed" by pumping until five buckets have been filled. From then on, continuous pumping for one hour (the operator may have to be changed every 10-15 minutes!) is accompanied by recording of the number of buckets filled, the level of the water, and the electrical conductivity of the water, at ten minute intervals. At the end of the hour's pumping, the recovery of the well is measured by noting the water level at one minute intervals for five minutes. This data can be used to calculate the porosity of the aquifer, as explained below.

With test holes at intervals on a grid system, it is possible to prepare a full geological map of the project area, to indicate the most desirable sites for wells, but this is not always necessary as, hopefully, the tests will verify that the users' preferred sites yield enough water of the right quality. Nevertheless, it is worthwhile to check that a single test well is not simply a "lucky strike" into a small confined aquifer, which will not replenish on a year-by-year basis. This can be most readily checked by a line of test boreholes providing the data for a cross section indicating geological strata and water levels, to demonstrate the continuity of the proposed aquifer.

Borehole acceptability

The bucket filling test will give an average yield for the test borehole over an hour's pumping. To convert this into the equivalent yield of a larger diameter production well, including the thickness of the gravel pack, the yield is multiplied by a factor which depends on the "radius of influence" (R), the radius of the test well (r_t) and the radius of the proposed production well plus gravel pack (r_w). The equation is:

$$Q_t = Q_w \times \frac{\log(R/r_w)}{\log(R/r_t)}$$

Taking some typical values: a production well delivery rate of $1m^3/h$ is enough for most handpump applications; for a radius of influence of 20m, with a production well radius of 110mm (including gravel pack), a test well with a radius of 45mm would need to yield 850 litres/h or more to indicate an acceptable site. There is one important qualification to this simplified form of analysis: if the pumping test is carried out in the wet season, and a fluctuation in the water table may occur in the dry season, the yield must be adjusted to allow for the depth of aquifer which will be tapped in the worst condition. So if, for example, a 4m deep aquifer is lowered by 1.5m between seasons, the wet season test would need to be higher by a factor of 4.0/2.5 to guarantee the required yield from a production well in the dry season.

Water quality criteria for acceptability vary from country to country, and usually standards are set by the national agency responsible for rural water supplies, based on the WHO guidelines (WHO, 1983).

5.3 WELL DEVELOPMENT

Water flow into the well is improved and future clogging problems are mitigated when the completed well is properly "developed" before the handpump is brought into normal use (in Bangladesh, the handpump itself is used to develop the well, as explained in section 5.1 under the heading *Jetted wells*). Without adequate well development, the life of the well may be considerably reduced and excessive sand ingress may occur, causing damage to pumping elements. The main aim of well development is to remove fine particles from the formation zone close to the well, so creating a highly permeable zone around the intake.

Of the available methods of developing drilled wells, the ones most applicable to handpump applications are overpumping, intermittent pumping, backwashing, and surging.

Figure 5.9 Proper well development means longer well life

Overpumping

In this method, the well is pumped, using a special pump for the purpose, at a gradually increasing rate up to double the design rate. Pumping continues until the pumped water is completely free of sand. The method is simple, but not very effective. In effect, all that happens is that the formation zone around the well is subjected to a continuous one-way suction through the well screen. After initial removal of some of the fine particles, others bridge across gaps between the coarser particles and remain close to the intake. Subsequent intermittent use of the production pump causes the finer particles to be dislodged again and they will then enter the well.

Intermittent pumping

By pumping initially at a high rate, the water level in the well and in the zone around it is subjected to a considerable drawdown. Pumping is then stopped and the water is rapidly dumped back into the well (it can be stored in tanks at the surface during the initial pumping). This procedure is repeated many times until the pumped water remains clear of sand. The advantage of this intermittent pumping method is that it produces rapid pressure changes and flow reversals in the formation zone around the well screen. This loosens the fine particles, which will then pass through the screen during the rapid pumping. An airlift pump without a foot valve is ideal for this operation, which is hard on the pumping equipment.

Intermittent pumping is simple and inexpensive and achieves better results than overpumping alone. Its effect is more limited in high permeability aquifers.

Backwashing

The backwashing method is similar to intermittent pumping except that it starts with rapid filling of the well from tanks of water. Fast filling induces vigorous water flow out through the screen and gravel pack and into the formation zone. Water is then pumped out of the well to reverse pressures and flows in the formation zone around the screen. Repetition of the cycle until the water remains clear completes well development. An airlift or rugged sand pump is needed, but the method is simple and usually effective.

Surging

In this method, a surge plunger produces the necessary flow reversals and pressure changes in the formation zone. The plunger is suspended down the well, some 3-5m below the water level, and is moved up and down using a "surging line". Surging starts slowly and the speed gradually builds up until the maximum speed is achieved, depending on the slack in the surging line. If a percussion rig has been used to drill the well, the rig's spudding beam is ideal for producing the surging action.

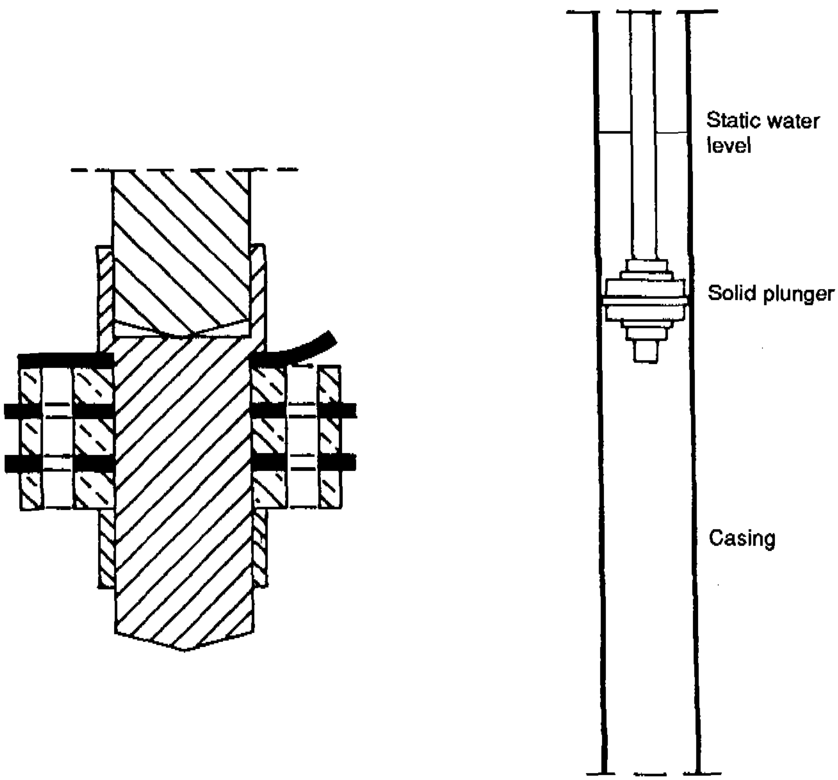


Figure 5.10 Well development using a surge plunger

After an initial period of surging, often 5-10 minutes but sometimes much longer, the surge plunger is pulled out and sand deposits are removed from the bottom of the well by bailing. The cycle is repeated until no more sand appears in the bailer.

Surge plungers can be solid or fitted with valves. A solid plunger consists of a set of steel or wooden discs with rubber discs sandwiched between them to seal against the well casing or riser pipe. In the valve-type plunger, a flapper valve is incorporated and covers holes drilled through the discs. The solid plungers produce the same water displacement on the upstroke and the downstroke, while the valved plungers result in a strong water displacement on the upstroke and a more gentle movement on the downstroke.

Figure 6.1 Some of the stages in handpump installation

6. *Handpump Installation*

Construction and development of the well in the manner set out in Chapter 5 provides a sound basis for optimum performance of the handpump. Poor alignment of the well or inadequate provision for keeping out sand will inhibit performance and shorten the life of any handpump.

To maximize pump life and avoid the need for frequent interruptions for maintenance or repair, installation of the handpump in the well should be carried out with care and precision. Incorrect installation is to blame for many of the failures and operational problems frequently attributed to faulty pump design. Typical problems involve damage to pump components through the use of the wrong tools or installation techniques, components dropped into the well because mountings are not secure or couplings are not tightened enough, cylinders set at the wrong level so that drawdown leads to air pumping or much reduced output, and foot valves located too near to the bottom of the well resulting in clogging by sand and silt deposits. Excessive or inadequate tightening of nuts or bolts can mean that caretakers have trouble removing them, or that they fall off prematurely.

Sanitary protection of the well is best assured by careful design and construction of the wellhead and apron. Extending the well casing at least 150mm above the proposed apron level helps to prevent leakage of polluted water into the well, and any manhole covers over dug wells should be set above apron level for the same reason. Apron design should ensure that spilled water drains away from the well and any troughs for livestock watering or laundry facilities should be located well away from the well (at least 15m).

6.1 HANDPUMP TYPES AND COMPLEXITY

The different operating principles employed in handpumps have been described in Chapter 2. Different manufacturers have developed these principles in varying ways, to produce pump models intended for a range of different applications. Each pump therefore has its own special needs in terms of installation and maintenance, and it is important, wherever possible, to obtain full instruction sheets or manuals from the manufacturer, and to ensure that the right tools and equipment are available for pump installation. Manufacturers should note that handpump installation, and particularly maintenance, may frequently be carried out by artisans with limited literacy. Instructions should therefore be given in as simple a way as possible, with a maximum of illustration.

Some pumps are very easy to install; others may demand heavy lifting equipment to be on hand or require special tools and skills to assemble complex components. In general, it is true to say that pumps lifting from greater depths are likely to be heavier and more complex than those lifting from shallow depths, but there are exceptions to this rule, and even some of the suction pumps on the market need lifting gear for installation simply because of the weight of the pumphead.

Suction pumps

Limited to pumping lifts of 7m or less, suction pumps have a very simple below ground structure, consisting of a drop pipe and sometimes a foot valve. All the moving parts of the pump (except for foot-valve components) are located above ground, so that there is no requirement for lowering of heavy cylinders or pumprods into the well. The chief concern in suction pump installation therefore should be to ensure a good sanitary seal at the wellhead. Some pumps bolt directly to a flange on the drop pipe, which extends above the apron; others are fixed to base plates concreted into the apron or to a plinth raising them above the apron level.

The other important safeguard is to set the foot valve well above the bottom of the well, allowing for a possible build up of sand in the well without interfering with the operation of the valve.

Direct action pumps

For lifts of 15m or less, direct action pumps are gaining rapidly in popularity. One reason for this is their comparative simplicity of installation, and consequently operation and maintenance. Components of most direct action pumps are light, and usually include semi-buoyant pumprods. Special care is needed to ensure that all the pumprod joints are watertight, or buoyancy may be lost and the pump will then become very heavy to use. Accurate alignment of the rising main and pumprods is important, as the annular gap is usually small and abrasion can damage the rising main as well as making the pump more difficult to operate. The cylinder setting too should be determined accurately, to allow for future drawdown, but prevent silting up.

Deepwell reciprocating pumps

Deepwell pumps are more complex and need great care in installation. Conventional handpump cylinders, manufactured from brass, cast iron and gunmetal, are heavy in themselves and even harder to lift when connected to 30m of 12mm galvanized steel rod and 32mm i.d. galvanized steel rising main. Techniques for lowering such assemblies progressively down into the well generally call for two or more skilled workers with additional labourers and, particularly for deep installations, a block and tackle on a substantial A-frame. The correct length of pumprods and rising main is critical to ensure proper operation of the plunger in the cylinder, and both rods and rising main may have to be cut and rethreaded on site to obtain the right setting. When galvanized steel pipes are being used, they are best supplied in manageable lengths (say 3m), to ease site handling.

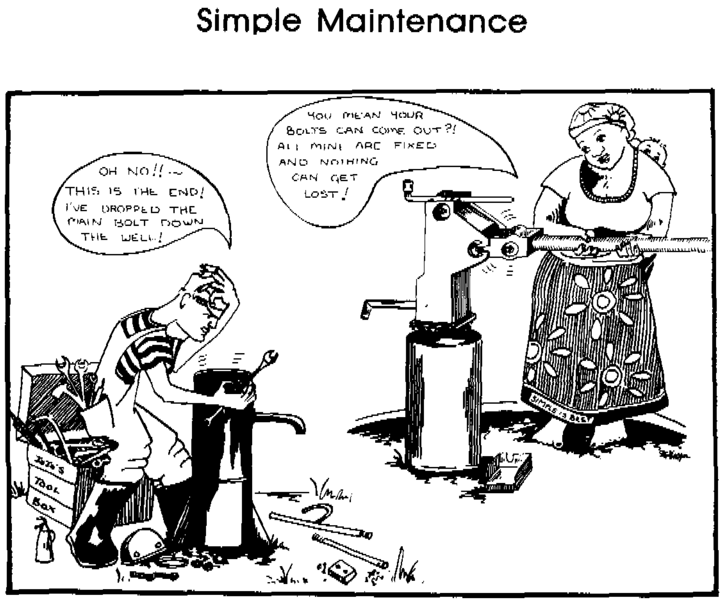


Figure 6.2 An amusing demonstration of variations in the complexity of handpump installation, taken from a brochure promoting the Afridev

Accurate measurements of well depth and cylinder setting will ensure that the cylinder can be located sufficiently deep to account for any anticipated drawdown of the water level in the well and far enough from the bottom of the well to reduce the danger of silting up.

Some modern pump designs, based on VLOM principles, employ larger diameter rising mains, which allow the plunger and foot valve to be withdrawn for seal replacement or other maintenance without removing the rising main. The cost of this maintenance improvement is a heavier rising main. Use of plastic rising mains is increasing, reducing the weight problem, but adding additional skill requirements in jointing and special site storage arrangements to prevent ultraviolet attack on sensitive materials or end distortion prior to installation. Compensating for this additional complication in installing and supporting the rising main, installation of VLOM-type cylinders is very much simpler and can be simplified still further where designs incorporate snap-fit connectors for pumprods instead of the conventional threaded connections. In the case of the Afridev pump, as already mentioned, villagers have removed, replaced and re-installed plungers and foot valves from depths of about 40m in less than half an hour, without the need for any lifting tackle and using only one simple tool.

In selecting handpumps for deepwell applications, the skills and tools needed for installation and particularly maintenance should be one of the key criteria.

Rotary pumps

With rotary pumps, the cylinder of the reciprocating pump is replaced with a rotor/ stator, also located near the bottom of the well. Again, galvanized iron rising main and pumprods plus the pumping element have to be lowered into an accurate position in the well and, in this case, connected to the sealed gearbox which forms part of the heavy pumphead. Installation therefore inevitably calls for considerable skill and for lifting equipment.

Diaphragm pumps

The hydraulic operation of diaphragm pumps has the great advantage that installation, even in the deepest wells is quick and simple. Both the hydraulic circuit and the rising main can be light flexible hose, by which the pumping element itself can be easily lowered into the well by hand. Assembly of the ground-level primary cylinder is comparatively straightforward, and the pump can be fitted with either a lever action pump head for manual operation or a pedal for foot operation. In each case, assembly can be accomplished by trained area mechanics without special equipment. As in all pump installations, achieving a satisfactory sanitary seal at the pump head is important, particularly so in this case because current models include a footplate directly on top of the apron, which means that the well casing cannot be extended above the apron.

Figure 6.3 Good apron design is essential, to prevent unsanitary conditions

6.2 APRON CONSTRUCTION

The apron is a slab of impervious material, usually concrete, which surrounds the pump. Its purpose is to provide a firm footing for pump users and to drain spilled water away from the pump so that it cannot seep back into the well and cause contamination. It may also be used for washing clothes or utensils, or for personal bathing. In many pump designs, the anchorage for the pump head is built into or bolted to a concrete base incorporated in the apron.

Appropriate design for the apron can have a major impact on continuing use of a new pump. Initial enthusiasm for the new water supply makes the pump a natural focus of village life in the weeks immediately following its installation. Good apron design, avoiding the creation of stagnant pools of muddy water, can encourage users to see that the area around the pump remains clean and tidy, and it can remain an important focal point. By incorporating suitable clothes washing and bathing facilities at or close to the pump, it can also serve to promote better hygiene behaviour and hence improved health in the community. It is common in some countries for spilled water from the pump to be drained to a small vegetable plot, where it can be used to irrigate the crop. Such an arrangement can be a good incentive to motivate a pump caretaker.

The pump apron therefore has an important amenity role, in addition to its practical purpose. Apron construction can also provide a useful opportunity for villagers to become involved in the installation work, whereas much of the well construction and pump installation may well have been carried out by "outsiders".

The condition of existing pump aprons may often be a guide to a community's capacity to look after water installations. In the more capable communities, aprons will be kept clean and cracks will have been filled with mortar from materials bought on the local market.

Design considerations

The apron should be constructed of strong building materials and on firm foundations, as the loading can be considerable when lots of people gather round the pump. Anchor bolts holding the pump to the apron will be subjected to high and fluctuating loads, so they need to be firmly and accurately fixed in position. The apron can be built to any shape, to suit local preferences. Circular designs are popular in some regions, in which case a minimum radius of 1m is recommended; for a square or rectangular shape the minimum size should be $4m^2$. If no separate platform is provided, the apron must be large enough to permit simultaneous use by 3-4 people for drawing water, clothes washing, bathing children, etc.

In the case of dug wells, a precast concrete slab spanning the well lining will be an integral part of the pump apron. This needs to seal the well against pollution and have an access hatch large enough for a man to gain entry for cleaning or deepening of the well. Typically, a 150mm thick reinforced concrete slab may be cast in a mould

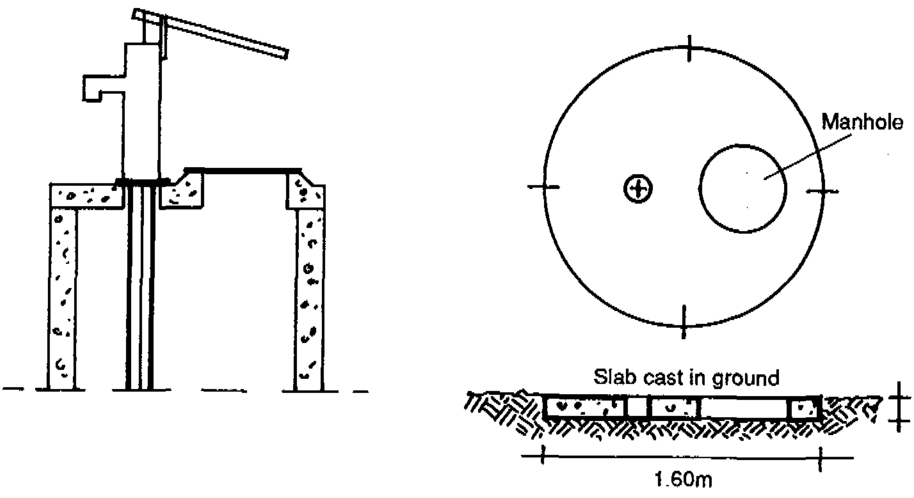


Figure 6.4 Apron design for a dug well

excavated in the ground. Extra reinforcement is needed around the access hatch, which should also be provided with a concrete lip to keep out spilled water. Construction of such a slab is described in the publication *Hand Dug Wells and Their Construction* (Watt & Wood, 1976).

Apron design should take account of future pump or well repairs. In some cases, aprons are damaged every time the pump has to be lifted for repair.

A gentle slope is needed away from the pump discharge point, and the drainage water should then be channelled into a concrete or masonry gulley or a pipe leading it away to a ditch or soakaway (or to a vegetable plot). A perimeter kerb helps to ensure that most of the spilled water follows the intended route. Drainage is made easier if the well is located on a low hill, or if the ground is made up to create a gentle slope away from the apron (the ground must be properly compacted). To prevent erosion of the ground surface or the creation of muddy pools where disease-carrying insects can breed, any water flowing away from the apron must be retained by impervious material until it reaches a suitable discharge point.

Users often like to have a small block on which to rest their container while filling. The shape of locally used containers will fix the shape of such a block. Standard apron designs help to ensure that each of the important design features are included, but there is also scope for users to influence such things as handpump position and orientation of the drain.

Construction

The pump anchorage is the fixed point of the apron, which must be accurately positioned as the first operation. In some cases, the pumphead will fit directly onto the well casing, or onto the drop pipe in the case of some suction pumps. More commonly, a template will be provided with the pump for fixing bolts into the concrete base, or there may be a steel frame to be built into the concrete, which provides a rigid anchorage. This is a potential source of future problems, which calls for great care during installation. There are many examples of pumps no longer fixed to the apron because bolts have loosened or corroded or have been pulled out of the concrete. Fixing and levelling of the pump mountings in such a way that they will not be disturbed during slab construction calls for skill and experience, and village construction crews need help from agency technicians for this critical stage.

Once the pump mounting is rigidly fixed (sometimes the pump itself may be installed in advance of platform construction), setting out of the apron slab can begin. First, any vegetation and loose topsoil must be cleared and replaced with well compacted hardcore made from broken brick or gravel and sand, to a level which allows for about a 100mm layer of concrete, including a drainage fall from the pump position to the outlet point. Pegs hammered into the ground around the intended slab perimeter fix the finished level of the concrete and set a line for the edge formwork (in some cases, the perimeter kerb is constructed first in brick or concrete blocks, to provide an outside form for the slab and a small retention wall for the water).

A 1:2:4 (cement:sand:aggregate) mixture provides a strong concrete platform, and it is important that the concrete is well cured by covering it with permanently moist sacks

Figure 6.5 Proper drainage is essential, and should include a soakaway to avoid unsanitary conditions

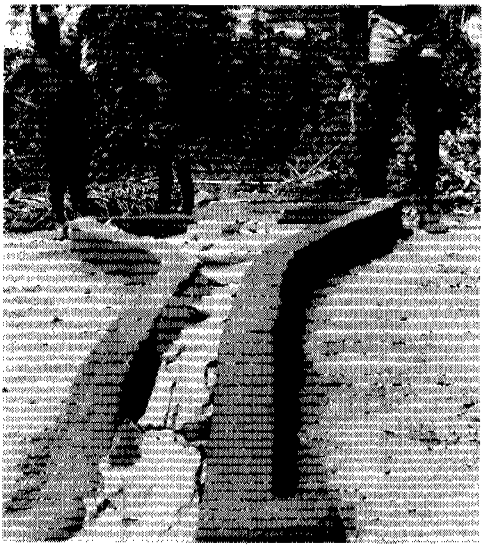


Figure 6.6 Use of moist sand or leaves is a more effective way of curing the concrete than these dry sacks. Keeping the concrete moist for several days is essential for proper curing

or wet sand for several days. Pump users should be encouraged to keep an eye on concreting operations, to check that cement goes into the concrete and not to the black market, and to make sure that the concrete stays moist. A gentle slope can be achieved by levelling the concrete with a long board and finishing it with a wooden float. Mortar rendering can be applied, provided it is properly cured.

One useful ploy is to remove the pump handle, or otherwise immobilize the pump, while the apron is curing. Any premature use of the pump will weaken the anchorages. The caretaker should explain this to the users and only fit the handle when the full curing time has elapsed.

From the apron drainage outlet, a gulley with a minimum slope of 1 in 30 should be constructed to lead the water away at least 5m from the edge of the slab. The gulley is also best constructed from concrete, after stripping away any surface soil, but if the ground surface is reasonably firm and impermeable below the topsoil, a trench can make an adequate drainage channel. If the drainage water is not to be used for irrigating a vegetable plot or for an animal drinking trough, it should be led to a proper soakaway, so that it does not create unhygienic surface pools. A soak pit about 800mm in diameter and a metre deep can be filled with stones, broken brick and gravel, to ensure that the water is controlled as it seeps away into the subsoil. Poor natural drainage can also be improved by planting moisture absorbing shrubs and trees. Planting trees may often be a better solution than a drainage pit, which can tend to clog quickly, especially in clay soils.

The area around the apron should be cleared and sloped to ensure proper drainage. Low spots can be located by splashing water over the surface, and these should be filled. The path to the well should not approach from the uphill side, as in the rainy season, it will act as a water channel, bringing dirty and erosive water to the wellhead. Finally, a fence around the well site, made from local materials, helps to keep animals away and delineates the area to be kept clean.

Apron maintenance is critical, to prevent unhealthy conditions developing and to safeguard the well from contamination. As with the handpump, responsibility for apron maintenance should be clearly established before the scheme is implemented.

6.3 INSTALLATION RECORDS

As we have seen in Chapter 3, information on hydrogeology is a crucial part of community water supply planning. Records of existing installations provide a valuable and economic data source. Information about the well and the pump is also of critical importance in maintenance and repair of the pumps during future years. The information should therefore be recorded in the pump logbook which will later be kept by the pump caretaker and the water agency.

In addition to the geological data recorded during the preliminary surveys and the well construction phase, individual handpump installation records should include, as a minimum:

- Name of village and geographical data;
- Diameter of well casing and depth of well;
- Year and month the well was constructed;
- Water level measured before installation of pump;
- Estimated yield;
- Pump make and model;
- Cylinder diameter and setting depth;
- Water quality data (iron, chloride, etc, where these are a problem);
- Date of pump installation;
- Name of caretaker.

Most agencies develop standard forms to record installation data.

Figure 7.1 A mechanic equipped with simple tools and a bicycle can carry out most servicing of modern handpump models

7. *Handpump Maintenance*

The deplorable failure rate of handpumps in so many countries in the past is predominantly due to inadequate provision for maintenance. It is uneconomic and impractical for central agencies to look after the maintenance of thousands of pumps scattered widely across rural areas of a country or region. Yet, this has been the system most frequently adopted in handpump programmes implemented during the last twenty years or so.

The modern approach to maintenance, in which the community plays a maximum part in the upkeep of the pump requires careful planning and organization, and puts important, but manageable, responsibilities on implementing agencies as well. In this Chapter we look at some of the shortcomings of past maintenance strategies, analyse the alternatives available on the basis of the true requirements of properly selected and installed handpumps, and discuss ways in which preferred strategies can be organized and funded.

Not all the answers are available; structures for community management of water supply systems are still in their infancy, though many clear principles are emerging from successful programmes.

First some of the main reasons for the poor record of past strategies:

- Maintenance is often viewed as a system for repairing pumps after they break down, rather than preventing breakdown;
- Costs of despatching mobile maintenance teams from a central depot to a distant pump for routine maintenance such as seal replacement soon become unsupportable;
- When a new handpump is not a felt need of the local community, villagers may refuse to support the pump and have no interest in assuming their part in maintenance, even when the government actually carries out the main part;
- The manner in which maintenance is organized rarely promotes the involvement of women, whereas women are the main users of pumps and have the greatest direct interest in their proper functioning;
- A handpump water supply may be rejected and not maintained when the water from it looks or tastes different from the traditional water source or when the site is not agreed upon by the community;
- Poor manufacturing quality increases the chance of pumps breaking down. This may be the result of design changes to reduce costs, induced by procurement procedures which favour low capital costs and ignore recurrent costs for future maintenance;
- Inappropriate choice of materials for pumps, such as iron or steel journals and bearings, can result in a need for maintenance functions like regular lubrication,

which are not practical. Similarly, failure to recognize the corrosive nature of many groundwaters results in the use of materials such as galvanized steel pumprods and rising mains, which fail rapidly in such environments;

- Pump designs which require complicated maintenance or special tools not available locally soon fall into disrepair;
- Poor installation results in many of the breakdowns which occur during the first few months of service;
- Frequently pumps are not standardized, so that too large a variety of handpump models is used. The varying maintenance requirements make it impossible to stock adequate spare parts or train enough skilled mechanics;
- Records of pump performance and maintenance work are often inadequate, so that breakdown cannot be anticipated and prevented by scheduled servicing or anticipatory maintenance;
- Functioning and use of pumps are poorly monitored and results are not being used to make organizational changes.

International organizations and bilateral aid agencies provide funds for new handpump installations, but in the past have not been so readily prepared to finance the software elements necessary to make community maintenance successful, or to continue their involvement into the early years of pump use. This is considered to be the responsibility of national and local authorities in the developing countries and of the benefitting communities.

National governments face a real need to extend provision of handpump water supplies to unserved communities, but find it increasingly difficult then to make more and more funds available for maintenance of existing pumps. From the governments' point of view, there is often more political advantage in implementing programmes for new installations than in maintaining existing ones.

The vicious circle of neglected maintenance leads to fewer skilled mechanics, shortage of spare parts and caretakers remaining unpaid or lacking support. Inevitably, maintenance becomes even more inadequate and when pumps break down they cannot be repaired. Handpump users will not tolerate wasted journeys to broken pumps. Instead they return to traditional sources, and associated health risks.

In Chapter 3, we discussed ways of planning programmes in such a way that the technology chosen is suitable for maintenance with resources available to the community. The prime requirement is that maintenance should be timely and affordable on a continuing basis. That also means a maximum role for the community, an element which was emphasized, along with some brief examples of successful maintenance arrangements, in Chapter 4.

7.1 APPROACHES TO MAINTENANCE

The emphasis on community management of maintenance, and the important point that reliability depends as much on how quickly a pump can be repaired as on how frequently it breaks down, has led some to the conclusion that handpumps should be designed so that they can be made by village craftsmen from materials available locally and using simple tools. Maintenance could then be carried out at the community level and breakdowns could be repaired immediately. The argument is supported by the observation that many simple pumps of traditional design have been built and maintained by village craftsmen. However, these pumps are mostly used for low lift water pumping for irrigation and have been largely unsuccessful for intensive community use in domestic

Figure 7.2 The Sarvodaya SL5 handpump is manufactured entirely in village workshops in Sri Lanka and requires no external intervention for maintenance

water supply. Nevertheless, one should not overlook the potential for local manufacture and village-level maintenance of handpumps in appropriate settings. The example of the Sarvodaya SL5 pump manufactured locally and maintained through a network of regional and village workshops in Sri Lanka has been described in Chapter 2.

This type of provision for maintenance is the opposite extreme to central maintenance in which the community has no role whatsoever to play, except to report breakdowns. However, when handing over full responsibility to the community, it is important for central and local governments to undertake a support and monitoring role, in order to ensure proper standards and health care.

Also, it is not reasonable to assume that the local community can cope alone, however well selected the handpump may be, and however many well trained local caretakers and mechanics are available. Problems such as well clogging or excessive sand intrusion cannot be solved by local caretakers. A backup maintenance service is essential, and should have the necessary resources and equipment, and be able to supply the necessary spare parts promptly and reliably. This backup service may be provided by the government alone, or through a private sector organization or a national NGO, as in the Sri Lankan example.

Another approach is to design and construct sturdy pumps which require little or no maintenance. Several decades ago, this approach was widely adopted, especially in countries with colonial administrations. Heavily built pumps were used, with bearings and other moving parts totally enclosed for long life. Some of these pumps survive today, but the majority eventually broke down and then proved impossible to repair. Few such pumps are installed today, partly because they are very expensive, and mainly because they are totally unsuitable for community involvement in maintenance.

The favoured approach now is to use pumps which offer long life of non-wearing parts and simple economic replacement of wearing parts. In that way, routine servicing becomes possible at the village level, while the more expensive backup service needed for major repairs should be called upon only infrequently.

7.2 MAINTENANCE SYSTEMS

Handpump maintenance systems are often characterized by the number of levels (tiers) in their organizational structure. In a one-tier system, all maintenance is exclusively undertaken by a single entity. This may be a central organization, a private sector agency, or the community itself. In a two-tier system, maintenance work is shared by the user community and another organization, usually the water supply agency. When a three-tier system is employed, local authorities or area mechanics carry out some maintenance functions.

Until recently, central maintenance was the only practical option, because maintenance and repair of the heavy and complex handpump models generally available required skills, tools, spare parts and lifting gear not available to village communities. That situation has been changing rapidly, and the pros and cons of alternative maintenance systems need to be weighed carefully when pumps are being chosen, with the main criterion that the greater the role that the community can successfully adopt, the greater the chances of the completed project being both sustainable and replicable.

Centrally organized maintenance

When the government or water supply agency assumes responsibility for handpump maintenance, it has to provide staff, equipment and transport, establish workshops and stores, and arrange procurement and distribution of spare parts. District mobile maintenance teams have to visit pumps for maintenance or repair (almost inevitably the latter), when the community notifies them of a pump breakdown or poor functioning.

Figure 7.3 Mobile maintenance teams are costly and eventually unsupportable for regular maintenance

Responsibility is clear, but that apparent advantage is outweighed by the lack of community commitment and long waiting times for repairs, which soon leads to breakdowns going unreported, as villagers become frustrated by lengthy waits and are unable to take any action themselves. Experience shows that, while central maintenance can seem efficient in the early stages of a handpump programme, it is invariably expensive and soon proves unable to keep up with the needs, as the number of pumps and breakdowns grows.

With many pumps scattered over wide areas, costs of transport become prohibitive, frequently amounting to more than half the total costs, which are anyway not affordable in the long term.

Village-level maintenance

If it was possible for all maintenance operations to be carried out by a community-based pump caretaker, this would be a highly attractive system. However, it is neither fair nor realistic to assume that villagers can look after handpumps without any external support or technical assistance. A backup maintenance system is essential, caretakers and water committees need periodic training and monitoring of performance, major repairs of the pump or well call for higher levels of skill and equipment, and the provision of spare parts can only be secured with government or private sector support.

Community-based maintenance

The term "community-based maintenance" has been chosen to reflect the approach whereby final responsibility for as many maintenance operations as possible rests with the user community. Irrespective of the pumps used, there will be maintenance tasks beyond the capabilities and means of the village pump caretaker, who will also need technical support, spare parts supply and backup from outside the village. However, the key point is that the *initiative* for organizing such support when it is needed should come from within the community, and that *payment* for any services or materials supplied should be managed by the community.

Pump selection has to be suitable for community-based maintenance (a VLOM pump), and pump caretakers have to be trained during pump installation and equipped with any necessary tools and an initial stock of spare parts. There must also be a village structure capable of supervising the caretakers and mechanics and organizing the recovery of maintenance and repair costs.

Current research and development work is leading to lighter, easier to maintain pumps coming on the market, suitable for increasingly heavy duties. Major repairs will generally require the services of at least a trained mechanic, but experience has shown that, with the right training and incentives, locally-based mechanics can economically look after up to 20 communities in their neighbourhood, and make a useful income from such activities, while providing a prompt and reliable service. Providing that such arrangements are organized by the community from its own resources, dependence on area/block mechanics, either from the local authority or the private sector, can be incorporated into a community-based maintenance system (as indeed can occasional visits from central maintenance teams, for coping with catastrophic failures).

In its most satisfactory form, community-based maintenance has access to village skills and resources for routine servicing, area mechanics for any repairs outside the capacity of the pump caretaker, and district maintenance teams when all else fails. As Chapter 4 makes clear, achieving satisfactory community-based maintenance involves planning and decision making with the community from the very early stages of projects, and means that the promoters of community water supply schemes must be committed from the start to establishing a community structure able to take the necessary responsibilities.

7.3 MAINTENANCE NEEDS

In planning the most suitable maintenance system for a particular project or programme, the types of maintenance operations needed on the various pumps under consideration need to be properly defined. Some pump components will last for many years, without any maintenance, others need regular repair or replacement because of wear or vulnerability to damage. There is also a considerable difference between above-ground servicing such as seal replacement in a suction pump, and the same operation in a high lift pump with the cylinder 40m or so below ground.

As programmes progress, the water agency should endeavour to collect data on the number and type of repairs carried out on each handpump type, and build up a dossier of maintenance needs. In the initial stages of a programme, use must be made of other available data, such as those coming from the UNDP/World Bank Handpumps Project.

In *Community Water Supply: The Handpump Option*, the repair and maintenance needs of each handpump tested in the field has been recorded and illustrated. The information is broken down according to the frequency of essential interventions needed on each of the pump components (handle, fulcrum, rod hanger, pumprod, rising main, plunger seal, pumping element, foot valve, and "others"). While this information can clearly only relate to the specific conditions of the field trials, it provides a useful indication of the types of failures which do occur with different types of pumps. In global terms, 75% of all repairs in the field trials were on below ground components.

Above-ground maintenance

Servicing and repair operations on the pumphead are usually the simplest for a pump caretaker to carry out. Nevertheless, it is important to recognize the special demands of particular pumps. In some cases, for instance, exposed moving parts in the pump head may require frequent lubrication. While this is a simple operation, it does mean that there must be dependable supplies of grease, and assurance that the task will not be neglected (as it frequently is). Sometimes, using locally available oils for lubrication can reduce dependence on outside sources.

Important wearing components in the pumpheads of reciprocating pumps are the bearings. Where handle bearings need replacement, provision has to be made for supporting the weight of pumprods, while the repair is undertaken. Special tools may also be needed to remove and refit ball races, and correct alignment is often critical to future pump performance. Pumps are now beginning to appear on the market in which plastic bearings which can be snapped into place have replaced the ball races, and such pumps may be favoured where simple maintenance is seen as a key criterion.

Rod hanger failure is also an above ground failure, though the type of repair needed means that it is best thought of in the same category as pumprod breakage, discussed under below ground maintenance.

In rotary pumps, the gearbox is generally supplied as a sealed unit with long-lasting lubricant. As such, it cannot be repaired on site, but must be replaced by specialists if it does fail. In diaphragm pumps, the ground-level primary cylinder may need servicing, to repair the plunger or replace seals. The components are easily accessible, and in West Africa, such repairs are routinely carried out by village mechanics, using a single spanner. Direct action pumps have only a T-bar handle passing through a bush in the pumphead above ground and any repairs needed are easy to carry out, providing spares are available.

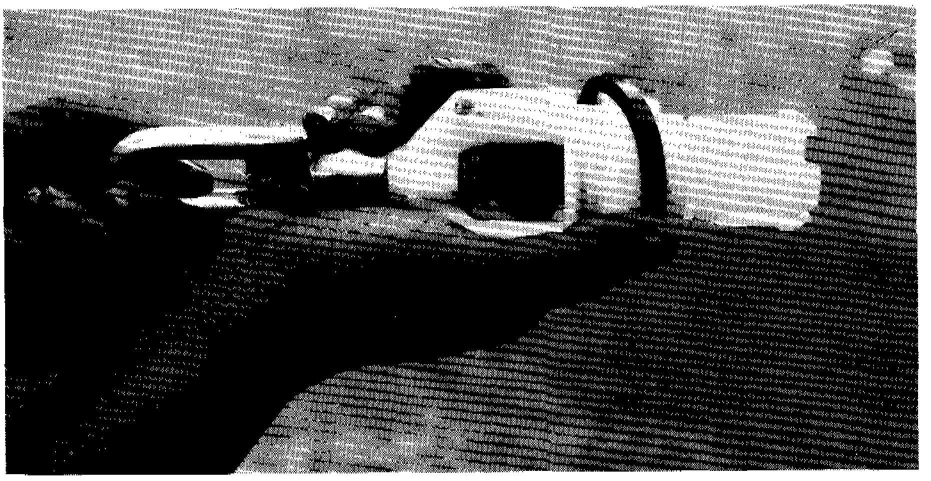


Figure 7.4 Seal replacement is the most frequent servicing need

Below-ground maintenance

A quarter of all repairs carried out on reciprocating handpumps involve replacement of the plunger seal. Commonly made from leather, new plunger seals are cheap and readily available. The problem is that replacing them is often a difficult and time-consuming operation that requires special tools and lifting equipment. One of the greatest contributions to improving handpump reliability would be simplification of seal replacement and a reduction in the frequency of seal failure.

Progress is being achieved on both fronts. Open-top cylinders, which allow the plunger and foot valve to be withdrawn through the rising main, eliminate the need to lift out the rising main. Use of nitrile rubber seals instead of leather has given extended seal life in several pump models. Work is also going on into the development and testing of seal-less plungers, in which a naturally tight fit between the plunger and the cylinder wall, or a labyrinth arrangement of grooves inducing turbulence at the interface, restricts leakage past the plunger while eliminating the key wearing part (The Volanta is one pump already fitted with a seal-less plunger).

Foot-valve seals too need regular replacement, and provision for their easy removal has a significant impact on pump dependability.

Another crucial factor affecting seal life is the efficacy of well protection. A properly constructed well with suitable screen and gravel filter to prevent sand intrusion will require far fewer visits to replace plunger seals and foot valves than one in which sand is continually pumped through the cylinder.

Pumprod breakage also accounts for a significant number of handpump failures. Often corrosion is to blame, and it is important to recognize that galvanized steel pumprods do not have adequate protection against corrosive groundwater. The zinc coating gives only short term protection, and anyway is commonly damaged during tightening of threaded connections.

Recovering below-ground components when the rising main slips or breaks can be very cumbersome. A simple design precaution, which few manufacturers have yet adopted, is to attach a permanent safety line (nylon is the most suitable material) to the cylinder, so that it can always be retrieved. The purpose of the safety line has to be explained to the installation crews, as nylon ropes are very valuable and tend to disappear. As with pumprods, galvanized rising mains are susceptible to corrosion, and failures may also occur due to fatigue stresses, internal abrasion from chafing of pumprods, or thread failures.

Rotary pumps have the advantage over plunger-type pumps that the seal is provided by the tight fit between rotor and stator. They are therefore less susceptible to damage from sand pumping, and require significantly less servicing of below-ground components. When failure or reduced performance of the pumping element does occur, however, it is inevitably a job for skilled mechanics with heavy lifting equipment, and replacement parts must be imported. The trade off for less frequent interventions is therefore more complexity and expense and the possibility of long delays when repair is needed, defeating the objectives of providing safe water.

Diaphragm pumps do not suffer from seal failures or from pumprod/rising main breakages. They also have the considerable advantage that the pumping element can be hauled out of the hole, even from great depth, without the need for any lifting equipment. The penalty in this case is that the pumping element (diaphragm) is a costly imported item. It can be damaged by a buildup of sand, which eventually causes rupture, or by prolonged wear, and provision for procurement and distribution of spares is an important criterion, when considering the use of diaphragm pumps.

Seal replacement is a common repair needed with direct action pumps, though the light weight and inherent simplicity of these low lift pumps make such operations straightforward, and usually within the capacity of a pump caretaker. Also, the high speed movement of the plunger that is a feature of direct action pumping makes them good candidates for seal-less plungers. Pumprod breakage or leakage is another source of trouble with direct action pumps, and makes it necessary for the proposed maintenance system to be equipped for any special jointing system needed to repair the rods.

Well maintenance

Eventually, even the best constructed and developed well may need maintenance. Sand movement in the formation may lead to progressive clogging of the gravel pack or the well screen, or sand passing through the filter arrangements may build up in the bottom of the well until it interferes with operation of the foot valve.

Rehabilitation of a drilled well will usually call for a visit from a skilled team, with the equipment necessary to remove the handpump installation, bail or pump out the sand deposits, and redevelop the well by repeating the original development sequence.

Dug wells too may silt up with time, or, more commonly, may be left dry by a progressive lowering of the surrounding water table. In this case, villagers themselves will usually have the necessary tools and skills to deepen the well, at least for a short distance. Advice may well be necessary however, if extension of the well lining is needed, and there will be a need for a motorized pump to dewater the well during re-excavation.

Apron maintenance

Continued use of handpump installations depends too on the pump surroundings being maintained in a clean and attractive condition. Apron design should be such that it is easy for the caretaker, well committee or users, to keep the platform clean and tidy, and to prevent the formation of muddy pools. Cleanliness of the well surroundings should be seen as a community contribution towards the new supply and performance monitoring of the water point should include cleanliness checks.

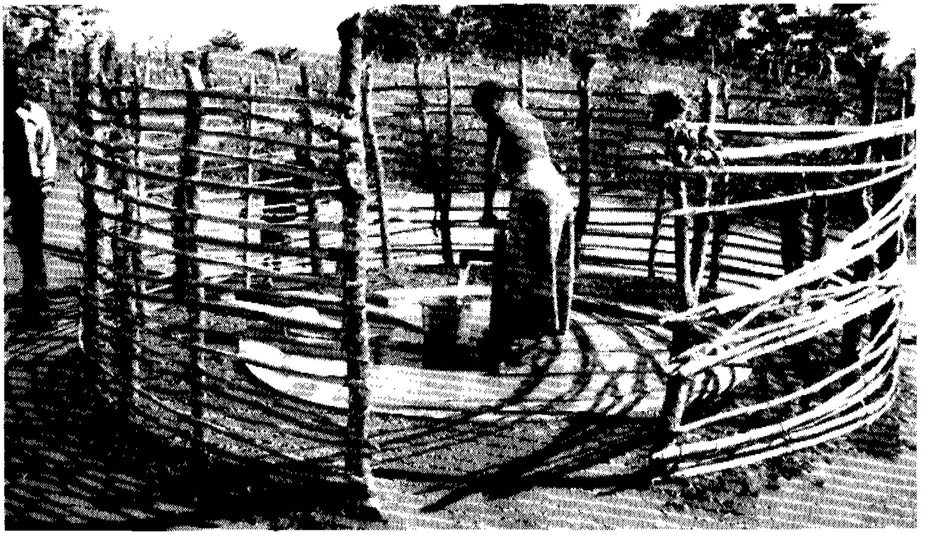


Figure 7.5 Fencing can further improve the cleanliness of the pump environment

Maintenance schedules

In a community-based maintenance system, as much as possible of repair and maintenance work should be undertaken by the pump caretaker, with the help of community members. It is helpful for the caretaker to have a checklist of activities to be undertaken, and a record book to keep a note of pump performance and any repairs carried out. Ideally, this maintenance schedule should also attempt to programme the activities of area mechanics and any central support which might be needed. Linking the tasks to

Table 7.1 Typical job list for a village pump caretaker

Daily	• clean outside of pump and platform • check drainage of excess water and ensure that no stagnant water collects • promote hygienic conditions around the pump • see that animals are kept away • check operation of pump • check whether the pump is firmly fixed to its base • record checks in log book
Weekly	• oil or grease all moving parts in pump head • check with users whether there are any problems with the pump • check the condition of plunger seals and foot valve by operating the pump slowly, e.g. at 10 strokes per minute; if no water is raised, dismantle the pump head, remove the plunger and foot valve, clean moving parts, or replace them if they are worn (alert area mechanic as necessary) • check and tighten all nuts and bolts • record all work in log book • check the boundary hedge or fence and repair any damage
Monthly	• carry out all weekly tasks • check the pump stuffing box and adjust locknut as necessary; do not overtighten, but allow some slight leakage around the pumprod • report to the area mechanic whether the pump requires servicing or major repair
Half yearly	• assist the area mechanic in inspection of the inner parts of the pump • assist in servicing and repair • repair or arrange for the repair of any holes or cracks in the platform
Yearly	• check all exposed and moving parts of the pump for rust • clean parts to be painted and apply paint • check wear at handle pivot points and bearings and assist area mechanic to replace parts where necessary

special days of the week, such as Sundays (Fridays in Moslem societies), helps to establish regularity and associate the work with services to the community.

A system of fully scheduled maintenance, in which wearing parts are replaced at prescribed intervals before they break down, would have considerable benefits as far as provision of spare parts and reduction of downtime are concerned. Unfortunately, such arrangements are presently rare or non-existent, and the schedule shown in Table 7.1 is based on a compromise of diagnostic visits from area mechanics to supplement (and hopefully reduce) the need for call outs to breakdowns. Any such schedule can only be prepared for a specific project, so the activities listed need adjustment, to suit the type of handpump used and local conditions. It is presented as a job list for the pump caretaker, though some of the tasks also imply support action from an area mechanic.

The need for up-to-date and complete records of work done by the pump caretaker, the area mechanic and the central maintenance organization cannot be overemphasized. Records provide a basis for determining the frequency of routine maintenance and servicing of pumps and so help to develop realistic work schedules.

7.4 MANPOWER AND TRAINING NEEDS

The three-tier maintenance system developed in Tamil Nadu and some other states in India for the India Mark II deepwell pump is often cited as an example of a community-based system with governmental backup and support. In reality, the system is supervised and managed from the top, so that it lacks the key ingredient of village-level control. It involves:

- village-level pump caretakers;
- governmental sub-district level (block) service mechanics;
- governmental district level mobile maintenance teams;

Pump caretakers

A permanent resident of the community is selected by community leaders, or by the Block Development Officer in consultation with these leaders. Increasingly, the caretaker is a woman, as young men may leave the village when a job opportunity arrives, and anyway are inclined to neglect their pump maintenance duties when there is no payment. In fact, a payment system is recommended, as otherwise there is little incentive for the caretaker to be diligent. Sometimes, the task is entrusted as a part-time job to a local artisan, shopkeeper, or social worker.

The chosen caretaker is given a short course on the importance of safe water for health, and also trained in routine maintenance and minor repairs on the pump. In India, the advantages of standardization are well demonstrated by the fact that training materials, spare parts, tools, etc, for the India Mark II handpump are fully interchangeable from district to district, and even state to state. A certificate is sometimes issued to caretakers at the end of their initial training.

Figure 7.6 A handpump caretaker's certificate, as issued by the Tamil Nadu Water Supply and Drainage Board

The caretaker is responsible for keeping the platform around the well clean and for all routine maintenance. Basic tools are supplied by the governmental agency's maintenance organization. The caretaker also has the job of reporting pump breakdowns. For this purpose, there are pre-stamped and addressed postcards in the local language on which the pump components are shown schematically. When unable to fix a breakdown, the caretaker indicates the type of repair required on the postcard and sends it to the water agency's district office.

Area (block) mechanics

In India a Block is an administrative unit consisting of many villages. At this level, several service mechanics are employed by the local authority. Each has about 50 handpumps to supervise. The mechanics work under the supervision of the Block Development Officer, and use a bicycle to travel between pumps. Visits are scheduled when the agency is notified of a pump breakdown.

The block mechanic is trained to fix most problems in the pumphead, but usually cannot deal with major repairs and problems in the below-ground parts of the pump, particularly for cylinder settings beyond about 25m. If this is required, he notifies the officer in charge of the mobile maintenance teams.

Mobile maintenance teams

At the district level, mobile maintenance teams are each responsible for 5-10 blocks, i.e. for 300-500 pumps. Each team consists of a junior engineer, a fitter, a helper and a driver. They use a pickup truck for transport and have a small workshop at their disposal at the district office. Each mobile team receives a set of tools specially designed for use with the India Mark II pump. In theory, the mobile teams should only have to visit a pump once a year for a full service, as they are expected only to have to do major repairs or scheduled servicing. The aim is to be able to respond promptly, but the system becomes overloaded when the district maintenance teams are called in for almost all repairs beyond the most simple ones.

It can take several weeks (or months) before the team can fit in a visit to a village for a major repair, such as rethreading the pumprod or replacing the foot valve. In an attempt to cut down on the number of visits, an approach is being tried in which the pump head and cylinder of every pump visited are replaced with a new or reconditioned unit, whether the new parts were needed or not. Repairs are not carried out in the field, but in the district workshops, where all the spares are stocked. Repairing and reconditioning of replaced parts is to be carried out in the rainy season, when travel to pump installations is restricted.

Even with this system, the workload of mobile teams was too high, and a modified, two-tier, system was developed in Rajasthan state. In this system, the local mechanic (*mistry*) acts as both caretaker and block mechanic. He is given specialized training, lasting for three months, and is then put in charge of 30-40 handpumps. The mechanic is accountable to the user communities, and the village headman must certify that his pump is functioning satisfactorily before the mechanic is paid by the block development office. The pump users pay charges to the block development office and so have a keen interest in seeing that the mechanic does his job.

Manpower

Proper functioning of handpump maintenance depends critically on the number and the competence of manpower available. In the two and three-tier systems discussed above, there is a need for:

- caretakers for preventive maintenance and minor repairs;
- mechanics for major repairs and servicing;
- administrative staff to handle supplies, equipment and spare parts;
- storekeepers for spare parts and materials;
- drivers and maintenance mechanics for vehicles;
- management staff and supervisors.

Few data are available on the manpower requirements for adequate handpump maintenance. The number of staff engaged in maintenance operations in Bangladesh is summarized in Table 7.2. It does not include administrative staff or management and supervisory staff in the government agency, and shows how the number of tubewell mechanics per 10,000 pumps has reduced during the dramatic increases achieved in the number of handpumps installed.

Table 7.2 Maintenance staff per 10,000 handpumps in Bangladesh (excluding caretakers)

	1977	*1987*
Executive level and supervisory staff	1	1
Middle level	9	8
Operating level	50	30
Total	**60**	**39**

Source: IRC and UNICEF

Training

An essential task of the central maintenance organization is to train pump caretakers and area mechanics. Workshop practice and classroom instruction needs to be supplemented by on-the-job training, which can often be conveniently given during handpump installation.

Training of mechanics should cover the basic principles of handpumps, common problems and maintenance and repair procedures for the types and models of pumps used. Again, the value of standardization will be apparent, in limiting the breadth of training needed. Well illustrated and prepared booklets are particularly helpful for training, and manuals on procedures should be available. Most manufacturers provide instruction manuals for installation and maintenance of their handpumps.

Samples of all pump models used in a handpump programme, and the tools required to dismantle and re-assemble them, should be available for practice. A collection of broken or worn pump parts is useful for demonstrating causes of pump failure.

Pump caretakers will rarely be willing or able to spend more than a few days away from their village, and it is essential that their training should be conducted in just a few days in or near the village.

7.5 COSTS AND FINANCING

The type of maintenance system used will make a substantial difference to the recurrent costs of a handpump programme. Wherever teams of skilled mechanics have to travel large distances to service scattered pumps, staff and transport costs will dominate. Many attempts have been made to compare alternative maintenance systems on a theoretical basis, and the figures inevitably show that community-based maintenance is several times more economic than a centralized system. Fewer data are available which show direct practical comparisons, simply because there are few instances where different maintenance systems have been used in the same circumstances.

At the lower end of the scale, the European Development Fund programme in two provinces of Burkina Faso is quoted as costing just $0.05 per user per year to keep 85% of the handpumps working using a system based on private mechanics trained through the programme and equipped with a $600 tool kit. The Livulezi project in Malawi, where pump caretakers assisted by government-trained mechanics equipped with bicycles look after handpumps is estimated to cost $23.90 per pump per year, or $0.10 per user per year, including parts, labour, transport and overheads. Estimated costs of the three tier system in India range from $0.20 to $0.35 per user per year (World Bank 1987).

In comparison, systems which depend principally on mobile teams generally have annual maintenance costs per pump measured in hundreds of dollars, representing per capita costs of $0.50 to $2.00 per year.

Cost recovery

The financial burden on governments of rural water supply maintenance is rapidly increasing in countries where community water supply is seen as a social service. Recovery of a sizeable proportion of the costs of handpump water supplies from benefitting communities must be achieved if these supplies are to be sustained and replicated. It is difficult for village communities to appreciate fully the benefits of a new supply until it has been functioning for some time, and limited cost recovery over a short period may be an acceptable way to reach full recovery later. It is important for the water supply agency to avoid an accumulation of maintenance and repair costs which cannot be met from regular budget funds.

Regardless of whether finance for pump installations comes from national sources or external aid, the relationship between new installations and maintenance commitments has to be recognized from the start. Unless there is a financial basis for meeting recurrent costs, investments made in handpumps will be wasted. Agreement on the community's contribution to capital and recurrent costs needs to be reached before the pump is installed.

A water committee or other local organization has to be established to select the most suitable payment system and collect and administer water charges, and must be able to impose some type of sanction if payment is not forthcoming. These arrangements are neither easily nor quickly organized, but are necessary if repair costs are to be met.

Financing systems

Little information is yet documented on the type of financial management best suited for community-managed handpumps. Basically there are two approaches: *community-based finance* and *well-based finance*.

In a community-based system, the community as a whole contributes to the maintenance, and sometimes also the replacement, of all the community water supplies, including sometimes the upkeep of traditional sources. Resources come either from general community income where there is a capacity to raise local taxes or a revolving fund, or from regular or occasional contributions collected from households.

Financing from community income fits in with a policy of no direct charges to consumers. It also means less administrative complexities in collecting funds, writing receipts, and recording many small payments. On the other hand, pump maintenance is then in competition with many other interests for scarce resources. All too often, preventive maintenance funds are diverted for purposes with a higher political priority at the time, driving up the costs of putting things right later and leading to longer breakdown times. Only with good budgetting and a close guard on actual expenditure can the water organization and users try to prevent unwarranted diversion of pump maintenance funds. Another drawback is that indirect financing from community funds is not linked directly to water use. Light users, particularly those without easy access to a pump will thus pay the same as those who draw large amounts, perhaps even for commercial uses.

Individual household contributions for water system maintenance establish a clearer link between pump use and financing, provided that an equitable system of tariffs, collection and management can be found. This subject can only be resolved by the community itself, and was discussed in some detail in section 4.5. User group meetings and well committees may be instrumental in agreeing which households are rated full users, which are partial users, and on the use of flat or graded tariffs.

In a well-based system, each neighbourhood using a well will be responsible for its own site and the handpump, including the financing of maintenance and repair. A community water committee will normally be on hand to resolve problems beyond the group's capacity. An advantage is that close social ties help to achieve more equitable payments, and to cement the feeling of ownership. Difficulties can arise when some neighbourhoods face greater technical problems (aggressive well water is one typical example) and therefore higher costs which are outside their control (in such cases the community-based system has an element of automatic cross-subsidy).

The IRC publication *What Price Water?* has details of village structures appropriate for each alternative finance method, but it would be wrong to imply that all the answers are known. The fact is that community-based financing of water supply systems is a relatively new approach. There is a need to try out and document innovative approaches in pilot schemes, and to share information on those systems which work well under various conditions, and why. This is an important area for future research and development.

7.6 ORGANIZATIONAL IMPLICATIONS

For water sector agencies, the change from central to community-based maintenance means a fundamental change of approach, which also has implications for manpower development and institution building programmes. Project organizations which in the past have themselves carried out maintenance and repairs, will instead become trainers and supervisors of pump caretakers, area mechanics and village water committees. Different skills and attitudes are called for, and training courses for water supply technicians need to be altered.

Education and training

Socio-economic and health aspects also have to be included in the curricula of technical training institutes. In a field which is rapidly building up experience of innovative approaches, trainers and professional teachers need ready access to up-to-date information — a process which demands initiatives both from the teachers and from researchers and field workers who are the sources of the information.

Even courses which presently include elements dealing with community issues may find that the emphasis needs to be changed. Often trainees may be encouraged to determine the needs of communities through activities such as social surveys and group discussions, and to educate and motivate villagers to develop action plans jointly with the agency staff. However, the aim should not be to persuade villagers to accept technology and behavioural change which the agency staff believe to be right. As Chapters 3 and 4 make clear, successful projects involve a two-way process, in which the right solution evolves from decisions taken by the community, and agency staff respond to villagers needs and desires even when this means compromising their own views.

Institutional change

The skills to work with communities depend on the right selection and training of individuals. Different corporate skills and institutional arrangements are also needed for community-based management to be effective. Technical agencies need to be staffed and organized to develop and support community organizations with management and technical training, hygiene education, and backup support for maintenance and repair. Essentially this means reorienting technical staff from a purely technical role into a much broader support role. It will also frequently mean water agencies collaborating closely and regularly with other government departments at the local level. Typically, the technical agency will need help from organizations specializing in community development, health and finance, and from local cooperatives active in the community.

For the collaborative approach to work successfully, institutional links need to be forged and formalized, the management structure of water agencies may need adapting to fit its revised role, and individual career development patterns have to be devised, which make it attractive for trained staff to work on training tasks and at the community level.

Some countries have already made considerable progress in developing workable structures for maximizing community-level management of water projects. In Malawi, for instance, community consultation and organization is the responsibility of technical staff, whose selection, training, and career development depend on an aptitude for social work as well as technical performance. In Burkina Faso and the Upper Region of Ghana, a special corps of social agents carries out the specialized community tasks in collaboration with technical staff in the water agency. In other programmes — several regions of Tanzania, for instance — departments of water, health and community development share the work, based on a formal division of tasks.

Another form of community/private sector/government collaboration operates in Balgladesh, where 80% of the people use handpumps and 80% of those handpumps are functioning. In fact, the government's implementation staff remain highly technically oriented, with few community-related skills. The maintenance system works because the caretakers, who have usually provided most of the "community" contribution required for tubewell/handpump installation are generally the owners of the land on which the pump is located. When the pump breaks down they either fix it themselves or pay a government tubewell mechanic or a local handyman to do so. Other pump users benefit from this proprietorial attitude of the caretaker — whom they usually perceive as "the owner" of the pump. It would be against the caretaker's religion to deny anyone water, so everyone has access, though not necessarily on an equal share basis.

The potential for collaboration among water agencies and indigenous NGOs should not be overlooked. In Asia, organizations such as the Philippines Business for Social Progress (PBSP) or the Sarvodaya Movement in Sri Lanka have demonstrated the role that NGOs can play in maximizing community participation in the planning and management of water projects. National and local NGOs often have a wealth of experience in the introduction of water supply and sanitation technologies to rural communities. Their staff come from the communities they serve; they operate without profit and therefore have no vested interest; and they have an awareness and understanding of the culture, the politics, the economics, and the level of technical sophistication necessary for the development of cost-recovery and maintenance schemes. The main challenge now lies in transferring this type of experience on a much larger scale.

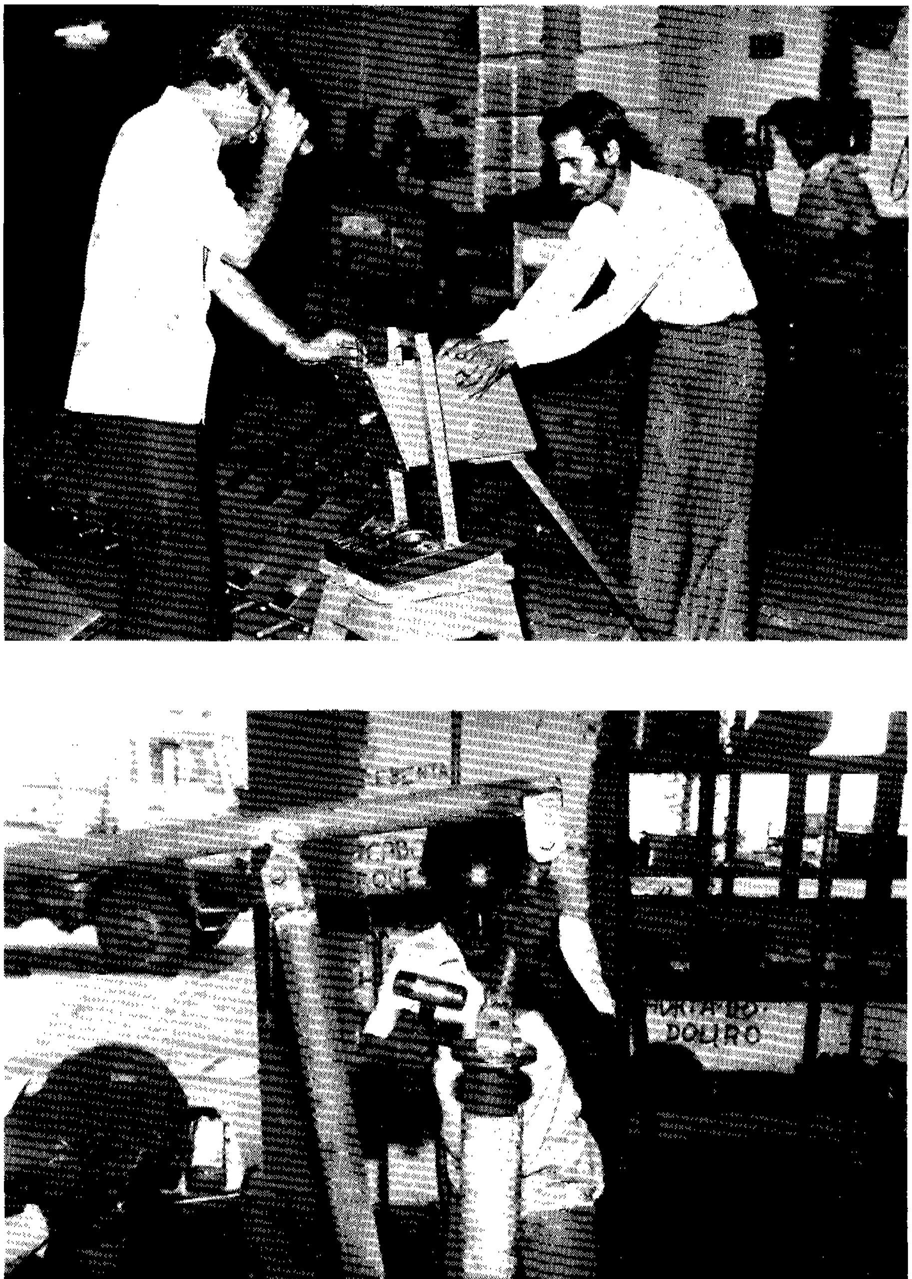


Figure 8.1 Local manufacturing is already being practised in several countries

8. *Local Manufacture*

When handpumps break down they must be repaired promptly, for reasons which have been emphasized throughout this publication. One of the constraints hampering rapid repair of pumps in rural areas of developing countries is frequently a shortage of readily available spare parts. Inadequate stocks may be held, there may be delays caused by import restrictions, shipping costs may be prohibitive, or it may simply be difficult to organize proper distribution facilities within the country.

It is logical to suppose that many of these problems could be overcome if the pumps, or at least the main wearing parts, were manufactured in the country of use. Local manufacture can also facilitate involvement of end users in the development of the pump and its adaptation to local conditions (IDRC, 1987). This argument has led promoters of handpump research and development to encourage the design of pumps suitable for manufacture in developing countries. However, there is no advantage and no cost saving if poorly fabricated handpumps give poor performance and unreliable service.

The aim should be to develop pump specifications which are appropriate for the level of industrial development of the country concerned, and to back them with quality control and inspection procedures which ensure that standards are met. If this can be achieved, the **benefits** of local manufacture will include:

- a supply of quality pumps at a reasonable price;
- manufacture within the country, so that supplies of pumps, and particularly spare parts, are readily available with substantial savings in transport costs;
- savings in foreign exchange;
- stimulation of local industry and creation of employment opportunities;
- standardization made easier.

The **pitfalls** of local manufacture of handpumps also have to be recognized. Handpumps are made from many different parts, and a variety of manufacturing processes is needed to produce a single pump. Leather or another flexible material is used to make plunger and foot-valve seals; various metals are used for the pump head, cylinders, plunger assemblies, valves and other parts; paint is needed to protect cast iron and machined parts against rust; and other materials may include rubber, nylon, nitrile, and epoxy resins. Plastic pipe and other plastic components are being used increasingly in handpumps. Thousands of locally produced handpumps have failed or been abandoned by users because of poor performance and lack of reliability. Some common defects are:

- poor quality of materials, such as cast iron components with excessive phosphorus content;

- tolerances too large, resulting in poor alignment;
- roughly finished cylinders producing rapid seal wear;
- no corrosion protection;
- cupseals of incorrect size or unsuitable material;
- threading poorly made or incompatible.

Inconsistencies in the dimensioning of handpump components are a common problem, so that replacement and spare parts do not fit.

There are two basic assumptions involved in the promotion of local handpump manufacture. One is based on the premise that handpump research and design requires collaboration of manufacturers from industrialized countries with local enterprises, to ensure that external resources, experience and quality control are combined with the advantages of local production. To invest in such research and development, the manufacturers must see opportunities to recover that investment through a market in the developing countries. Developing designs suitable for local manufacture simply to hand them over to a series of entrepreneurs in other countries is hardly an attractive proposition. Joint-venture arrangements can achieve this purpose, and there are numerous examples now of established manufacturers collaborating with companies in developing countries in the manufacture of handpumps modified to suit local conditions.

The second premise is that fostering research and development within developing countries facilitates the development of designs which are most appropriate for local conditions. The close relationship between technical and software components calls for collaboration among researchers, promoters, manufacturers and implementors, all of which need to be aware of the social, political and economic situation of their country. By developing a local research and manufacturing capability, technology can be kept alive, improve and adapt to changing national conditions. The resulting sustained research and development effort is important if long-term goals of self-reliance are to be achieved.

Handpump manufacture may be organized from the top down or from the bottom up. In the top-down approach, central commercial producers are responsible for manufacture of handpump components and spare parts, as is the case with the India Mark II, and with the Volanta pump in Burkina Faso. In the bottom-up approach, critical components are still manufactured centrally, under strict quality control, but other components, such as the above-ground structure and/or main replacement parts are produced at the village level or sub-contracted to cottage industries. The CIDA/SEEDS programme in Sri Lanka, described in Chapter 2, is an example of the bottom-up approach.

Just as manufacturers in industrialized countries need to see a future market before investing in research and product development, growth of local handpump manufacture in developing countries will only be stimulated if potential manufacturers can see outlets

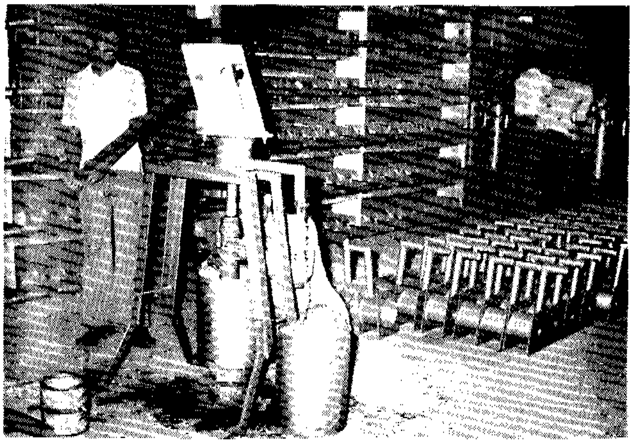


Figure 8.2 Pre-delivery inspection of India Mark II pumps

for their products. It follows that governments seeking to encourage local manufacture need to make it clear to prospective manufacturers that good quality locally made handpumps at the right price will be considered eligible for consideration in community water supply programmes, and to publicize the scale of future programmes so that market opportunities are clear.

Any standardization policy based on a single handpump design faces the danger that it may create a monopoly position for one manufacturer, who can then take advantage of his position to offer lower quality products or charge higher prices. However, there are examples of how this situation can be avoided, such as in India. The Indian government has standardized on the India Mark II handpump for the whole of the country's rural water supply programme, and there are now more than a million such handpumps installed in India, manufactured to an Indian national standard. Yet competition remains intense, because the standard pump design is manufactured by some 36 licenced manufacturers. Quality is maintained by means of a rigorous pre-delivery inspection procedure, yet the price of the pump is cheaper in 1988 than it was in 1978.

8.1 QUALITY CONTROL

Good quality control is in the interests both of the purchaser and of the manufacturer. Unless a consistent quality of pump is supplied, locally produced pumps will soon be rejected, and many potential benefits will have been lost.

Quality control costs money. In India, where quality control and inspection is carried out by an independent contractor appointed by the government and UNICEF, it is estimated that assuring that pumps meet the country's stringent specification adds 5-8% to the ex-factory price of pumps, depending on the order size.

The starting point for quality control should be inspection of the raw materials used to manufacture the pumps. Wherever possible, pump specifications should make use of national standards, or international standard specifications, so that inspectors have a clear basis for accepting or rejecting batches of, for example, pig iron, where the carbon and silicon content may be critical. A specific national standard for handpump materials is a great help. In Bangladesh, for example, hundreds of thousands of cast iron No.6 pumps are built successfully to UNICEF's own standard, because local foundries have become familiar with the standard.

Also before manufacture begins, the manufacturers jigs, machinery and other equipment need to be inspected and checked for dimensional accuracy and suitability.

During manufacture, a percentage of selected pump components should be inspected at key stages in the production process, with dimensional checks accompanying visual inspection and physical testing. Again, it is important that both manufacturers and inspectors should be aware of the specified criteria and tolerances which will be permissible. Initially, quite a high proportion of component production (up to 10%) may have to be checked to establish standards, but the percentage can be progressively reduced as internal quality control improves.

Pre-delivery inspection of randomly sampled pumps is the final stage, and should cover the quality of finish and workmanship, dimensional accuracy, alignment, welding quality, and other checks related to the types of materials used. It may also be necessary to have a recognized approval stamp, so that batches of pumps can be marked to indicate that they have been cleared by the inspectors, or to have another sure method of assuring that rejected pumps do not reappear on the market.

An additional safeguard, to maintain quality standards, can be achieved by the government operating an approved list of licenced manufacturers. The threat of removal from the list for future contracts provides powerful leverage.

8.2 CAST IRON MANUFACTURE

Until comparatively recently, most conventional handpumps had cast iron bodies and used cast iron or brass cylinders. Most pumps made from cast iron components were imported and, with notable exceptions such as India and Bangladesh, few foundries in developing countries have been able to produce large quantities of cast iron pumps of consistently acceptable quality. As a result, cast iron pumps are progressively giving way to those made from fabricated steel sections and to plastic pumps.

Manufacturing requirements

For the manufacture of cast iron handpumps, an iron foundry and machine workshop are needed. In an enterprise limited to handpump manufacture, purchase of castings from a jobbing foundry may be more economical. If a foundry is to be part of the community water supply project investment, it will almost certainly need to manufacture other castings as well to be economically viable. More often, it will be feasible to interest an existing foundry in extending its activities to include handpump manufacture.

Tools and machinery will depend on the complexity and level of production. Basic operations include casting, grinding, boring, drilling, threading and cutting. A lathe will be needed for boring the larger holes, for small holes a bench drill press is adequate.

An example of a foundry layout and equipment is shown in Figure 8.3. The layout should allow a natural flow of materials and parts through the manufacturing plant, and storage of components and of assembled pumps. The foundry capacity required is mainly related to the machine workshop throughput. If, for example, the workshop can handle about 1,200 pieces per week, the foundry should be able to process enough iron for 600 pieces per pour, based on two pours per week. About 10 persons could handle this amount of foundry work, depending on the equipment used. Foundry staff would make the moulds, assist in pouring, shake out the castings and transport them to the machine shop. The foreman and the material handlers would also make the initial charge in the furnace (Figure 8.3). Details of the casting process are outside the scope of this publication, but expert advice is essential in the establishment of operating procedures and quality control methods, if good quality pumps are to be produced.

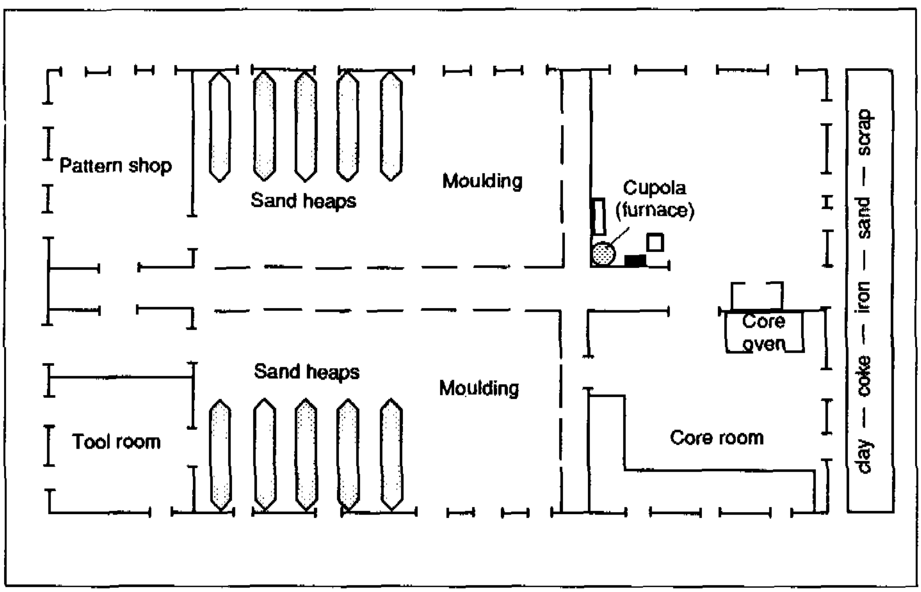


Figure 8.3 A typical foundry layout (Source: Battelle Memorial Institute)

Machine shop staffing depends on the volume of pump production to be handled and on the tooling and equipment. Table 8.1 gives an indication of possible needs for a weekly production of 20-40 pumps.

Table 8.1 Machine shop staffing (for production of 20-40 pumps per week)

Operation and equipment	*Number of persons*
Handling and shipping of materials	2
Grinding	1
Lathes	3
Drilling	3
Pipe threading	2
Pipe coating	1
Inspection and painting	1
Tap-die assembly	1
Foreman	1
Total	**15**

Raw materials

The raw materials needed for grey iron castings are pig iron and coke. Table 8.2 gives some indicative specifications for foundry pig iron suitable for handpump manufacture. It is drawn from a publication of the Battelle Memorial Institute in Colombus, Ohio, USA, entitled *Report on Foundry Pig Iron and Coke for Manufacture of the AID/Batelle Handpump*, by RD Fannon and ST Varga. Scrap iron is often included with pig iron, in permitted quantities. Use of a limited proportion of scrap iron increases the hardness of the casing.

Table 8.2 Specifications for constituents of foundry pig iron (permissible range of % content)

Silicon	*Carbon*	*Manganese*	*Sulphur*	*Phosphorus*
2.50 - 2.75	4.10 - 3.85	0.50 - 1.25	0.05 max	0.30 - 0.50
2.76 - 3.00	4.05 - 3.70	0.50 - 1.25	0.05 max	0.30 - 0.50
3.01 - 3.25	3.90 - 3.65	0.50 - 1.25	0.05 max	0.30 - 0.50
3.26 - 3.50	3.85 - 3.60	0.50 - 1.25	0.05 max	0.30 - 0.50

The significance of the four lines is that silicon and carbon content are directly related. It is difficult to control the carbon content of foundry pig iron, but best results are obtained if the content can be held reasonably close to the values indicated in the table. If the phosphorus content exceeds the permitted range, the pig iron will be hard and brittle and difficult to machine.

Foundry coke is difficult to make to narrow specifications, but some indicative figures for the maximum content (% by weight) of critical ingredients are: fixed carbon - 88%; volatile matter - 1%; ash - 12%; sulphur - 1%.

8.3 WELDED STEEL CONSTRUCTION

Foundry technology is generally more complex than cutting and welding of mild steel, which is why handpumps manufactured from welded steel components are increasing in numbers. Steel pumps have the additional advantage that they are less vulnerable to the sort of shock loads sometimes imposed during loading and unloading in developing countries. Most handpump welds are not especially critical, and will be adequate if they are watertight, though structural welds do exist on some pumps, for instance where the handle fulcrum support joins the pumphead. Visual inspection is usually enough to check the adequacy of welds, provided that the inspector is experienced in recognizing danger signs.

Manufacturing requirements

The type of processes needed for manufacture and assembly of steel handpumps will depend on the complexity of the pump design, but some general indications can be given by considering a typical workshop for producing the India Mark II pump (Figure 8.2).

The Mark II is made mainly from standard steel plates, tubing and profiled sections. It includes a cast iron cylinder and drop pipe connector, a seamless brass liner, a bronze plunger assembly, a bronze foot valve with rubber flapper, and a short length of machine roller chain. One plant in India, producing 600 units of the Mark II pump a month with single eight hour shifts six days a week, had the following requirements:

- 100kg of mild steel per pump;
- 5,000kWh of electricity monthly (installed power = 90kW);
- 15 skilled workers, mostly welders and machine operators;
- 35 unskilled labourers;
- 10 clerical staff;
- 3 engineers;
- a comprehensive set of jigs and fixtures;
- 5,000m^2 of floor space.

It should be noted that, in this case, the manufacturer arranged production so that many pump components were made to order by subcontractors.

On a smaller scale, the equipment and staffing of a machine shop in Zambia producing 20 pumps per month are shown in Table 8.3.

Table 8.3 Machine shop requirements for production of 20 handpumps per month

Operation and equipment	*Number of persons*
Lathes	3
Arc welding	2
Cutting	1
Drilling	2
Foreman	1
Total	**9**

Source: Technology Development and Advisory Unit, University of Zambia, Lusaka, Zambia

Machining

Interchangeability of spare parts is an important element of handpump maintenance. Components must therefore be machined accurately. Valve seats in particular need to be even and smooth, without flaws, cracks, crevices or pits. The mating parts of pumps need to be machined accurately to fit flat in one plane, and nuts should fit squarely when tightened. Hole edges need machining, to provide a snug fit for pins, bolts or bearings. Saw cuts should be deburred, pipe threads cut fully and of sufficient length to ensure proper engagement. For cylinders and journals, proper machining is especially important, to achieve a smooth bore.

Jigs and fixtures

A fixture is any device which holds a pump part in position while it is being machined, or for other work such as cutting or drilling. A jig also holds the object, but in addition incorporates special arrangements for guiding the working tool to the proper position.

Fixtures are used for milling and grinding, while jigs are needed in operations such as cutting, drilling, boring and similar work. Jigs and fixtures improve the dimensional accuracy of the work and so assist in achieving uniformity and interchangeability of parts. The quality of jigs and fixtures is critical to consistency, and quality control inspections should include regular checks on them.

Figure 8.4 Women at work on a lathe

8.4 HANDPUMPS ASSEMBLED FROM STANDARD PIPE COMPONENTS

It is possible to put together a handpump from standard pipe components, though such pumps are not necessarily cheaper than specially designed pumps. Examples from Thailand and Zambia, using mainly galvanized iron and steel pipes, are illustrated in Figure 8.5.

Another handpump design of this type is the Shinyanga pump, which was developed for local manufacture in Tanzania for use in the Shallow Wells Project in the Shinyanga Region. This pump consists mainly of standard galvanized iron pipe and fittings, but also uses angle and plate steel. Components are joined with standard nuts and bolts. The pump cylinder is 500mm of 100mm diameter PVC pipe, and the fulcrum upright and pump handle are wood.

8.5 PLASTIC PUMPS AND COMPONENTS

Some relatively simple production methods make local manufacture of plastic handpump components an attractive proposition in many developing countries. The choice of methods depends mainly on the properties of the type of plastic to be used, and also on the size and design of the pump.

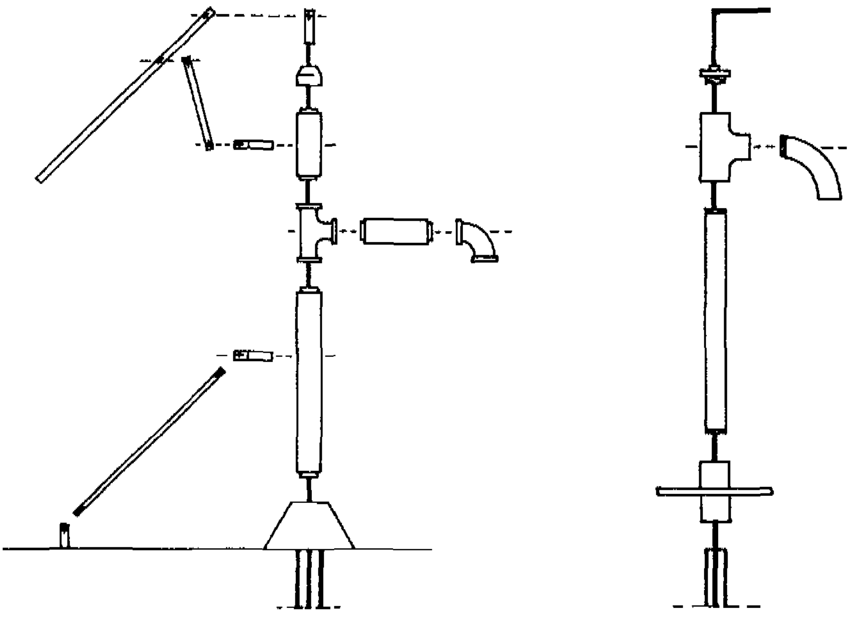


Figure 8.5 Pumps made from standard pipe components in Thailand (left) and Zambia (right).

The suitability of plastics as materials for local handpump manufacture is based on:

- relative ease of plastics manufacture and assembly;
- low cost of mass production components;
- parts can be produced under contract by existing plastics manufacturers;
- components produced are uniform;
- quality control is comparatively easy.

The processes involved may include casting, injection moulding, compression moulding, extrusion, and machining.

Casting

Thermosets and some thermoplastics are suitable for the casting process. Heated monomer plastic is poured into an open mould, where it is cured and polymerized. It solidifies with the help of a catalyst as it cools. The process is relatively slow but has the advantages that mould and equipment costs are low, small runs are economic, and large and thick pieces can be made.

Moulds can be metal but soft inexpensive materials like plaster or rubber are practical alternatives. The simple hand-pouring technique is not difficult to master, but some skill is needed to control the casting process. The technique is particularly appropriate when only small numbers of a particular component are required.

Injection moulding

Injection moulding is the most widely used production method for thermoplastic articles. Granular plastic polymer is fed into the injection moulding machine, where it is heated and flows under pressure into a mould cavity. There it is cooled and solidifies into its final shape.

Initially, injection moulding was used to manufacture small items, weighing just a few grams. Today, objects weighing many kilograms can be made in this way. Virtually all thermoplastics can be injection moulded; some thermoset plastics can also be processed, but the equipment needs to be modified to control the temperature more closely, as the thermoset must not be allowed to polymerize before it is in the required shape.

Injection moulding has the advantages of speed, accuracy, and low production costs. Moulds are expensive, so injection moulding is best used when large numbers of components are needed.

Compression moulding

In compression moulding, a measured amount of plastic material is loaded into a two-piece heated mould, which is then closed under pressure. The heated plastic is forced to flow into the shape of the cavity. With thermoplastic materials, the mould is then cooled to harden the plastic. After some time, the pressure is released and the solid article can be removed. When using thermoset materials, hardening is achieved by curing at high temperatures.

Compression moulding is a relatively simple process and mould costs are less than those of injection moulding. The technique is used mainly for very large items.

Extrusion

In the extrusion process, plastic resin is melted and forced through a die shaped to form the extruded product. Cooling is usually carried out by passing the completed item through a water bath. Extrusion is mainly used with thermoplastic polymers.

Unlike most other plastic production techniques, extrusion is a continuous process, and typical products are pipes, sheets, rods, and wire insulation. Uniformity and smoothness of extruded products comes from proper control of operating temperature and pressure. Extruded plastic pipes for water supply are manufactured in many developing countries.

Machining of plastics

Machining from solid stock is a useful way of making plastic pump prototypes in small numbers. However, one big advantage of plastics is the availability of techniques for mass production, and this is lost if all items require substantial machining.

Machining operations that are used with plastics include filing, sawing, sanding, grinding, drilling, tapping, and lathe turning. Most plastics can be machined using conventional wood or metal working machines. The quality, work rate and ease of manufacture can be improved through proper use of good quality jigs and fixtures.

Assembly techniques

The main ways of joining or assembling plastic components are solvent cementing, mechanical joints, and plastic welding. Choice of method depends on the application, the conditions under which assembly takes place, and the properties of the plastic material.

Solvent cement is an effective, simple and cheap way to bond two plastic surfaces together, in which the strength of the joint depends on the contact area and the cleanliness of the surfaces. It is often useful to roughen the surfaces with abrasive paper. Good fit and alignment is important, and the joined parts should not be loaded until hardening is complete, which means after at least one day. The solvent cement is applied by dipping or, with large areas, brushing with glue guns or ordinary paint brushes. Solvent cements form their bond by softening the plastic surfaces so that they fuse together. The cements usually contain volatile ingredients and need to be stored tightly sealed in a cool place to preserve their quality.

The variety of mechanical joints used for plastics includes screws, clips, rivets, pins and bolts. Such devices have the advantages that they can be loaded immediately and that disassembly remains possible. Plastic fasteners are becoming available in the form of snap-on or snap-in hinges and clasps. Mechanical fasteners can also be made an integral part of the plastic component, as with screw threads.

Thermoplastics can be joined by heat welding. Heat is applied to melt the surfaces, which are then joined and solidified by cooling. In hot gas welding, the plastic parts are joined using a filler rod of similar or compatible material. This technique is commonly used for uPVC, but may also be used for polyethylene, polypropylene, and other thermoplastics. Other methods, known as hot plate welding, high frequency welding and ultrasonic welding vary only in the manner in which the heat is generated. It is also possible to use a technique known as spin welding, in which one part is spun while the other remains stationary, and heat is generated by friction at the interface.

Handpumps from standard plastic pipe fittings

Some handpump designs, of which the Blair is an example, can be made largely from standard plastic pipe and fittings. The big advantage is that no special manufacturing facilities are needed such as moulds or foundry equipment. Handpumps of this type are usually of simple design and suitable for assembly by village craftsmen. So far they have only been used in shallow well applications and for relatively small user groups.

8.6 HANDPUMPS MADE BY VILLAGE ARTISANS

The durability and quality control needed in community water supply handpumps means that they almost invariably have to be made in well-organized mass-production facilities. There is however considerable scope for village craftsmen to produce pumps suitable for light duty applications in an environment where they can be quickly and easily repaired when anything goes wrong. In general, such pumps are likely to serve one or a few families drawing water from a shallow well, probably within the suction limit (7m).

Village artisans can make useable components, or even complete pumps, from locally available materials, such as wood, bamboo, leather, and PVC pipe. For example, experienced village craftsmen have proved quite capable of making cupseals from

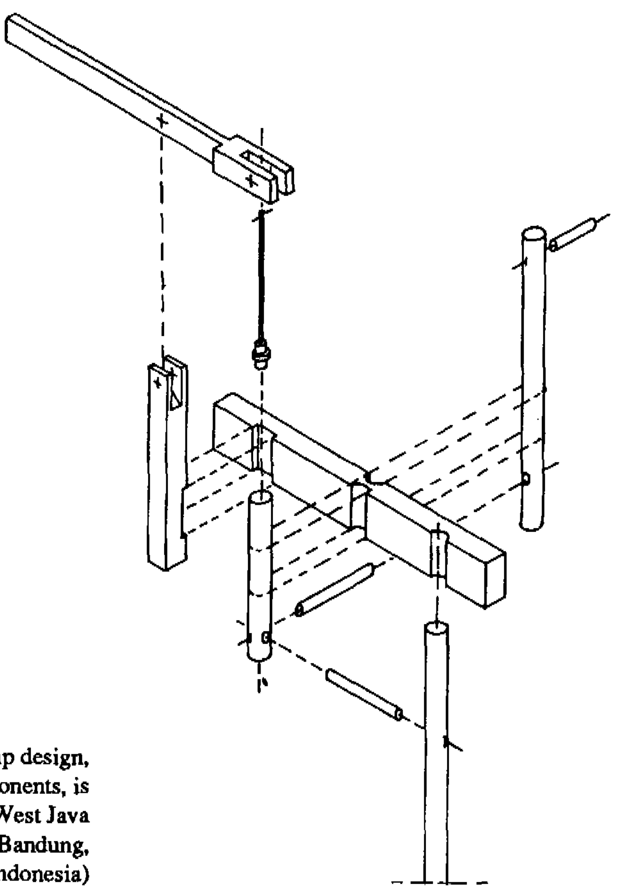


Figure 8.6 This pump design, with bamboo components, is made by artisans in West Java (Source: DTC-ITB, Bandung, Indonesia)

leather. In an emergency or when new cupseals are impossible to obtain, replacement seals can be made locally from car tyre material or good leather. With leather, oversize material is first soaked in water and clamped into the plunger, or an object of the same size and diameter. The plunger is then forced into a pipe of the same diameter as the pump cylinder. When the cupseal is dry, it is removed and the wrinkled edge is trimmed with a sharp knife. With a centre hole and graphite grease or wax applied to the wearing surface, the cupseal is ready to be fitted in the pump cylinder.

Villagers have also made complete plunger assemblies and valves from wood with leather or rubber seals. Wooden handles are often used and have a number of advantages for village use:

- they are easier to replace when worn or broken than are iron or steel handles;
- being of sturdy construction and generous size, the weight of the pump handle can counterbalance the pumprods and make the pump easy to operate;
- the bearing surface of the wooden handle wears preferentially rather than the pin on which the handle rotates.

The great merit of village-made pumps is that they can be repaired — or even replaced — when they break down, without waiting for a visit from an outside mechanic or mobile maintenance team. The pump shown in Figure 8.6 can be made cheaply by a village craftsman in West Java in about two days, and its simple construction means that even if it breaks down regularly, it can be repaired very quickly and there is no need for users to revert to alternative contaminated sources.

References and selected bibliography

Addison, H. (1985). The pump user's handbook. London, UK, Pitman & Sons.

Agboton, I. et al (1986). Stratégie de la maintenance des ouvrages d'hydraulique villageoise en République Populaire du Bénin. Journées Techniques du Comité Interafricain d'Etudes Hydrauliques, Brazzaville, Congo, Comité Interafricain d'Etudes Hydrauliques (CIEH).

Anandarup, Ray (1984). Cost-benefit analysis: issues and methodologies. London, UK, John Hopkins University Press.

Andersson, I. (1982). Wells and handpumps in Shinyanga Region, Tanzania: level of service from small-scale water supplies. (Research Paper no.77). Dar es Salaam, Tanzania, University of Dar es Salaam, Bureau of Resource Assessment and Land Use Planning (BRALUP).

Andersson, I. (1984). Improvement of traditional sources: a realistic alternative. In: Malin Falkenmark and Jan Lundqvist (eds.), Water for all: coordination, education, participation: report from an international seminar. Linköping, Sweden, University of Linköping, Department of Water in Environment and Society, 237-248.

Arlosoroff, S. (1986). UNDP/World Bank activities on low-cost water supply and sanitation management. International Conference on Water and Wastewater Management in Asia, Singapore.

Baldwin, G.B. (1984). The Indian Mark II handpump and its three-tier maintenance system. Waterlines, 1, 4, 8-12.

Bannerman, R. (1981). Handpump maintenance programme in Ghana Upper Region: paper presented at 6th WEDC Conference, 24-28 March, 1980 at Ahmadu Bello University, Zaria, Nigeria. Loughborough, United Kingdom, University of Technology (WEDC-Group).

Bastemeijer, T.F. and Visscher, J.T. (1987). Maintenance systems for rural water supplies. (Occasional Paper no.8). The Hague, The Netherlands, IRC.

Bénamour, A. (1981). Hydraulique villageoise et moyens d'exhaure. Ouagadougou, Burkina Faso, CIEH.

Blankwaardt, B. (1984). Hand drilled wells: a manual on siting, design, construction and maintenance. Dar es Salaam, Tanzania, Rwegarulila Water Resources Institute.

Blow, C.M. (1975). Rubber technology and manufacture. London, United Kingdom, Newnes & Butterworths.

Boot, M. (1984). Making the links: guidelines for hygiene education in community water supply and sanitation: with particular emphasis on public standpost water supplies. (Occasional Paper no.5). The Hague, The Netherlands, IRC.

Boot, M. (1987). Evaluating water supply and sanitation projects: training course: modules and guide for moderators. The Hague, The Netherlands, IRC/UNICEF.

Brush, R.E. (1981). Wells Construction: hand dug and hand-drilled wells. Washington, D.C., USA, Peace Corps.

Brydson, J.A. (1975). Plastic materials. London, UK, Whitefriars Press.

Burgeap (1986). Maintenance des ouvrages hydrauliques moyens d'exhaure dans le cadre d'un projet d'hydraulique villageoise. Journées Techniques du Comité Interafricain d'Etudes Hydrauliques, Brazzaville, Congo, CIEH.

Cairncross, S. et al (1980). Evaluation for village water supply planning (Technical Paper no.15). The Hague, The Netherlands, IRC.

Charnock, G. (1982). Malawi's Livulezi projects provides a primer for pump studies. World Water, 5, 1, 22-23, 25-26.

Chong, Kah-Lin (1983). Wear of plastic ring seals of reciprocating water pump. Kuala Lumpur, Malaysia, University of Malaya

Chowdhury, Z. (1978). The paramedics of Savar: an experiment in community health in Bangladesh. Development Dialogue, 1, 41-50.

Chulalongkorn University (1980). The development of a PVC handpump: report by mechanical engineering department of Chulalongkorn University with support from WHO and UNICEF. Bangkok, Thailand, Chulalongkorn University.

Collett, J. and Pearson, H. (1975). Oil soaked bearings: how to make them. Appropriate Technology, 2, 4, 11-13.

Collins, H.E. (1980). Pumps: troubles and remedies. New York, USA, Hill Publishing Company.

Consumers' Association Testing and Research Laboratory (1980). Hand/foot-operated water pumps for use in developing countries: final summary report on handpumps testing project. Harpenden, UK, Consumers' Association Testing and Research Laboratory.

Consumer Research Laboratory (1987). Handpumps for community water supply: report of the research and development coordination meeting and an agenda for action. Harpenden, UK, Overseas Development Administration.

DHV (1982). Shallow wells. Amersfoort, The Netherlands, DHV Consulting Engineers.

Dijon, R. (1981). Operation and maintenance of rural water supply schemes: paper presented at the Interregional Seminar on Rural Water Supply, Uppsala (Sweden). New York, USA, United Nations.

Diluca, C. (1983). Les pompes à main en hydraulique villageoise: conditions d'utilisation et d'entretien dans les pays membres du CIEH. Ouagadougou, Burkina Faso, CIEH.

Donaldson, D. (1983). A technical/managerial review of USAID-assisted handpump programmes in Sri Lanka, The Philippines, Honduras, and the Dominican Republic. (WASH Working Paper no.29). Arlington, USA, Water and Sanitation for Health Project (WASH).

Donaldson, D. (1984). Operation and maintenance of rural drinking water and latrine programs in Honduras. (WASH Field Report no.129). Arlington, USA, WASH.

DPHE, UNICEF (1987). The Tara Handpump: Production manual and drawings (International version). Dhaka, Bangladesh, UNICEF.

Driscoll, F.G. (1986). Groundwater and wells: 2nd edition. St. Paul, Minnesota, USA, Johnson Division.

Dworking, D. (1980). Rural water projects in Tanzania: technical, social and administrative issues (AID Evaluation Special Study no.3). Washington, D.C., USA, U.S. Agency for International Development (USAID).

Dworking, D. et al. (1980). The potable water project in rural Thailand. Washington, D.C., USA, USAID.

Eubanks, B. (1971). The story of the pump and its relatives. Salem, USA, Privately published.

Fannon, R.D. and Varga, S.T. (1972). Report on foundry pig iron and coke for manufacture of the Aid/Battelle handpump. Columbus, USA, Battelle Memorial Institute.

Finnwater Consulting Engineers (1980). Rural water supply construction project in Mtwara and Lindi Region: final report: January 1978-March 1980. Dar-es-Salaam, Tanzania, Government of Tanzania/Government of Finland.

Gibbs, K.R. (1984). Diarrhoea and the decade in a developing country: the Bangladesh case. In: Institution of Civil Engineers, World Water '83: The World Problem. London, UK, Thomas Telford, 189-195.

Goh Sing Yau (1985). Laboratory and Field Testing of Handpumps. Ottawa, Canada. International Development Research Centre (IDRC).

Grey, D. and Langenegger, O. (1984). Implementation of handpump schemes for rural water supplies in Africa: paper presented at the 2nd African Water Technology Conference Nairobi. Washington, D.C., USA, World Bank.

Hahn, R. (1983). Handpump testing and development. Lund, Sweden, Lund Institute of Technology.

Hall, G.B. (1979). Inspection and the India Mark II handpump. In CPHEEO and UNICEF Report of the National Conference on Deepwell Handpumps: Madurai, July 10-13, 1979. New Delhi, India, Central Public Health and Environmental Engineering Organization.

Handpump Development News (1987). Nos 5, 6, 7. Papendrecht, The Netherlands, B&R Consulting Engineers.

Harkness, R.M. (1983). Village women, water and development: an evaluative study of the water supply project in Bolgatanga District, Upper Region, Ghana. Ottawa, Canada, Carleton University.

Heffinck, P. (1978). Survey on the maintenance and condition of government handpump tubewells in rural Bangladesh. Dhaka, Bangladesh, UNICEF.

IDRC (1987). IDRC handpump network: proceedings of the meeting held in Bangkok, Thailand, 1-3 October 1986. (IDRC Manuscript Report no.159e). Ottawa, Canada. IDRC.

Indian Standards Institution (1957). Standard specification for leather pump buckets made from vegetable-tanned leather. New Delhi, India, Indian Standards Institution.

Instituto Ecuatoriano de Obras Sanitarias (1975). Manual del primero curso sobre operacion y mantenimiento de distemas de aqua potable en el area rural. Guyayaquil, Ecuador, Instituto Ecuatoriano de Obras Sanitarias.

James, B.E. (1984). USAID handpump program in Ecuador. (WASH Field Report no.123). Arlington, USA, WASH.

Janssens, R.I.M. (1981). Trainer's guide to flipchart for the India Mark II deep-well handpump caretaker training programme. New Delhi, India, UNICEF.

Jayasinghe, K.H. et al (1983). Socio-cultural dimensions of water supply and sanitation. Helsinki, Finland, University of Helsinki, Institute of Development Studies.

Johnson, D. (1974). Pumping capabilities of simple handpumps at different altitudes (VITA Report no.2). Arlington, USA, Volunteers in Technical Assistance.

Johnston, M. (1986). Unique stimuli for action: two cases of hygiene and sanitation education. Solo, Indonesia, Yayasan Indonesia Sejahtera.

Johst, P., Kramer, G. and Storgaard, B. (1979). Drinking water to rural areas in Bangladesh: an evaluation of the rural tubewell water supply project. Copenhagen, Denmark, DANIDA.

Karim, R., Miller, R.L., and Pecht, G.A. (1982). Foundry manual. New York, USA, Ammann and Whitney.

Kirimbai, M. and Wijk, C.A. van (1983). Impact of water supply on hygiene improvements in Tanzania: a study in 8 villages in Morogoro and Shinyanga regions. The Hague, The Netherlands, IRC.

Knight, R. (1981). Technical assistance in the manufacture and quality control of the AID/Battelle handpump in The Dominician Republic. (WASH Field Report No.20). Arlington, USA, WASH.

Laak, F.H.J. van de (1980). Organization and maintenance of village handpumps water supplies. In: Morogoro Conference on wells: proceedings of the Morogoro Conference on wells held at Mikumi Wildlife Lodge, 18-22 August 1980. Dar es Salaam, Tanzania, Ministry of Water, Energy and Minerals.

Langenegger, O. (1987). Groundwater quality — An important factor for selecting handpumps. Abidjan, Côte d'Ivoire, unpublished paper.

Laubjerg, K. (1984). Bangladesh rural water supply and environmental sanitation programme: socio-economic studies. (Report no.2). Dhaka, Bangladesh, DANIDA.

Mammo, A. (1981). Shallow wells and handpumps: rural water supply in developing countries: proceedings of a workshop held in Zomba, Malawi, 5-12 August 1980. Ottawa, Canada, IDRC.

Mauluka, L. (1983). Community participation in the construction and maintenance of rural groundwater supplies in Malawi. In Malin Falkenmark and Jan Lundqvist (eds.), Water for all: cooperation, education, participation: report from an international seminar. Lingköping, Sweden, Department of Water in Environment and Society, 162-180.

McJunkin, F.E. (1977). Handpumps for use in drinking water supplies in developing countries. (Technical Paper Series no.10). The Hague, The Netherlands, IRC.

Micro Industries Development Assistance Society (1984). A comparative study of the caretaker system of the DPHE/UNICEF rural water supply programme. Dhaka, Bangladesh, Micro Industries Development Assistance Society.

Morgan, P. (1980). A simple hand-operated water pump suitable for shallow wells. Harare, Zimbabwe, Blair Research Laboratory.

Msukwa, L.A.H. and Kandoole, B.F. (1981). Water by the people: an evaluation of the rural water supply programme in Zomba District. Blantyre, Malawi, University of Malawi, Centre for Social Research.

Osei Poku, K. (1976). Well drilling programme and selection of suitable handpumps for use in Ghana. Accra, Ghana, Ghana Water and Sewerage Corporation.

Pacey, A. (1980). Handpump maintenance in the context of community well projects. Rev. ed. London, UK, Intermediate Technology Publications.

Pashkevich, A. and Birch, R. (1984). Job aids for quality control in the manufacturing of the AID handpump. (WASH Field Report no.124). Arlington, USA, WASH.

Ploeg, J.D. van der and Wijk-Sijbesma, Ch. van (1980). Community participation in the rural well construction programme of Guinea Bissau. Aqua, 9/10, 21-23.

Plumtree, A. and Rudin, A. (1977). Plastic well casings for use with hand-operated water pumps. Waterloo, Canada, University of Waterloo.

Potts, P.W., Knight, R. and Sternber, Y.M. (1979). Feasibility of local manufacture of the AID hand-operated water pump and other technology appropriate for rural water supply programmes in The Philippines. (WASH Field Report no.3). Arlington, USA, WASH.

Prasad, R. (1979). Handpumps: problems and the search for remedies: proceedings of Indian Academy of Science, Vol. C2, Part 4, pp.473-505.

Roark, P. (1984). Women and water. In Peter Bourne (ed.), Water and sanitation: economic and sociological perspectives. Orlando, USA, Academic Press, 49-68.

Sacher, H., Werner, H. and Beyer, M.G. (1983) How useful are rural water supply programmes: joint UNICEF/GTZ assessment of UNICEF-assisted rural water supply projects in Bangladesh, Nepal and Burma. New York, USA, UNICEF.

Sclafani, J.A. (1981). Popular participation and the Bahr-El-Ghazal domestic water supply project: lessons and implications for UNICEF policy. Khartoum, Sudan, UNICEF.

Scotney, N. (1980). Developing health education component for the UNICEF water and sanitation programme, Sudan. Nairobi, Kenya, African Medical and Research Foundation.

Sharp, D. and Graham, H. (1982). Village handpump technology: research and evaluation in Asia. Ottawa, Canada, IDRC.

Shawcross, J.F. (1978). Handpump maintenance: organisational consideration: for water supply projects in developing countries. Interim Report.

Squire, Lyn and Tak, Herman G. van der (1975). Economic analysis of projects. London, UK, Johns Hopkins University Press.

Standards for centrifugal, rotary and reciprocating pumps 13th ed.). Cleveland, USA, Hydraulic Institute.

Sternberg, Y.M. (1978). Testing of wood bearings for handpumps. (P.U. Report no. RES 13). Washington, D.C., USA, World Bank.

Subba Rao, R. (1975). Report on study of handpump (shallow tubewell) for WHO/UNICEF-assisted project and other rural water supplies. Phase II: Design, fabrication and testing of modified handpump. Calcutta, India, All India Institute of Hygiene and Public Health.

SWS Filtration Ltd. (1985). Notes on the installation of small well screens. SWS Filtration Ltd.

Tanzania, Prime Minister's Office (1983). Understanding and improvement of village hygiene: training/job manual for trainers, pump caretakers, village water committees and village health staff. The Hague, The Netherlands, IRC.

Tanzania, Prime Minister's Office (1984). Proceedings of the interministerial meeting on community participation and health education in the Tanzanian rural water supply programme. Dodoma, Tanzania, Prime Minister's Office.

Tanzania, Prime Minister's Office, The Netherlands, Ministry of Foreign Affairs and IRC (1984). Project for the development of a community participation component in the Tanzanian rural water supply programme. Final report, The Hague, The Netherlands, IRC.

Tata Economic Consulting Services (1984). Semi industrial projects assisted by UNICEF in India: assessment of India Mark II handpump project. New Dehli, India, UNICEF.

Thanh, N.C., Pescod, M.B. and Venkitachalam, T.H. (1979). Design of simple and inexpensive pumps for village water supply systems (final report no.67). Bangkok, Thailand, Asian Institute of Technology.

Trietsch, R. (1983). Shallow wells and handpumps: a Tanzanian experience. Water Supply, **1**, 4, 31-40.

UNICEF (1979). Guide to selection and training of village handpump caretakers. Madras, India, Tansi Press.

UNICEF (1979). India Mark II deepwell handpump: installation and maintenance manual. New Delhi, India, UNICEF.

Visscher, J.T. and Hofkes, E.H. (1983). The Buba-Tombali water project. The Hague, The Netherlands, IRC.

Water Resources Center and Asia Foundation (1981). Installation manual for cylinder pump. Cebu City, Philippines, University of San Carlos, Water Resources Center.

Watt, S.B. (1975). Approaches to water pumping in West Africa: paper presented at FAO/Danida seminar on small-scale resources development in West Africa. Ouagadougou, Burkina Faso, CIEH.

Watt, S.B. (1976). 21 chain and washer pumps from the 1958 Peking Agricultural Exhibition. London, UK, Intermediate Technology Publications.

Watt, S.B. and Wood, W.E. (1976). Handdug wells and their construction. London, UK, Intermediate Technology Publications.

Wavin (1986). Wavin direct action handpump: institutional manual for installation and maintenance. The Netherlands, Wavin Overseas.

White, A.T. (1981). Community participation in water supply and sanitation: concepts, strategies and methods. (Technical Paper no.17). The Hague, The Netherlands, IRC.

WHO (1983). Minimum evaluation procedure (MEP) for water supply and sanitation projects. Geneva, Switzerland, World Health Organization.

Whyte, A. (1986). Guidelines for planning community participation in water supply and sanitation projects. (WHO Offset Publication no.96). Geneva, Switzerland, World Health Organization.

World Bank (1984). Laboratory testing of handpumps for developing countries: final technical report. (World Bank Technical Paper no.19). Washington, D.C., USA, World Bank.

World Bank (1985). Rural water supply and sanitation: a framework for improving investments. Draft Policy Paper. Washington, D.C., USA, World Bank.

World Bank (1987). Community water supply, the handpump option. Washington, D.C., USA, World Bank.

Wijk-Sijbesma, C.A. van (1983). Maintenance and repair systems for handpump wells: an appraisal study. The Hague, The Netherlands, IRC.

Wijk-Sijbesma, C.A. van (1985). Participation of women in community water supply and sanitation: roles and realities (Technical Paper no.22). The Hague, The Netherlands, IRC.

Wijk-Sijbesma, C.A. van (1987). What price water: user participation in paying for community-based water supply. (Occasional Paper no.10). The Hague, The Netherlands, IRC.

Appendices

I. COMMUNITY WATER SUPPLY: THE HANDPUMP OPTION — EXECUTIVE SUMMARY*

An estimated 1,800 million people need improved water supplies in the fifteen years to the end of the century, if developing countries are to reach the target of full coverage. The first half of the International Drinking Water Supply and Sanitation Decade (1981-1990) has seen increases in the percentages of the rural population with access to safe water supplies, but only in Asia has the pace been quick enough to envisage a target of essentially full coverage by the end of the century (ten years later than the original Decade goals). In Africa, present progress rates would leave half of the rural population still without safe water in the year 2000, while in Latin America, it may be ten years into the next century before full coverage is achieved unless progress improves dramatically.

Accelerated progress is hampered by financial and technical resource constraints faced by many developing countries, and the problem is aggravated by the growing number of completed projects which are broken down or abandoned, or functioning much below capacity. Attempts to increase the pace of providing improved community water supplies have often been frustrated because the technology used has proved impossible to sustain in village conditions.

To make a lasting impact on the urgent needs, community water supply (CWS) strategies must be based on sustainable and replicable programs, and must take account of the pace at which resource constraints can be overcome. Human resource development programs take time to produce results, and institutional changes can only be accomplished gradually.

The Integrated Approach

Successful CWS programs involve a combination of hardware and software — technology and institutional/organizational support elements — matched in such a way that each community recognizes the benefits of the improved supply, can afford at least the costs of operating and maintaining it, and has the skills, spare parts, materials and tools available to sustain it. To maximize health benefits, parallel investments in health education and sanitation programs should be planned alongside CWS improvements.

This "integrated approach" to CWS planning involves consideration of a number of

* This Executive Summary is extracted in full from the World Bank publication *Community Water Supply: The Handpump Option*

key issues, each individually important, and together forming a complete package for achieving dependable services:

- Effective involvement of the comunity in the design, implementation, maintenance and financing of planned improvements, with promoting agencies providing technical assistance and support services as needed. The community"s needs and wishes have to be reconciled with its capacity and willingness to pay for the level of service planned.
- Provision for full recurrent cost recovery, with support of capital (construction) costs for poorer communities offset by full recovery where higher service levels are provided.
- Maximum involvement of in-country industry in the supply of services and materials for project construction and maintenance (e.g. supply of pumps and spare parts, servicing and repairs), with the important proviso that quality control and reliability should be assured and that costs are competitive.
- Technology chosen to match the resources available to sustain it.
- Institutional and manpower development programs matching the needs of the planned water supply system.
- Parallel programs in health education and sanitation improvements.

Service Level and Technology Choice

The decision about the level of service (i.e. the amount of water provided per capita and the convenience of obtaining it) that a particular community or district should have involves consideration of many of the issues listed above. The aim is that the technology chosen should give the community the highest level of service that it is willing to pay for, will benefit from, and has the institutional capacity to sustain.

Choices may have to be made between surface water and groundwater as the principal source (sometimes supplemented with rainwater) and then from handpumps, public standpipes, or yardtaps as the method of distributing the water to the beneficiaries. Costs and benefits will both be linked to the number of water points provided, with improved convenience of water collection ranking high in the consumers' evaluation of potential benefits.

Groundwater has many advantages over surface water as a source for CWS improvements, the main one being that, provided wells are judiciously sited in relation to existing or future latrines, safe water should generally be assured without the need for treatment (other advantages are listed in Chapter 2). The resource demands of water treatment plants needed to make supplies from surface water sources safe to drink are beyond the reach of most communities, and use of untreated surface water frequently represents an unacceptable health risk.

In cases where an upland catchment can be protected against contamination, a gravity-fed system can be reliable and safe, but only a small percentage of the population in need of improved supplies live in such areas. It will therefore be rare for CWS programs to be based on surface water as the source, and the technology choices analysed in this report are focussed largely on groundwater-based CWS systems.

Assuming that equal system reliability can be achieved, the three main technology options — handpumps, standpipes, and yardtaps — generally represent progressively increasing service levels, and call for increasing financial and technical resources for their implementation and maintenance. The choice of appropriate technology for a particular project or program can only be made when resource constraints have been taken into acount, including the capability of the users to operate and maintain the alternative systems under consideration.

The theme of ***reliability*** recurs throughout this document. In community water supplies, one of the most important influences on system reliability is the length of time for which pumps stand idle when they break down. The response times of centralized maintenance organizations covering dispersed communities can stretch to several months. Box 5.2 in Chapter 5 shows graphically how handpump maintenance carried out by an area mechanic within a week of breakdown makes a pump which breaks down on average every 8 months more "reliable" than one which lasts for an average of 18 months before it breaks down, but then must wait two months for the mobile maintenance team to arrive.

In considering the service level to be provided by a particular technology, reliability is an important parameter. Thus, a reliable handpump supplying 30 liters per head per day for 95% of the year, will be providing a higher level of service than yardtaps designed for 150 liters per head per day but working only two hours a day because of leakage, breakdown, fuel shortages, or limited water available at the intake.

Comparison of costs, resource needs, and benefits of the CWS options have to be based on a realistic assessment of the reliability and sustainability of each technology.

Financial Implications

Capital costs of the three technologies generally range from US$10-30 per capita for wells equipped with handpumps to US$30-60 per capita for motorized pumping and standpipes and US$60-110 per capita or more for yardtap services. In global terms that means that cost estimates for meeting rural water supply needs to the year 2000 range from US$50,000 million to US$150,000 million, depending on the choice of technology.

With the obvious difficulties of mobilizing financial resources for this scale of investment, rapid progress in meeting basic needs can be achieved only if a large proportion of the population in need receives services at the lower end of the cost range. Upgrading to a higher service level may then be financed by the community later, as benefits from the inital investment and from other sources increase available resources.

Analysis of data from a wide range of CWS projects indicates a similar divergence in the recurrent (operation and maintenance) costs of the three options to that already noted in the capital costs. With a centralized maintenance system, the annual per capita cost of maintenance of a handpump-based CWS system can range from US$0.50 to US$2.00. Well planned community-level maintenance can bring that figure down as low as US$0.05 per capita per year (see Box 3.1 in Chapter 3). By comparison, centralized maintenance of a standpipe system with motorized pumping costs from US$2.00 to US$4.00 per capita per year, and for yardtap maintenance the range is US$4.00 to US$8.00.

There are circumstances in which communities may value the time saved due to the extra convenience of yardtaps so highly that they are willing and able to pay the extra price. The analysis method outlined in Annex 3 is designed to help identify such communities. More frequently, the serious shortage of readily available cash resources will mean that recurrent costs must be kept to a minimum, and handpumps will be the indicated choice.

Resource needs

As with financial considerations, comparison of other resource demands of the different technologies also points to a substantial role for handpumps in meeting basic human needs. The most significant difference between handpump projects and those based on standpipes or yardtaps, is the switch to motorized pumping, and the consequent need for dependable energy supplies and skilled pump mechanics, when a piped distribution system is provided.

In cases where reliable low-cost electric power is available from a central grid, an electric pump can be a relatively inexpensive and operationally simple means of lifting water. Communities which have the financial and technical means available to implement and sustain projects based on electric pumping should be given every encouragement to do so, as this frees scarce public sector funds and external aid for projects serving poorer communities. However, the number of communities with dependable electricity supplies is presently small—well below 10% of the total rural population in Africa, only a little higher in most countries in Asia, and reaching 40-50% in China and the more developed countries of Latin America.

In the absence of reliable electric power, the alternative power source for motorized pumps is diesel engines. The logistic problems of ensuring dependable diesel supplies for dispersed communities have rarely been successfully overcome, and there are few examples of diesel-powered rural water supply systems operating successfully in the long term. The cost of trucking diesel fuel over hundreds of kilometers will usually prove prohibitive. Future developments in solar technology may eventually make solar pumping economic for drinking water supplies, but at the moment such schemes have very high initial costs and require skilled maintenance. Similar conditions apply to windmills.

Adding the institutional constraints and the severe shortage of skilled mechanics in developing countries, it is clear that systems involving motorized pumping are appropriate for only a minority of those in need of new supplies in the coming years. For the rest, it seems clear that drilled or dug wells equipped with handpumps will be the appropriate choice. This makes it vitally important that handpump-based projects are planned and implemented in ways which ensure that they perform reliably and can be sustained in the long term and widely replicated.

The Handpumps Project

In 1981, as one of the activities in support of the International Drinking Water Supply and Sanitation Decade (IDWSSD), the United Nations Development Programme and the World Bank initiated a global/interregional project for the Laboratory and Field Testing and Technological Development of Community Water Supply Handpumps (The Project). The main objectives have been to promote the development of designs and implementation strategies which will improve the reliability of schemes based on groundwater and handpumps, and which will enable schemes to be managed by the communities and replicated on a large scale.

Technology was thought to be at the root of past problems experienced with handpump-based CWS systems, and the Project has carried out laboratory tests in the UK and field trials in 17 countries to measure the performance of about 2,700 handpumps. Field trials lasted at least two years on most pumps, with some 70 different pump models represented in the trials. Test results and conclusions about the performance of each of the pump types still on the market are included in the Handpump Compendium at the end of this document. In Chapters 5 and 6, the pumps are "rated" for different operating conditions, and worked examples illustrate different pump selection applications.

From the beginning, the Project has promoted the concept of **VLOM** (Village Level Operation and Management of Maintenance) as a means of overcoming some of the major obstacles to sustainable water supply systems. Now recognized as one of the fundamental principles of handpump design and CWS project planning, the **VLOM** concept seeks to avoid the high cost, long response time, unreliable service, and other operational difficulties in the repair of handpumps through central maintenance systems.

Many past failures of CWS systems can be blamed on the inadequacies of central maintenance, in which a water authority dispatches teams of skilled mechanics with motor vehicles from a base camp, often serving a large district, to respond to requests for repairs or to carry out routine maintenance. Instead, maintenance should be a community responsibility, and this in turn means that the pump design has to be suitable for repair by a trained caretaker or area mechanic with basic tools, and that spare parts should be affordable and readily available to the community. The Project strongly advocates that pump maintenance responsibilities should be delegated to village committees, and that pumps should be selected with such maintenance in mind.

Developing country governments and donor agencies are increasingly changing their policies to include these principles in projects or programs. This is a significant departure from previous practice, particularly in Africa, where many different types of unsuitable pumps have often been brought into a country through donor assistance. Recipient agencies have thus taken on unmanageable maintenance commitments, which rely on public-sector mobile maintenance.

Planning and Implementation

Few handpump system failures can be blamed solely on the pump. Other major causes are: inadequate or unrealistic provisions for maintenance; poor management, supervision, monitoring and evaluation; poor well design or construction, allowing sand to enter and damage pumping elements; and the corrosive effects of groundwater, which are much more extensive than had previously been suspected.

Experiences in the field trials and data from many other CWS projects have enabled the Project to formulate guidelines for the planning and implementation of CWS projects using wells equipped with handpumps. The guidelines, amplified in Chapter 3, deal with six critical elements — the community; the aquifer; well design and construction; the handpump; the maintenance system; and finance.

Community Involvement

The highest potential for sustainability is achieved when the community is involved in all phases of the project, starting from the planning stage. If the scheme is to continue to operate satisfactorily, people have to recognize the need for the improved service, be able and willing to pay for the maintenance cost (and eventually the construction cost), and be willing to manage its maintenance.

Aquifer Analysis

Competing demands for other water uses, such as irrigation pumping, have to be taken into account when evaluating aquifer potential for handpump projects. To avoid unnecessarily high costs, the well needs to be deep enough to allow for seasonal and long-term lowering of the water table, but no deeper. Legislation and administrative enforcement are needed in some areas to prevent overpumping for irrigation leading to drawdown of the water table and putting existing handpumps out of service.

Well Design and Construction

Wherever the rock is not fully consolidated, screens and filter packs are essential to prevent sand and silt intrusion. Otherwise rapid damage will occur to commonly-used types of seals and valves. The right choice of drilling equipment, backed by appropriate organization of drilling, can significantly reduce drilling costs and result in more dependable wells.

Handpump Selection

A number of factors influence handpump selection in addition to the cost of the pump itself. Among the most importamt are suitability for the intended maintenance system (e.g. can it be repaired by a trained pump caretaker?), durability, and discharge rate. Pump choice will depend on the required lift and the number of users per pump. Standardization on one or a few pump types for any one country can have a significant impact on maintenance and is an important selection criterion; and corrosion resistance has to be taken into account when water is aggressive.

The Project has prepared *Draft Standard Bidding Documents* for handpump procurement, to assist governments and support agencies to take account of important pump characteristics when purchasing pumps through international competitive bidding.

Community Management of Maintenance

Under the system recommended by the Project, the community organizes and finances all repair and routine maintenance of the handpump. Work is carried out either by a designated community member with minimal training and basic tools, or by an area mechanic (usually with a bicycle or moped) covering a number of pumps. The public authority has an important role to play in the training of caretakers and mechanics, and the organization of an adequate spare parts distribution system, but should then hand over maintenance of the scheme to the beneficiaries.

Financial Management

Even when the community is willing to pay for and manage the upkeep of its water supply system, the scheme may founder unless a suitable mechanism is found for collecting money, arranging repairs and paying caretakers or mechanics. Initial training of selected water committee members in simple accounting and financial management has been effective in a number of countries. The Project is seeking evidence of practical community-level cost recovery and management mechanisms, to add to those described in Chapter 3.

Today's Handpumps

The standard test procedures used in the laboratory and field trials revealed many shortcomings in existing handpump designs. Manufacturers responded well, by modifying their products and introducing new models, and there are now many more pumps on the market which are durable and which allow for substantial involvement of villagers in pump maintenance.

As a result, in the vast majority of developing countries, it is now possible to design a handpump-based water supply system which can be sustained in reliable operation without dependence on continual intervention by a central authority.

The Project has assisted a number of firms in developing countries to begin handpump manufacture. Manufacturers from industrialized countries are also being encouraged to combine with enterprises in developing countries to make pumps under licensing or joint-venture agreements. In-country manufacture, backed by public or private sector distribution facilities and retail outlets, strongly improves the likelihood that spare parts will be available when needed, and facilitates standardization of pump types in a country to simplify caretaker training and stocking of spare parts.

Encouraging as these developments are, there remains a scarcity of handpump models which can be described as **VLOM** and are suitable for lifting from depths of more than about 25 meters (though the majority of the population in need lives in regions where the water table is not so deep). The heavy weight of downhole components makes extraction of the complete assembly from deep wells difficult. An added problem is that handpumps deliver less water when pumping from greater depths. The pumps are therefore heavily used and so suffer rapid wear — a problem which is aggravated by the tendency for deep wells to serve more people per well, in order to spread the higher costs of the well and pump over a larger number of users.

For low lifts (up to about 12 meters), direct action pumps like the Tara prototype developed in Bangladesh, in which the operator lifts and lowers a T-bar handle directly attached to the pumprods, have a number of advantages. Elimination of the bearings that are part of lever or flywheel-operated pumps reduces maintenance needs, and the pumps can be manufactured in developing countries at a relatively low cost. They make extensive use of plastics materials, which make the pumps light in weight and corrosion resistant. Direct action pumps have the great advantage over suction pumps that they can lift from more than the 7-meter limit for suction (important since groundwater levels are falling in many parts of the world) and that they do not need priming and therefore avoid the risk of contaminating the well by pouring in polluted water.

For high lifts (down to about 45 meters), a below-ground design which allows extraction of the piston (and footvalve if desired) without removal of the cylinder and rising main appears to be the most promising **VLOM** design. However, only a very few low-cost, durable and corrosion-resistant **VLOM** designs for below-ground components have been used successfully in preliminary tests for lifts between 25 and 45 meters.

Development of more **VLOM** pumps for use beyond 25 meters remains an important task for the next phase of the Project - and for manufacturers and implementing agencies.

To take standardization further, attempts are now being made to develop designs in which some of the same components can be used for pumps designed for different depth ranges. In East African development work, for example, a standard 50mm-diameter cylinder with the same plunger, footvalve and pumprod is being tested with different pumphead configurations for the whole range of lifts from 0 to 45 meters. For low lifts, the below-ground components are connected to a T-bar handle to be operated as a direct action pump; at higher lifts, a lever handle is used, with the handle length varying (two options) depending on the lift.

In Chapters 5 and 6, the monitoring results and experiences of Project staff and others have been used to "rate" each of the 42 handpumps tested by the Project which are still on the market, under a series of design criteria which may influence pump selection. The criteria will not always match precisely conditions under which particular pumps have been tested in the field, and in assessing pump performance over a range of conditions, Project staff have frequently had to make "best judgment" decisions on the basis of their own experience and the available field and laboratory evidence. A methodology is suggested for using the ratings to compile a short list of acceptable pumps for a project or program, and some worked examples illustrate application of the selection procedures in specific cases. It is clear from the worked examples that some pumps are much more suited than others to conditions in developing countries, and that as pumping lift increases, the number of pumps suitable for village-level maintenance declines rapidly.

Future Tasks

Implementation will be the central emphasis of the Project's second phase (1987-91). In their collaboration with governments and donors, Project staff will urge inclusion of the "systems approach" in CWS programs.

Every opportunity will be taken to collect data, demonstrate successful approaches, and develop detailed implementation guidelines on the critical elements identified in the first phase: drilling technology and well design; community participation; training at all levels; in-country manufacture, standardization and spare parts distribution; corrosion and water quality; complementarity of water supply, sanitation and health education; evaluation of benefits and selection of service levels; and non-domestic uses of groundwater.

Governments and donors have an important part to play, by committing resources to the implementation of low-cost CWS programs and by sharing experiences, so that lessons can be learned and model strategies developed for each element of the CWS package. Technical assistance will be made available wherever possible, to support activities aimed at furthering community management of low-cost water supply and sanitation systems.

II. DISCHARGE ESTIMATES FOR RECIPROCATING PUMPS

The theoretical discharge capacity of a single-acting plunger pump is the product of the volume swept by the plunger in the cylinder during the upstroke and the number of strokes per unit time. Referring to figure II.1, the swept cylinder volume V for a cross-sectional area A and stroke length S is:

$$V = A.S$$

For a circular cylinder of diameter D, the discharge capacity Q of the pump operating at N strokes per minute will be:

$$Q = \frac{\pi}{4} D^2.S.N$$

The actual discharge usually differs slightly from the theoretical discharge because the valves do not close instantly when the plunger changes direction, and because there is some leakage round the plunger when pumping. The difference between the actual and theoretical discharge is known as the slip, and is calculated as:

$$\text{Slip} = \frac{Q_t - Q_a}{Q_t} \times 100\%$$

where:
Q_t = theoretical discharge capacity
Q_a = actual discharge rate

Typically, there is a decrease in required pumping effort roughly in proportion to the slip. Thus, the work applied by the user for each litre of water pumped remains about

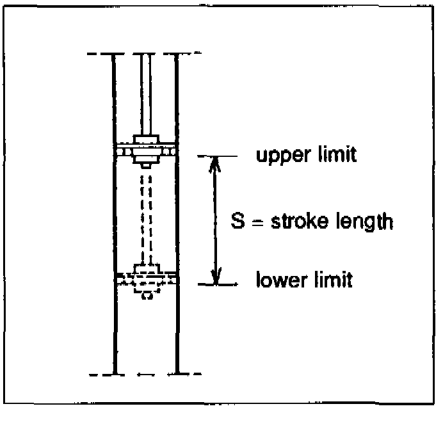


Figure II.1 Volume swept by a plunger in a pump cylinder the same, even for quite high values of slip. In some pump installations with a long suction pipe of small diameter suspended from the cylinder, the flow velocity may be sufficiently high to keep the footvalve open during part of the downstroke, so that the actual discharge rate exceeds the theoretical maximum. This phenomenon is called *negative slip.*

Most reciprocating handpumps discharge water only during the upstroke and are termed *single acting*. Pumps discharging water on both the upstroke and the downstroke are called *double acting* and involve a more complicated valve arrangement.

Static head

The static head against which a handpump operates is the vertical distance between the standing water level in the well and the level at which water is discharged. Figure II.2 shows four different pumping arrangements, to demonstrate determination of static head.

In case I, the pump cylinder is immersed in the water down the well. The water is lifted a distance D to the pump spout, but water in the well outside the rising main exerts positive pressure on the plunger equivalent to the head S. The pumping head on the plunger is therefore D - S, or W. In case II, the pump cylinder is located above the water level in the well. Here, the static pumping head consists of the lift from the plunger to the discharge spout plus the suction head needed to raise water to the plunger. So W = D + S. Cases III and IV mirror cases I and II, but with the inclusion of a pressure head needed to lift the water above the spout to an elevated tank. In each case, the static head increases by the height to the tank, F.

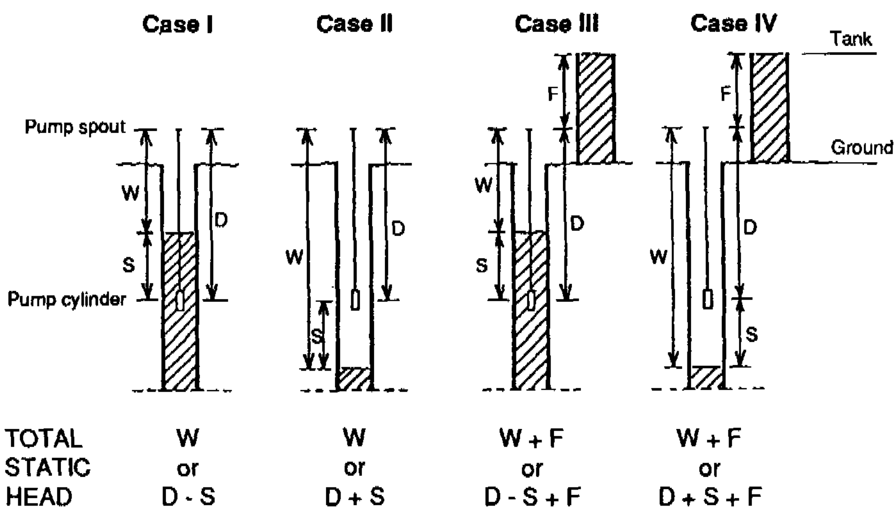


Figure II.2 Determination of static head

Drawdown

When water is pumped from a well, a drop in water level will occur. The extent of the drop (drawdown) will depend on the rate of pumping and the rate at which the well is recharged with groundwater. The pumping head under operating conditions, including drawdown, is often referred to as the *dynamic head* and is the true measure of the pumping lift for which a handpump needs to be designed.

The rate of withdrawal for most handpumps is in the order of $1m^3/h$, and the drawdown resulting from such a small withdrawal is likely to be very small in most cases. However, in wells located in low-yielding aquifers, handpumps can effect a drawdown of several metres after a period of continuous pumping. In the UNDP/World Bank field trials in West Africa, drawdowns of more than 10m were recorded in some wells during normal daily pumping, sometimes doubling the static head.

In areas where motor pumps are used to provide irrigation water, drawdown of the groundwater table can be considerable, and can lead to handpump wells running dry if due allowance has not been made in fixing the cylinder setting.

Friction head

During pumping, additional head losses are caused by hydraulic friction in the rising main, by turbulence where water flow is disturbed by valves, pumprod and rising main connectors or spacers, and by inertial energy losses caused by alternating acceleration and deceleration of the water flow. In handpump installations with adequately sized piping and well-designed cylinders and valves, friction head losses are generally small, and a negligible proportion of the total dynamic pumping head.

Suction head

The cylinder of deepwell pumps should always be installed deep enough to ensure that it remains submerged when the water in the well is at its lowest level. Deepwell pumps therefore operate without suction head. In suction pumps, where the cylinder is located above the water level, the maximum allowable suction head depends on the quality of the pump and the altitude of the project site. It is common practice to limit the actual suction head to two-thirds of the theoretically possible suction head, to account for imperfect sealing and the consequent reduction in the water column height which can be supported by atmospheric pressure. Table II.1 shows the recommended maximum suction head at different altitudes.

Table II.1 Maximum allowable suction head of good quality suction pumps at various elevations

Elevation above mean sea level (m)	*Barometric pressure equivalent (m head of water)*	*Maximum advisable suction head (m head of water)*
0	10.4	6.9
300	10.0	6.6
600	9.6	6.4
900	9.3	6.2
1200	8.9	5.9
1800	8.3	5.6
2400	7.7	5.2
3000	7.2	4.8

Energy Analysis

By definition, handpumps are driven by human energy, and the most important energy parameter is the required rate of work or power output. Generally, handpump users do not pump for hours at a time, but only for the few minutes needed to fill a container, after which another operator takes over.

Few reliable data are available on human power output for hand pumping, but it is often estimated to be 60-75 watts (0.08-0.10 horsepower). Lower outputs are sometimes used, and in Indonesia a figure of 50 watts power output was adopted for handpump design. Pump operators can achieve higher outputs for short periods, but hand pumping should not be strenuous, and the required output should be kept to a comfortable level, taking into account that women and young children are the most frequent users. Ease of operation encourages users to take generous amounts of water and to return more frequently, which has important implications for health improvements.

Some verification for the suggested 50-60 watts design figure comes from observations in Zimbabwe. Measurements of the time taken to fill containers from three shallow wells with different pumping depths but the same cylinder size (50mm) were converted into the effective power output. Direct comparison of work done in lifting water from the three pumps, gave an effective power output of 25-30 watts. For a typical handpump mechanical efficiency of 50%, the user effort can be seen to have been 50-60W.

The power required to operate a handpump can also be calculated, using the formula:

$$P = \frac{\rho_w . g . Q . H}{\eta}$$

Where:
P = power output (watts)
Q = discharge rate (litres/sec)
H = pumping head (m)
g = gravitational acceleration constant (m/s^2)
ρ_w = density of water (kg/litre)
η = overall efficiency of the pump (%)

The power output requirement rises as pumping lift or discharge rates increase and falls with increasing pump efficiency. A rough estimation of the discharge rate which may be expected for a given pumping head can be obtained by inserting typical values of 60 watts for power output and 50% for pump mechanical efficiency in the above formula, which then reduces to:

$$Q \times H = 3$$

Expressing Q in litres/min, the corresponding equation is:

$$Q \times H = 180$$

While this equation is only a rough estimation, it gives an idea of whether particular pumps are likely to prove acceptable to users. For example, it indicates that a typical pump might be expected to deliver about 18 litres/min when pumping against a head of 10m. It follows that pumps which achieve discharges well below this figure should not be considered for such applications.

Force analysis

The greatest forces in a reciprocating handpump occur during the upstroke on the plunger, on the pumprod and couplings, on the handle and bearings, and on the pumpstand. The operating forces depend on the depth from which the water is lifted, the weight of the pumprod, the sliding friction of the plunger seals, and the friction of the bearings.

The hydraulic load on the plunger is that of a column of water of height equal to the pumping head. For a circular plunger, the hydraulic load is:

$$F = \frac{\rho_w . g . H . \pi D^2}{4}$$

where:
F = hydraulic load on plunger (N)
ρ_w = density of water (kg/m^3)
g = gravitational acceleration constant (m/s^2)
H = pumping head (m)
D = diameter of plunger (m)

The submerged weight of the pumprod and couplings should be added to the hydraulic force, to obtain the total force required for the upstroke. The weight of other moving parts, and the sliding friction of the plunger can generally be neglected.

As an example, take a handpump with a 3-inch (76mm) cylinder set at a depth of 15m below ground, with the water level in the well 10m below ground. Add a spout height of 1m and a discharge pressure of 2m head, and allow for a drawdown of 2m, to give a total pumping lift of 15m. If the pumprod is 1/2-inch (12.7mm) diameter steel, it will weigh 10N (1.0kg) per metre length. The hydraulic force, calculated from the formula above, is 667N, or 67kgf. To this must be added the pumprod weight of 150N (15kgf), to give a total upstroke force of 82kgf.

This is the theoretical average force during the upstroke. Tests using force meters have shown that actual peak forces in the pumprod are generally two to three times this calculated value. The pumprod, couplings, handle and bearings must, of course, be designed for these peak forces. Note too that the hydraulic force varies with the square of the pump diameter, so that a 2-inch (50mm) cylinder has less than half the operating force of a 3-inch (76mm) cylinder.

In figure II.3, the solid line abcd represents the theoretical force variation in *ideal* pump operation, without weight, friction, or inertial forces. At position a, the plunger is at the bottom of the cylinder. The pumprod force is zero because the ideal pumprod and plunger are weightless. As pumping starts, the plunger begins to move upwards, with the pumprod force increasing to b. This force remains constant until, at c, the plunger reaches its highest position. As the plunger stops, no more work is done, and the force returns to level d, which is the same as a. The plunger then returns to its original position and the cycle begins again.

Compare the actual forces, represented by the dotted line efghij. At position e, the plunger is at rest at its lowest point, and the pumprod force is caused only by its own weight. As pumping starts, the pumprod force increases rapidly to f, as the rod is stretched in developing the force and overcoming friction and inertial resistance in the water column. From f to g, the mass of water is kept moving by a reducing force. The

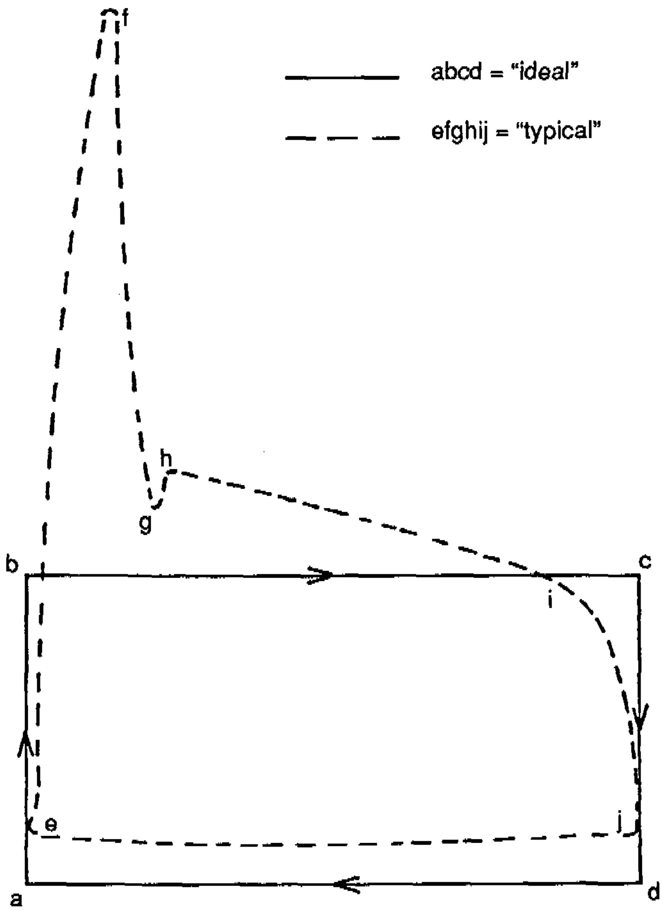


Figure II.3 Variations in pumprod force

kink from g to h is the closing of the plunger valve. At i, the plunger slows down, and by j it has reversed direction. The weight of the pumprod then returns the plunger to its starting point at e. A more complete analysis of the forces acting on the pumprod during a complete cycle is given in *Laboratory and Field Testing of Handpumps* (Goh Sing Yau, 1985).

The actual force exerted by the pump handle or crank mechanism on the pumprod of a reciprocating pump will often exceed 1,000N (100kgf), and can be as high as 2,000N (200kgf). The muscular force that a user can comfortably apply to the pump handle or rotating flywheel is limited to 250-300N (25-30kgf). With the mechanical advantage of a lever or flywheel, the operator's applied force can be multiplied to meet the force requirements of lifting water from depths as great as 80m. In practice however, handpumps should not be used for pumping lifts greater than 60m unless there is no alternative. Any pumping head greater than 45m has to be considered with reservation, as the discharge will be small and adequate maintenance will be very difficult.

For most operating conditions, a lever mechanical advantage of 5:1 should be sufficient, and lower mechanical advantages have merit, as they reduce the arc of movement needed to accomplish a full plunger stroke. This logic has prompted the UNDP/World Bank Handpump Project to challenge conventional thinking that cylinder sizes should be increased as depth reduces, to achieve higher discharges. Rather, it is argued, the stroke length should be lengthened and the mechanical advantage kept low, to give a comfortable arc of movement, and reduced pumprod forces because of the lower hydraulic load.

III. HANDPUMP RESEARCH AND DEVELOPMENT

The 1980s have seen intense efforts to modify handpump designs and correct recognized shortcomings. Research has focused on ways of simplifying pump maintenance and on improving the availability of spare parts.

Modern materials, especially plastics are being tested for many components subject to corrosion, and offer the important additional advantages of reduced weight and economic mass production. There are already pumps on the market in which different plastics are used for components such as bearings, plungers, seals, foot valves, rod connectors, and rising mains. Some must still be regarded as experimental; others have proved successful in rigorous laboratory and field trials

Research is still going on into ways of improving the reliability and reducing the cost of critical wearing parts, and with an emphasis on VLOM (village-level operation and maintenance) designs for deepwell pumps. One critical issue on which researchers are optimistic about an early breakthrough is the use of plastic rising mains for deepset cylinders. This would overcome two of the most severe shortcomings of conventional handpump designs — the rapid failure of galvanized steel rising mains when the water or soil is corrosive; and the difficulty of lifting heavy rising main, along with pumprods and cylinder, when routine seal replacement is needed.

The problem of corrosion has been particularly evident in West Africa, where it is estimated that about 70% of the region has groundwater classified as aggressive (with a pH value less than 6.5). Some two-thirds of handpump breakdowns in West Africa have been directly or indirectly attributed to corrosion (Langenegger, O. 1987). Table II.1 contains some preliminary guidelines on the use of galvanized materials in different types of groundwater.

Table III.1 Guidelines for the application of galvanized rising mains and pumprods with handpumps under corrosive conditions with pH as the corrosion index

pH	*Aggressivity of water*	*Application of galvanized material*
$pH > 7$	Negligible	Suitable
$6.5 < pH < 7$	Little to medium	Limited
$6 < pH < 6.5$	Medium to heavy	Not recommended
$pH \leq 6$	Heavy	Not recommended

Among the research activities prompted by the focus on handpump technology has been the construction of a purpose built test rig at the Consumers Association in the United Kingdom. More than 40 handpump models have been subjected to endurance testing in the rig during the last 8 years, and more trials are planned. New proposals include a suggestion to change the smooth uniform mode of operation in the endurance tests, so as to reflect the short sharp actions of many pump users and the lateral forces that people tend to apply.

Rising Mains

Conventional handpumps use galvanized steel rising mains, which are reasonably economic and widely available in developing countries. They do however suffer from two serious disadvantages: the pipes corrode rapidly in corrosive water, leading to unpleasant taste in the pumped water and early failure of the rising main itself; and the material is comparatively heavy when it has to be lifted from a deep well.

Modern pump designs are eliminating the need to remove rising main for routine maintenance, through the use of open top cylinders and larger diameter rising mains. The penalty is more expensive and heavier pipes for installation.

Stainless steel pipes have been used as an alternative to galvanized steel, to overcome the corrosion problem, but costs are very high, and the weight problem remains. It seems clear that plastic rising mains have great advantages, and already there is wide experience of the use of PVC and other plastics for rising mains down to depths of about 30m.

Beyond that depth, there have been some failures, partly due to the creep of the material, and partly due to fatigue failures resulting from the stress reversals. Research programmes are already under way to resolve both of these problems, and production of design guidelines for plastic rising mains for use down to 50m is seen as a top priority. With support from the Dutch government, a 100m deep test borehole has been drilled and Dutch consultant Inter Action Design is studying the dynamic behaviour of the rising main and other parts, with the emphasis on pumps at deeper settings (>45m) (Handpump Development News (HDN) Number 5, 1987). Other research will include investigations into alternative coupling systems, as both solvent-cemented and threaded joints pose problems for rising main applications.

Quality problems too are being addressed. There is evidence that uPVC pipes from different sources, though ostensibly made to similar standards, can vary widely. Guidelines are to be developed, which will include quality standards, quality control procedures and simple tests for uPVC pipes manufactured in developing countries (Consumer Research Laboratory, 1987).

Pumprods

As with rising mains, conventional galvanized steel pumprods fail rapidly in corrosive waters. At present, the only widely available alternative, though expensive, is stainless steel. A few handpumps operate succesfully with glass fibre reinforced plastic (grp) pumprods, or with timber rods, and for direct action pumps, buoyant plastic rods have great advantages.

Among the research topics for the future are alternative ways of coping with corrosion, either through different forms of coating (electroplating, plastic and rubber coatings, or plastic sleeves are being considered), or through anti-corrosive measures such as cathodic protection.

One aspect of pumprods which has already benefited from research activities is the connection system. Screwed threads cause difficulties when rods need to be dismantled and replaced during servicing. Snap-fit connectors have been developed in connection with the Afridev research programme supported by the UNDP/World Bank project. These allow the pumprods to be assembled and dismantled very quickly, without the need for any tools. The design and manufacturing control are critical, however, as the fittings must be capable of withstanding the pumping cycle, without breaking open and without resulting in slack in the pumprod. Experiments are still continuing, but there is optimism that snap-fit connectors will be successful.

At Sweden's Lund Institute of Technology, researchers are looking at alternatives to the connection between the handle and pumprods on the India Mark II. Though the present chain gives reliable service (3-5 years), simpler cheaper solutions are being sought. A double synthetic band has given good results and is thought to be cheaper than the roller chain and simpler for a village pump caretaker to change when necessary.

A different form of flexible coupling between the pumprod and the rodhanger bearing has been giving encouraging results in the Dutch research already referred to. A swivel is said to reduce the bending stress in the upper end of the pumprod considerably (HDN 7, 1987).

Cylinders

Increasing numbers of modern handpumps are departing from the standard reciprocating handpump cylinder design, which consists of a cast iron or brass casing, with a gunmetal plunger fitted with one or two leather cupseals. Such cylinders are inevitably heavy to remove and need frequent replacement of the leather seals.

Plastics are finding favour in many current designs, with injection moulding offering great advantages for economic production of spare parts in developing countries. PVC cylinders work successfully in several pump models, with stainless steel liners sometimes used to increase abrasion resistance where sand pumping is anticipated.

Engineering plastics are being used for plungers and footvalves, and there is a strong movement towards standard sized cylinders to be adopted for the full range of pumping depths (the concept of a "pump family"), to minimize spares stocking requirements.

The Swedish research into the India Mark II, already mentioned, includes comparison of alternative foot valves and plunger valves. Plastic foot valves are reported to be giving best results, with the O-ring identified as the only weak point.

More advice on piston and foot valve design is emerging from work at the University of Malaya in Kuala Lumpur, Malaysia. Research into valve performance in shallow wells shows heavier valve flaps to be more effective than light ones, though a compromise is needed to avoid unduly increasing the work input (Goh Sing Yau, 1985).

Elastomeric seals (neoprene rubber is the most common) are demonstrating advantages over leather seals, with greater wear resistance, particularly in sandy waters, though adequate manufacturing quality control may be difficult to achieve in some countries. For the future, researchers are being encouraged to investigate less conventional seals, including what is described as "dynamic sealing", in which the hydraulics at the plunger/cylinder wall interface effect a seal, without the need for any mechanical seal. Some pumps already use close fitting plungers without mechanical seals, with or without labyrinth grooves to increase hydraulic resistance at the interface. In the case of direct action pumps, in which the plunger velocity is higher than with lever action pumps, seal-less plungers seem a real possibility.

Open top cylinders have already proved practical and beneficial from the maintenance point of view, and research is continuing into ways of modifying some existing pump designs to suit this new concept.

Pumpheads

There are many different types of pump stand in use throughout the world, and this is likely to remain the case. Interchangeability of pump heads is an attractive concept, allowing water agencies to retain flexibility should one particular pump prove unsuitable, or parts become difficult to obtain. Standard baseplates, to allow different pump types to be fitted without the need to rebuild the apron slab, are seen as a long term benefit, and this development is being encouraged in some countries (Tanzania is an example), by the inclusion of standard bolt centres and types as part of the standard handpump specification.

Progress from steel pins to roller bearings made a big difference to handpump reliability, and cut down on damage to handles and pump heads. However, ball races remain difficult for village mechanics to fix accurately, and bearing wear is a common cause of handpump failure.

Acetal/nylon bearings have been developed for use with the Afridev, and early tests are encouraging, though problems remain with the bearing housing. Tests at the Consumers Research Laboratory in the UK show some promise with elastomeric bearings, though again further study is needed before conclusive recommendations can be made.

IV. COST COMPARISONS

Choice from a range of possible handpumps necessarily involves comparison of costs.

One method, based on the concept of the time-related value of money, is to calculate the *present value* of each cost item. So, the value of a particular cost is lower when it is incurred in the future (a cost of $100 incurred in one year's time would have a present value of about $93 at a discount rate of 8%, as that is the amount which if deposited now would become $100 in one year's time at 8% interest). The formula for calculating the present value (PV) of a cost (C) incurred in n years time, with a prevailing interest rate r, is:

$$PV = \frac{C}{(1+r)^{n}}$$

The discount factor $1/(1 + r)^n$ is given for various values of n and r in Table IV.1.

Table IV.1 Discount factors

Discount rate (%)	*Years* 4	6	8	10	12	15	20
6	.792	.705	.627	.558	.497	.417	.312
8	.735	.630	.540	.463	.397	.315	.215
10	.683	.564	.467	.386	.319	.239	.149
12	.636	.507	.404	.322	.257	.183	.104
15	.572	.432	.327	.247	.187	.123	.061

Over the expected lifetime (n years) of a pump therefore, the present value of all costs incurred in years 1, 2, 3, . . .n comes from the formula:

$$PV = C_o + \frac{C_1}{(1=r)} + \frac{C_2}{(1+r)^{2}} + \dots + \frac{C_n}{(1+r)^{n}}$$

Where C_o = initial capital cost.

If recurrent costs are presumed to remain the same each year, the present value of the lifetime costs is:

$$PV = C_o + C \times \frac{(1+r)^{n} - 1}{r(1+r)^{n}}$$

Table IV.2 Annuity factors

Discount rate (%)	*Years* 4	6	8	10	12	15	20
6	3.465	4.917	6.210	7.360	8.384	9.712	11.47
8	3.312	4.623	5.747	6.710	7.536	8.559	9.82
10	3.170	4.355	5.335	6.145	6.814	7.606	8.51
12	3.037	4.111	4.968	5.650	6.194	6.811	7.47
15	2.855	3.784	4.487	5.019	5.421	5.847	6.26

In this case, the multiplier term for the recurrent cost C is known as the annuity factor, and values for various combinations of n and r are given in Table IV.2. As an example of the use of this table, consider a handpump with an initial capital cost (C_o) of \$300 and future recurrent costs (C_1, C_2, . . . C_n) estimated to be constant at \$120 a year for the expected service life (n) of eight years. For a discount rate (r) of 10%, the annuity factor read from TableIV.2 is 5.335, and the present value (PV) of total lifetime costs can be calculated as:

PV = \$300 + \$120 x 5.335 = \$940

Using a similar priciple, cost comparisons can also be made using the *equivalent annual costs* method. This method has the advantage that it can be used for comparing pumps with different expected lifetimes. The initial capital cost of each pump is converted to an equivalent annual amount by multiplying it by the so-called capital recovery factor (Table IV.3). The capital cost is thus distributed as equivalent annual costs over the expected service life of the pump. Adding the average annual recurrent costs provides a means of comparing pumps on the basis of total equivalent annual cost.

Table IV.3 Capital recovery factors

Discount rate (%)	*Years* 4	6	8	10	12	15	20
6	.289	.203	.161	.136	.119	.103	.087
8	.302	.216	.174	.149	.133	.117	.102
10	.315	.230	.187	.163	.147	.131	.118
12	.329	.243	.201	.177	.161	.147	.134
15	.350	.264	.223	.199	.184	.171	.160

$$EAC = C \times \frac{r(1+r)^n}{(1+r)^n - 1}$$

where:

EAC = equivalent annual cost

C = initial capital cost

n = expected lifetime

r = discount rate

Using the same example as before, the initial capital cost of $300 is multiplied by the capital cost recovery factor for an eight year service life and a discount rate of 10%. Table 3.4 shows this figure to be 0.187. Adding the estimated annual recurrent cost of $120 produces a figure for the equivalent annual cost (EAC):

$$EAC = 0.187 \times \$300 + \$120 = \$176$$

Whichever form of calculation is used, the discount rate used can influence the comparison. For example, a simple not very durable pump of low initial capital cost but relatively high recurrent costs would be favoured by a high discount rate when compared with a more expensive strongly made pump with relatively low recurrent costs, because the high future costs of the first pump would be discounted more.

Cost comparison example

In this example, three handpumps, coded A, B and C, are presumed to have been preselected according to the procedure already outlined. It can be assumed therefore that all three pumps satisfy the specified requirements of ease of maintenance and repair, discharge capacity, pumping lift, reliability, and availability of spare parts. To compare the pumps, we calculate the equivalent annual cost. The calculation for Pump A is given as an example.

First, the present value of replacement parts:

$$PV_{repl} = \frac{C_2}{(1+r)^2} + \frac{C_4}{(1+r)^4}$$

$$PV_{repl} = \frac{100}{(1.1)^2} + \frac{100}{(1.1)^4}$$

$$PV_{repl} = \$82.6 + \$68.3 = \$151$$

The equivalent annual cost for the initial capital cost and the present value of spare parts is:

$$EAC_{cap} = (C_o + PV_{repl}) \times \text{capital recovery factor (Table IV.3)}$$

$$EAC_{cap} = (\$300 + \$151) \times 0.230$$

$$EAC_{cap} = \$104$$

To this must be added the average annual recurrent (maintenance) costs, so that:

$$EAC_{total} = \$104 + \$100 = \$204$$

Data on which the cost comparison is based and the results of the calculations for Pumps A, B and C are given in Table IV.4, in which the costs shown are real costs, expressed in constant prices, with no adjustment for inflation.

Table IV.4 Cost comparison data for three handpumps

Cost Item	*Pump A*	*Pump B*	*Pump C*
Capital cost ($)	300	600	700
Service life expectancy (years)	6	10	12
Replacement cost of parts ($)	100 in 2nd and 4th year	120 in 3rd, 6th and 9th year	150 in 4th and 8th year
Discount rate (%)	10	10	10
Annual maintenance cost ($)	100	80	60
Present value of replacement parts ($)	151	209	173
Equivalent annual cost of capital + replacement parts ($)	104	132	128
EAC total (including maintenance) ($)	204	212	188

Thus Pump C turns out to be the most cost effective, although it also has the highest initial capital cost.

IRC Publications

IRC's blue books in the Technical Paper Series cover a wide range of subjects and are used by thousands of workers in the community water supply sector. This series aims to integrate technical issues and software components, such as community involvement and operation and maintenance of water supply and sanitation facilities. Books in this series are prepared jointly by IRC staff and consultants.

Titles in the Occasional Paper Series are a reflection of ongoing work at IRC and related organizations. They concern subjects in a low key presentation and are addressing the needs of selected target groups. The Training Series comprises practical information and knowledge for use in training of various target groups. The Reference Series includes directories, inventories, thesauris, glossaries and other information tools in support of technical information exchange for community water supply and sanitation. These publications are designed to assist both documentalists and technical staff with information collection, storage, retrieval and use.

IRC titles of related interest include:

RENEWABLE ENERGY SOURCES FOR RURAL WATER SUPPLY
prepared by E.H. Hofkes and J.T. Visscher
(TP23) 184 pages 1987

MAINTENANCE SYSTEMS FOR RURAL WATER SUPPLIES
prepared by T.F. Bastemeyer and J.T. Visscher
(OP8) 46 pages 1987

WHAT PRICE WATER? User participation in paying for community-based water supply
prepared by Christine van Wijk-Sijbesma
(OP10) 94 pages 1987

[redacted]