a Sustainable Technology
Research and Development During
e Water Supply and Sanitation Decade

by John Reynolds

HANDPUMPS: TOWARD A SUSTAINABLE TECHNOLOGY

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UNDP-World Bank Water and Sanitation Program

First printing October1992.

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The UNDP-World Bank Water and Sanitation Program was organized as a joint endeavor of the United Nations Development Programme and the World Bank and has been one of the primary actors in worldwide efforts to meet the challenge of providing basic water supply and sanitation services to those most in need in the developing world. Partners in this venture are the developing countries themselves and the multilateral and bilateral agencies that fund the Program's activities.

The UNDP-World Bank Water and Sanitation Program produces its own publications and also releases works under the auspices of the World Bank. The Program's publications are divided into two series, a **Water and Sanitation Program Report** series and a **Water and Sanitation Discussion Paper** series. The Program Report series presents formal discussions of the Program's operations and research as well as examinations of relevant projects and trends within the water and sanitation sector. Program Reports are subject to rigorous external review by independent authorities from appropriate fields. The Discussion Paper series is a less formal means of communicating timely and topical observations, findings, and opinions concerning Program activities and sector issues.

Contents

In Memoriam

During the past decade, efforts to bring water supply to the rural poor have produced dramatic changes around the world. The concept of community management has established itself as the most sustainable approach. Technologies have been adapted to widely varying conditions and rigors. And most important for the millions of poor who lack access to safe water, these technologies have been low cost, and it is now possible for many communities to construct and maintain their own facilities. As this volume attests, John Reynolds played a pivotal role in this global change, guiding the development of technologies throughout the Water Decade. His death, which occurred before the publication of this volume, leaves us, his colleagues, with a deep sense of loss. We remember him for his great contribution to meeting the challenge of providing safe water to the hundreds of millions who lack it, and we dedicate this book, his last work, to his memory.

Drawing by John Reynolds (untitled, undated)

Introduction

Water is a fundamental human need. Four fifths of our planet is covered by it, but untreated surface water is rarely fit to drink. Yet in most inhabited parts of the world, unpolluted groundwater can be found below the surface. Handpumps provide a cost-effective means of access to groundwater, and therefore have an important role to play in delivering safe and sustainable water supplies to communities in developing countries.

Research and development coordinated under the UNDP-World Bank Handpumps Project have concentrated on the conventional reciprocating pump based on a cylinder and piston, with two nonreturn valves to direct the flow and a rod connecting the piston to an operating handle. Other pumping techniques have been considered, but none offers significant advantages over the reciprocating piston pump without also presenting serious drawbacks. The aim of the research has been to develop designs that take advantage of up-to-date materials and appropriate manufacturing techniques to produce sturdy and reliable pumps that can be manufactured in the countries of use and can be maintained within the limited human and financial resources of user communities.

Community Water Supply: The Handpump Option was published in 1987 and summarized handpump research and development undertaken within the UNDP-World Bank Handpumps Project up to and including 1985. This report deals primarily with subsequent research, both into existing handpumps and specific handpump topics.

This report is in four parts:

Part A, an overview, describes the context of handpump research and explains why it was necessary for the UNDP-World Bank Handpumps Project to be involved in directly sponsoring research.

Part B gives details of the research undertaken in a number of specific topics of handpump development, principally by the Consumer Research Laboratory (CRL).

Part C summarizes work carried out in Project field trials since the publication of *The Handpump Option.*

Part D summarizes the results of laboratory tests on handpumps carried out by CRL since publication of *The Handpump Option.*

Acknowledgments

I am sincerely grateful to all who have contributed to this report, both for providing the information on which it is based and for their subsequent help in editing it.

Specifically, my thanks go to staff of:

The World Bank, in Washington and in the Regional Offices

The Overseas Development Administration

The Consumer Research Laboratory

The InterAction Design Handpump Project

The Swiss Centre for Appropriate Technology

The Open University

John Reynolds
Colchester, UK, 1991

A. Overview

A1. Background

The handpump is not a new, nor even a recent, invention. Illustrations survive from Roman times of pumps with simple cylinders, pistons, and flap valves identical in their operation to many pumps in use today. Handpumps probably first appeared well before the Romans, since it is likely that pumps played an important role in the development of larger seagoing vessels.

And so it may seem strange that we should continue the technological development of something that has been around in substantially its present form for thousands of years. But the purpose of handpump research in the International Water Decade[1] has not been to reinvent the handpump. Instead, attention has been focused on the development of handpump concepts and detailed designs that can accommodate the realities of the scale of the demand for handpumps, probable workload and conditions of use in the field, limitations on maintenance and repair, and the industrial facilities available in developing countries to manufacture whole pumps and spare parts. Of paramount concern has been the development of pumps that can be maintained by the communities that rely on them.

The scale of demand

At the inception of the International Water Decade, it was estimated that up to two billion persons in rural areas of developing countries were drinking water that threatened their health and well-being. Since most developing countries have very limited financial and technical resources, the need for water supplies that can be sustained at low cost is obvious. Groundwater schemes using handpumps can be implemented at roughly half the cost of standpipe supplies, and about a quarter of the cost of yard-tap schemes.

The handpump therefore has a central role in achieving the goals of the Decade. Moreover, the importance of handpumps is not limited to their impact on the health of the communities they serve. In many cases, villages without handpumps rely on water sources that can be many hours away, and

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1. The General Assembly of the United Nations designated 1981-1990 as The International Drinking Water Supply and Sanitation Decade; hereinafter, "the International Water Decade" or "the Decade."

There are examples of handpumps serving communities of 400 or more, but a single pump typically provides clean water for between 100 and 200 persons. This means that as many as 20 million handpumps could be needed to satisfy the original demand, let alone the need for spare parts to maintain pumps and new pumps to replace those that have worn out or corroded.

The working environment

Most handpumps have a hard life. Many are in continuous use throughout the daylight hours for as long as they can survive such treatment. They are exposed to the elements, may be subject to pilferage and vandalism, and can be a convenient scratching post for domestic animals. At least some of the users can be expected to be unsympathetic in the way they use them, not out of any animosity but simply because they are unaware of the consequences of striking the handle repeatedly on its stops, for example.

Groundwater itself is often aggressive. Corrosion can cause rapid failure of pumps that might otherwise be very durable. Sand and other suspended solids can cause rapid wear in cylinders and seals.

The arrival of a pump is not always welcomed by everyone in the community: pumps may be objects of suspicion and outright hostility in the minds of those who see them as threats to the traditional patterns of village life.

Maintenance and repair

In the early years of the Decade, and particularly in the global field trials during the mid-1980s, it became apparent that maintenance was the single most important issue in handpump development. Although conditions vary considerably among countries, the limited skills available within rural communities of developing countries could not, in general, be expected to cope with the maintenance requirements of most of the handpumps available at the start of the Decade. Financial and practical constraints made it certain that centralized maintenance regimes achieved, at best, only limited success.

The concept of village-level operation and maintenance (VLOM) was developed in direct response to this. Initially, the VLOM concept centered on the handpump itself, the aim being to provide villagers the option of performing maintenance themselves by developing pumps that are:

- Easily maintained by caretakers drawn from the user community, with minimal skills, a few simple tools, and modest training;
- Manufactured in the country of use, or at least capable of being manufactured there, primarily to ensure the availability of spare parts;
- Durable and reliable under field conditions; and
- Cost effective.

As the field trials continued, however, it became apparent that the issue of maintenance was not confined to the handpump itself. The quality of construction of the borehole was also critical. Boreholes that failed to screen out sand and other contaminants cause consistent premature failure of handpumps that in other circumstances would have been reliable. Moreover, more maintenance difficulties arose from institutional or financial shortcomings than from technical problems with the hardware.

The VLOM concept was therefore expanded to include "software" or organizational topics. VLOM might now be better understood as standing for "village-level operation and management of maintenance," including:

- Community choice of when to service pumps;
- Community choice of who will service pumps; and
- Direct payment by the community to the maintainers and repairers.

Communities need to be encouraged to develop a sense of ownership, and hence of responsibility, for "their" pumps. With this in mind, it has also been suggested that user communities should be expected to make a financial contribution to the original cost of the borehole and the pump.

Manufacture

Although most developing countries might be described as lacking in manufacturing resources, there are substantial differences between countries. At the lower end of the scale are countries with little more than embryonic industrial facilities; raw materials and manufacturing skills tend to be in very short supply. By contrast, countries such as India produce a very wide range of industrial goods, and on an impressive scale; raw materials and a variety of manufacturing skills are more readily available.

Potential global demand for handpumps is in the millions of units. Within individual countries, this typically translates to demands for tens of thousands of pumps. "Home markets" of this order may not attract the attention of large-scale manufacturers, but they provide excellent opportunities for small and medium-size local firms.

Summary: The VLOM concept

The concept of a VLOM handpump has both hardware and software components. The handpump is one element of a system that also includes the borehole, the community relying on the pump, and the availability of local and national manufacturing facilities. In a VLOM handpump installation:

- **The borehole must be designed and constructed in a manner appropriate to the pump and local conditions.**
- **Routine maintenance and repair can be done by the user community, which will decide when to carry out repairs, who will do the work, and who will be responsible for paying them.**
- **Nonwearing parts of the pump must be durable and reliable, and parts subject to wear must be easy to service and inexpensive.**
- **As far as possible, the pump must be suitable for manufacture using existing local industrial resources, or facilities that can be readily established. Imported components are to be used only if they are critical to achieving other VLOM objectives.**

Established manufacturers are not excluded, since there is plenty of scope for joint ventures.

This situation argues for handpumps that can be manufactured by methods that are labor-intensive rather than capital-intensive and can also be [illegible] to make other products for which there is (or will be) local demand. Specialized techniques, or those requiring a substantial initial investment that must be amortized over a relatively large production run, are not suitable.

The importance of quality control has been clearly illustrated by the India Mark II. In a manufacturing environment where well-developed shop floor skills are at a premium, quality control is best assured by including it at the design stage. This can range from small details of design -- for example, shaping parts so that they cannot be assembled upside down -- to choosing processes that demand conscientious production management but rely less heavily on the skills of individual operators. It also includes designing jigs and fixtures which will automatically reject substandard components during manufacture and assembly.

A2. DESIGNING FOR VLOM

The VLOM concept encompasses a range of concerns, and it has important implications for the handpump as an item of manufactured hardware. It is a significant challenge to design for maximum simplicity of maintenance, ease of manufacture, and high efficiency throughout a long life of constant use, particularly to engineers who are accustomed to working in a relatively sophisticated environment.

Reliability versus maintainability

A useful first step is to recognize the trade-off between reliability and maintainability. The crucial consideration is to maximize the time the pump is functioning rather than to minimize the number of times it breaks down. Thus a VLOM pump that needs attention relatively frequently, but can be put right by the local caretaker within a few hours or days, is better than a conventional pump which breaks down less frequently, but then needs a mobile team to be called out to repair it, for which an average delay of three months is not unrealistic. Figure A1 illustrates the point.

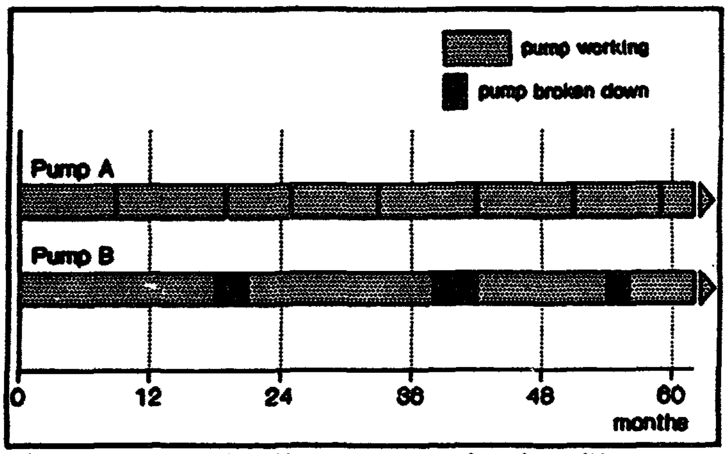

Figure A1: Reliability versus maintainability

This reasoning runs counter to the classical engineering definition of reliability as the mean time between failures (MTBF). For Pump A, the MTBF is about 8 months, for Pump B about 18 months. But if reliability is taken to be the proportion of the total time for which the pump is functioning, Pump A achieves about 99 per cent against less than 85 per cent for Pump B. In reliability engineering, this is defined as availability. Another way of expressing the same idea and more clearly illuminates the difference between the two pumps, is to compare the total "down time" -- for Pump A, the total down time is about 20 days, for Pump B it is over 250 days.

The essential difference between Pumps A and B lies in what is needed to maintain them. The consequences of failure in a VLOM pump are different by an order of magnitude from those for a pump which demands a centralized maintenance team.

This is not to say that reliability in the sense of MTBF is irrelevant, but only that it is subservient to ease of maintenance. Clearly, other things being equal, a pump which breaks down less often may be preferable to one which breaks down every few weeks. But it has been said that there can be some advantage in pumps which need regular attention, in that this helps to reinforce the commitment of the users to the maintenance of the pump and aids in developing and disseminating appropriate skills. This presupposes that the pump meets the requirements for VLOM, however: that it is simple to dismantle and reassemble, and spare parts are cheap and readily available, to ensure that it can be maintained within the limited human and financial resources available to the user community.

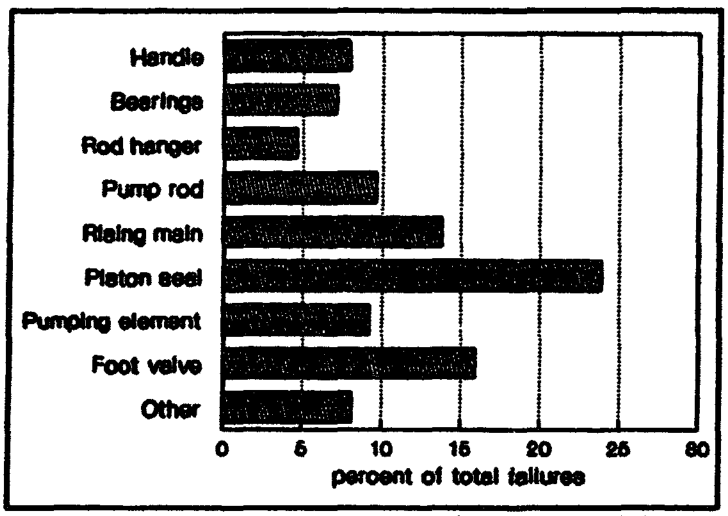

Figure A2: Field trials -- analysis of pump failures

It might be said that the best pump of all is one that never breaks down. This is the elusive "fit and forget" handpump some manufacturers have aimed for, and a few claim to have achieved. But evidence from both the laboratory and field trials has been that "fit and forget" is not a realistic option. Pumps that have been said to have been working for many years without any attention whatsoever have, on closer examination, often been found to have been pumping from very shallow sources, or simply little used. For whatever reasons -- social or cultural reservations about the pump, difficulties in using it, problems such as high iron content in the water produced are possible explanations -- the local community has preferred another water source.

The below-ground assembly

The Project field trials showed that three quarters of repairs needed to handpumps were related to the below-ground components (Figure A2).

Although these results may have been influenced by the choice of pumps used in the field trials (a relatively high proportion of pumps with leather seals, for example), they showed clearly that ease of below-ground repair was an important factor.

In many traditional handpumps, below-ground repairs are far from straightforward. A 40-meter below-ground string using 1.5-inch galvanized steel rising main and 12-mm steel pump rods will weigh about 200 kg. Full of water -- as it will be if it has to be extracted with the footvalve still functioning -- the weight will be close to 250 kg. Lifting tackle is essential. Moreover, with conventional threaded joints, a range of heavy tools and considerable skill are required for dismantling and reassembling the joints in the rising main and pump rods. Many pumps also require the entire pumpstand to be removed from the wellhead to give access to the rising main.

In the pump cylinder itself, results from both the laboratory and field trials suggest that synthetic seals offer better, or at least more consistent, performance than traditional leather seals. The conventional process for the production of the internal parts of pump cylinders was casting in brass or gunmetal. However, both the casting process and the required machining present serious problems of quality control.

The above-ground assembly

Figure A2 shows that a substantial number of handpump failures arose from problems with handles and handle bearings. Broken handles could generally be attributed to pump designers and manufacturers simply underestimating the severity of actual conditions of use, and the solution is relatively straightforward: make the handles stronger. The handle bearings, on the other hand, are bound to be subject to a certain amount of wear. The conventional choice for handpump bearings has been ballraces. But ballraces are expensive, prone to corrosion, call for close tolerances in the manufacture of their housings and tend to be difficult to replace in the field.

Plain bearings also have a respectable engineering pedigree. Their usual disadvantage is that they need regular lubrication, and this is not a realistic option in a handpump for use in rural areas.

VLOM solutions

Albert Einstein is quoted as saying that everything should be made as simple as possible, but not simpler. This is useful guidance for the VLOM pump designer. Putting the principle of VLOM into practice means designing for simplicity, certainly, but not in any sense producing an inferior or second-rate product. Nor is it a quest for a technology which is "appropriate" in the Schumacher sense; VLOM should recognize the existence of indigenous skills and materials and also of new materials and manufacturing technologies where these can play a part. In a practical VLOM handpump:

- The basic structural components of the pump should neither break nor wear out. Nonwearing parts should last ten years.
- The wearing parts should be readily accessible, require no special skills for servicing, and be inexpensive and of consistent high quality, to ensure interchangeability.
- The below-ground assembly should be as light as possible so that it can be extracted when necessary, even from deep settings, without the need for lifting tackle.
- The impact of corrosion should be minimized by using materials which are inherently corrosion-resistant.

In meeting all these objectives, the manufacturing processes and raw materials required should be available in the country of use, or it should be possible to establish them as self-supporting, commercial enterprises.

As the VLOM concept developed and crystallized, it was clear that the majority of established handpump manufacturers were reluctant to support the research required to develop practical VLOM pumps. Some were hostile and believed VLOM was unrealistic. Others could accept the logic of the idea but felt that the uncertainties of the market prevented them from committing the necessary investment.

Unable to find existing pumps that met their needs, Project staff in the field made their own with local raw materials and manufacturing facilities. The Bangladesh Deepset Mark I, precursor of the Tara, and the Maldev, later to evolve into the Afridev, are conspicuous examples. Seeing a need which existing manufacturers were unable or unwilling to fill, the UNDP-World Bank Handpumps Project, in cooperation with governmental and nongovernmental donor agencies, set out to coordinate research into specific topics of handpump design and construction. This research was designed to address directly the most important priorities for achieving practical VLOM pumps.

Throughout the program of research, laboratory work -- principally carried out by the Consumer Research Laboratory (CRL) and supported by the UNDP, the World Bank, and the Overseas Development Administration (ODA), UK -- has been coordinated with work in the field, mainly in Malawi, Kenya, India, and Bangladesh, with particular reference to the Maldev, Afridev, and Tara handpumps.

A3. The Research Program

Most of the pumps tested in the laboratory and in the Project field trials had been of the conventional reciprocating piston type, with above-ground lever arm operation. Other types had been included, however, such as hydraulic pumps (Vergnet, Abi-ASM), reciprocating pumps with rotary operation (Volanta, VEW), and screw-type pumps (Mono, Moyno). Although some of these unconventional pumps offered particular potential advantages, none had shown itself to be especially well-suited to achieving the VLOM objectives. For deep well applications, it was felt that the research effort should therefore be aimed primarily at developing conventional, lever-arm, reciprocating piston pumps. For lower lifts, direct action pumps (Ethiopia BP50, Tara) showed considerable potential to combine simplicity of manufacture with ease of maintenance, and to avoid many of the problems inherent in suction pumps.

The program of research was organized in five main topics:

- Plastic below-ground components
- Plastic and other dry bearing systems
- Sealless pistons and diodic valves
- Lightweight pump rods for direct action pumps
- Measurement of the stresses in uPVC rising mains

In practice, these strands of research were closely interrelated, as Figure A3 illustrates.

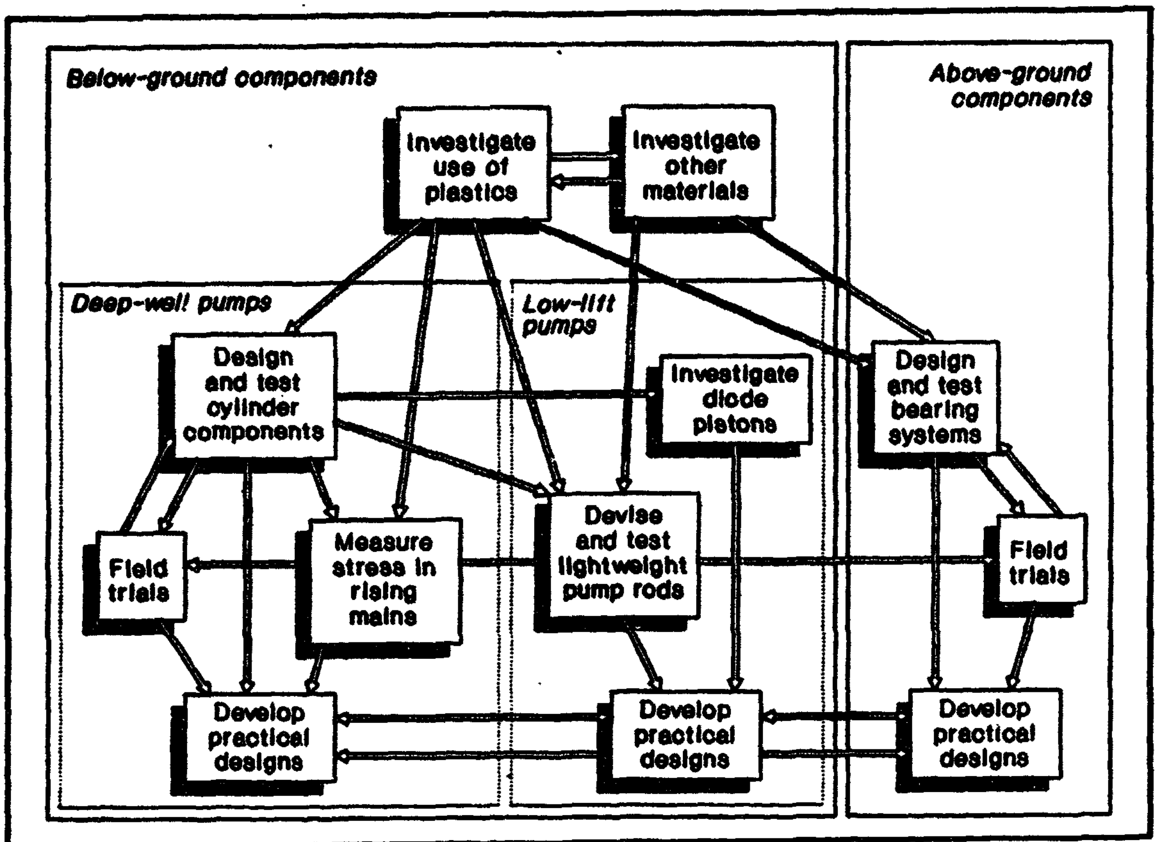

Figure A3: The handpump research program

Plastic below-ground components

The term plastic encompasses a wide range of materials with considerable differences in their properties. Appropriate plastics designed to make the most of their strengths can out-perform traditional materials in a wide variety of engineering tasks. Plastics offer light weight and corrosion resistance. They can be molded into intricate shapes, reduce the number of components required, and take advantage of methods of assembly that require neither tools nor special skills. Spare parts will be available when needed because individual components are cheap, rarely have an alternate use, and do not deteriorate in storage. Plastic molding is an attractive and appropriate industrial development that makes possible the manufacture of a wide range of low-cost products with ready markets.

Recognizing the need to develop below-ground components that were better suited to VLOM requirements, the Project, in collaboration with ODA, supported substantial research by CRL to establish the potential for the use of plastics in handpump cylinders. This research culminated in the development of the Afridev pump cylinder.

Plastic dry bearings

Plastic bearings have the potential to be inherently free from corrosion, ease the manufacturing tolerances required in associated parts, and do not need to be lubricated. They may wear out considerably more quickly than ballraces (although rapid wear is not inevitable), but they are much cheaper and easier to replace and could readily be integrated into a village-level maintenance regime.

The UNDP-World Bank Handpumps Project supported a program of research, based principally on field tests but including a substantial element of laboratory testing by CRL, to develop plastic plain bearings. The testing included various types of plastics, and also wooden bearings and torsional rubber bearings. Originally the work centered on the Maldev pump, but after 1984 was based on the Afridev and also involved the Swiss Centre for Appropriate Technology (SKAT) and DuPont Plastics of Switzerland. The result was the development of the two-part nylon/acetal Afridev handle bearing system.

Sealless pistons and diodic valves

Nearly one quarter of the pump failures documented in the Project field trials had been attributable to problems with piston seals. This research therefore set out to establish the potential for using "solid-state" pistons which achieved the functions of conventional seals and valves by fluidics techniques used in other engineering fields.

Although there are no examples of existing handpumps with "solid-state" valves, the Volanta and Ethiopia BP50 have shown that a pump can work satisfactorily without a flexible seal. Alternatives to flexible seals are well established in other fields of engineering, and they are widely used where a slight loss of fluid is acceptable and the main requirement is for a seal that needs little or no maintenance.

Solid-state control of fluids is also well established and extensively used in applications where mechanical control devices would not be practical. ODA supported research by CRL, in consultation with SKAT and the University of Sheffield, UK, to investigate whether these techniques could be applied to handpumps.

The research confirmed that "solid-state" pistons could be practical, particularly for direct-action pumps where piston speeds are inherently greater and there is direct feedback from the piston to the user. Some possible practical designs were suggested.

Lightweight pump rods for direct-action pumps

Direct-action pumps benefit from lightweight, high-displacement pump rods. In a conventional lever-arm pump, the weight of the rods is counterbalanced by the weight of the handle. In a direct-action pump, however, the user has to lift directly the combined weight of the rods and the column of water in the rising main. By minimizing the weight of the rods themselves and increasing their displacement to reduce the weight of the water column, the lifting force can be reduced and part of the total operating effort transferred to the down-stroke, which is ergonomically beneficial.

An obvious way to achieve the objectives of light weight and high displacement is to use sealed tubular rods. Various materials have been tried: uPVC in the Tara and Wavin pumps, polyethylene in the Nira AF85, and aluminum in the Pek pump. ODA sponsored CRL to investigate the availability of these and other potentially suitable materials, and to test a series of prototype rod configurations.

The research confirmed that uPVC, ABS, and polyethylene all had potential for use as lightweight pump rods. However, they all tended to buckle on the return stroke, and although that did not seriously affect the pump"s performance, it could cause problems of wear if both the rod and the rising main were of the same material. Since uPVC and ABS gave comparable performance, the best compromise might therefore be to use ABS rising mains with uPVC tubular pump rods.

Stresses in plastic rising mains

Most of the potential benefits arising from the use of plastics in the pump cylinder apply equally to the rising main. Light weight, corrosion resistance, and relatively low cost are the principle advantages of plastic compared to conventional steel pipes, and the research on plastic below-ground components envisaged from the start that plastic pipe would be used for the rising main. Moreover, plastic pipe, particularly in uPVC, is widely available and already manufactured in a number of developing countries.

While the potential significance of uPVC pipe to achieving the VLOM objectives has been apparent, doubts about its reliability have persisted. In other applications, the principle stresses in the pipe are generally those caused by internal pressure; like other pipes, different grades of uPVC pipes are specified by the internal pressures they can withstand. But in a handpump, the internal pressures are relatively small. Instead, the main sources of stress are the tensile loads (a combination of the weights of the pipe itself, the cylinder, and the water column) and the reaction to friction between the piston seal and the cylinder bore.

While the major static and quasi-static forces in a handpump rising main can be calculated fairly easily, the dynamic forces are more difficult to predict theoretically. The life of a pipe in practice will be determined not only by the absolute values of the forces involved but also by the way they vary throughout the pumping cycle. Moreover, little was known about the effect of external factors such as the type of pumpstand (lever versus rotary operation, for example) and the effects of shock loads generated by the handle striking its stops.

A research program was therefore initiated at CRL to determine the actual stresses in handpump rising mains for depths down to 45 meters. The work was sponsored by the UNDP-World Bank Handpumps Project, in collaboration with ODA. A parallel study was undertaken by Interaction Design with the support of the government of the Netherlands, for depths down to 100 meters.

This research has generated a very large amount of data on the stresses likely to be present in handpump rising mains. It has shown that the absolute levels of stress in the rising main are considerably less than the ultimate tensile strength of uPVC, and that failure is therefore more likely to be attributable to fatigue. The test results typically show higher frequency secondary stress variations superimposed on the basic cycle determined by the delivery and return strokes, for both the rising main and the pump rod. However, the magnitudes of the stress variations are such that uPVC pipes used as handpump rising mains, have the potential to offer service lives of the order of ten years, provided that the pipes are of good quality and that stress concentrations are avoided by appropriate design and handling.

The research included the analysis of samples of uPVC pipes manufactured in developing countries, comparing them with the UK-made pipe used for CRL's tests. Evidence of lack of quality control was found in all but one of the pipe samples.

Ongoing research: connectors for rising mains and pump rods

Following the measurement of the operating stresses in uPVC rising mains and pump rods, research has begun to evaluate and develop easy-to-use connectors for plastic rising mains and for pump rods. The initial research is being undertaken by CRL, with the support of ODA, GTZ, UNDP, and the World Bank. Eventually, the projects will include assessments in the field.

Each of these research topics is covered in detail in Part B, which explains the background to the research, methods used, findings, and conclusions for the individual topics.

A4. Field Trials

Field trials up to 1985 were reported in detail in *Community Water Supply: The Handpump Option*. Project research in the field since 1985 has been concentrated in Kenya, India and Bangladesh.

Kenya -- the Afridev handpump

Production of the Afridev pump began in 1985. A number of design improvements were introduced in 1987 to combat premature wear in the handle bearings and internal wear of the rising main caused by contact with the original polyethylene pump rod centralizers. These improvements were incorporated in the Afridev Specification published in that year.

The Afridev was designed for annual replacement of wear-prone parts--bearing bushes, valve bobbins, and piston seals. This strategy has been generally successful, and user communities have been able to sustain the pumps in good working order with their own resources.

India -- the India Mark II and Mark III (VLOM) pumps

The main objectives of research in India have been to improve the reliability of the India Mark II handpump and develop a derivative, the India Mark III, that will be simpler to maintain. It is estimated that improvements in the India Mark II will halve the number of breakdowns, with consequent annual savings in maintenance costs of about $12 million.

By design, most of the components of the India Mark III are interchangeable with the India Mark II. In the India Mark III, existing pump mechanic can carry out over 90 per cent of the repairs likely to be required, with the help of the user community and a few tools. Moreover, the Mark III makes it possible to train a village mechanic or blacksmith, thereby making the necessary skills available within the user community.

A number of experimental direct-action pumps using Afridev below-ground components have also been installed.

Bangladesh -- the Tara direct action pump

The Tara is a pump designed from the outset to be suitable for both manufacture and village-level maintenance within the very limited resources available in Bangladesh. The Tara enjoys very high user acceptance, can be installed at a low cost, and can be sustained at a cost of about $0.10 per user per year. It is truly a VLOM pump.

Details of field research are given in Part C of this report.

A5. Laboratory Testing

Initial research concentrated on handpumps which were available at the start of the Decade. The objectives were:

- To evaluate the major handpump types on the market
- To cooperate with manufacturers in the development of design improvements and new pump designs
- To provide information to assist developing country governments and donor agencies in choosing appropriate pumps for particular applications

Comparative tests on handpumps were devised and carried out by CRL in Harpenden, UK (at that time known as Consumers' Association Testing and Research, or CATR). The original test of 12 pumps was sponsored by the Overseas Development Administration (UK) and formed the basis for further tests carried out under the UNDP-World Bank Handpumps Project.

The laboratory test program was designed from the outset to provide reliable, comparative data on pump performance and endurance, and to assess likely maintenance requirements and the potential for local manufacture. The original test regime was devised after extensive consultation, to reflect actual conditions of use in developing countries, and to treat the pump not simply as a product but as a system that included its user. The regime has been refined over the years, but its basic principles remain intact. The results for a pump tested in, say, 1989 can be compared with one tested in 1981. An important element of the program has been to encourage dialogue with pump manufacturers to suggest ways in which existing pumps might be improved.

Results for pumps tested up to 1985 have been published in earlier UNDP-World Bank reports and were summarized in *Community Water Supply: The Handpump Option*. Laboratory results for pumps tested since 1985 are summarized in Part D of this report.

The response of handpump manufacturers to the laboratory findings has been mixed. Many manufacturers have been eager to discuss, and some ultimately to adopt, engineering improvements suggested by CRL, though only a few have been prepared to accept the challenge posed by the VLOM concept and make fundamental changes to their products.

A6. Conclusions and Future Research

Handpumps represent a technology which has been understood for thousands of years. Nevertheless, the challenge of developing handpumps which could be manufactured in developing countries and maintained by the communities that rely on them has been considerable. For most applications, the management of maintenance within the village is crucial to the long-term sustainability of handpump water supplies.

Handpump manufacturers have now espoused VLOM and use it liberally in their advertising, but in the early years of the Decade, when manufacturers were faced with VLOM as a concept rather than a practical proposition, they were reluctant to take on the research and development required to put VLOM ideas into practice. Unable to buy off-the-shelf pumps which met their needs, Project staff in the field began to make their own, using materials and manufacturing facilities available to them, and this initiative was the cornerstone of the handpump research and development program coordinated by the UNDP-World Bank Handpumps Project.

The consistent strategy behind the research and development effort has been to combine field testing with work in the laboratory. This has ensured that the work has been firmly rooted in the realities of conditions in the field, while drawing in expertise from a range of disciplines.

The result has been to confirm that VLOM is a practical proposition. It is exemplified in the Afridev and Tara handpumps, which incorporate design concepts that are fundamental to successful, sustainable, village-level maintenance. Some manufacturers have already followed these leads: versions of the Afridev -- the Aquadev from Mono pumps of the UK -- are already in production. Others have made significant changes to their pumps or have produced new models designed to satisfy VLOM requirements. For low lifts, direct-action pumps such as the Wavin and Nira AF85 are now available.

A conspicuous success of the program has been to show how plastics can ease maintenance, both in the below-ground assembly and for handpump bearings. Plastic parts are relatively cheap and inherently corrosion resistant. Their light weight makes it possible for below-ground assemblies to be withdrawn without lifting tackle.

Throughout the Decade, the research effort has concentrated on what were seen as the most significant outstanding design issues. Other issues remain, however, and all research tends to raise new questions as the original aims are achieved. Opportunities for the next phase of research are summarized below.

***Summary:* Opportunities for future handpump research**

Rising mains	Develop VLOM connector systems (this is already under way with the support of ODA and GTZ)
	Develop quality standards and quality control procedures, including simple tests, for uPVC pipes manufactured in developing countries
	Develop design guidelines for plastic rising main assemblies, including suggested material and dimensional specifications
Bearings	Investigate elastomeric materials for use as nonsliding bearings; develop practical designs
Cylinders	Investigate design and manufacture of elastic pumping elements (as used in the Vergnet pump) to reduce cost and improve reliability
	Test and develop practical designs for sealless pistons and solid-state valves
	Review, assess, and develop further methods of protecting cylinders against sand contamination
Direct action	Develop improved designs for pump rod and rising main pump connectors and centralizers
Corrosion	Assess techniques for combating corrosion, including cathodic protection, plating techniques, coating with plastics or rubber
Pump rods	Develop reliable, easy-to-release couplings

B. Research Into Specific Topics

B1. Plastic Below-Ground Components

Many familiar products once made from traditional materials like steel, brass, wood, clay, or leather are now produced largely from plastics. In many cases, the reasons for this are primarily economic. The raw materials tend to be relatively expensive, particularly on a weight-for-weight comparison with traditional materials, but they are generally much less dense. For a given weight of material, therefore, many more components can be produced from plastics than from traditional materials.

With plastics, the process of transforming the raw material into the finished product is very rapid, and there is little waste. The machinery for producing plastic components is inherently versatile: a single molding machine can produce an infinite variety of shapes that would require a daunting array of different machines to be produced "from the solid." Because plastic components can be readily molded into intricate shapes, a single plastic part can replace a number of parts produced by more conventional means, and it can also eliminate the need for subassembly. Moreover, the operator of the machine does not need specialized skills to produce components of consistent high quality.

Before plastic moldings can be made, however, a set of tools must be produced. These tools tend to be costly, and considerable skill is required in their design and manufacture to ensure consistent high quality in the final product. The high initial cost means that the economic advantages of plastics can be realized only over relatively large production runs. Since the initial investment has to be committed before a single component can be produced, a prospective manufacturer needs to be sure that a ready market exists for plastic products.

These factors tend to discourage all but the largest manufacturers of plastic products from undertaking research and development in fields where a market for new products is not immediately apparent. In handpumps, manufacturers also anticipated patent enforcement difficulties that could prevent them from achieving an adequate return on a large research investment.

The potential for plastics in handpumps

The main force driving the growth in the use of plastics may be economic, but plastics also bring real engineering benefits in applications that are appropriately designed and developed. In handpumps, the light weight and corrosion resistance of plastics commend their use in below-ground assemblies. With appropriate design, plastics also have the potential to simplify maintenance by eliminating the need for tools and minimizing the skills required of pump caretakers. Spares can be cheap, have long shelf lives, and are less likely to be "borrowed" for other purposes because they have no other practical uses.

There is good potential for manufacture in the country of use. Although developing countries are unlikely to be able to produce plastic raw materials, the processing of plastics can provide the means to manufacture a wide variety of products that find ready markets. A number of developing countries already have established molding and extrusion industries.

***Summary:* The Advantages of Plastics in Handpumps**

Light weight	**For ease of repair and maintenance**
Corrosion resistance	**Most plastics are not affected by water and will not contribute to galvanic corrosion of other parts with which they are in contact.**
Low cost	**Although a large initial outlay is required, the subsequent piece price of the components will be relatively low in quantity production, thereby making possible cheaper pumps and cheaper spare parts.**
Versatility	**Complex components are almost as easy to make as simple ones.**
Quality assurance	**Although plastics processing requires careful management and supervision, the quality of the finished product is not directly dependent on the skill of the production operator.**
Potential for local manufacture	**Plastics processing is established in some developing countries and attractive to others wanting to encourage new industries.**

Developing a design concept

The Consumer Research Laboratory undertook development of a design concept for the below-ground assembly of a handpump that would exploit the advantages of plastics. The work was jointly funded by ODA, UNDP, and the World Bank. The project did not set out to develop a definitive design, but rather to demonstrate how plastics could be used successfully in this application and thereby provide a knowledge base on which more specific designs could be developed by manufacturers and others.

The research was subsequently used in the development of the below-ground components of the Afridev handpump.

Designing for plastics rarely succeeds where the plastic material is simply substituted for a traditional material. The properties of plastics are distinctly different from those of conventional materials, and it is necessary to design from first principles, not only to realize the advantages that plastics can offer but also to avoid potential shortcomings. Moreover, the design must take account of the particular material to be used: the term "plastic" covers a great variety of materials with a wide range of physical properties.

CRL consulted a number of plastics manufacturers. Their consistent advice was that the suitability of plastics for specific applications was at least as dependent on the design and the working environment as on the intrinsic properties of the materials themselves. Hence even the toughest engineering plastics might fail in a poor design, while relatively cheap commodity plastics could be successful if the design were good enough. Moreover, the success of particular materials is predictable to only a limited extent: it is always necessary to make and test prototypes and modify the design in the light of test results.

The project was therefore divided into stages. In the first stage, a wide range of design ideas was explored and evaluated by laboratory and field tests on prototypes machined from the solid. These included a design by Ken McLeod for a high-density polyethylene (HDPE) piston to be used with a cylinder of standard uPVC pipe. A more limited selection of designs then went forward to the second stage, for which molded components were produced for further testing in the laboratory. In the third stage, experimental prototypes using the molded components were tested in the field, and the results of all the tests and assessments were brought together to produce final recommendations and conclusions.

The design objectives and constraints are summarized on the following page.

Stage 1: Testing of the McLeod design

A prototype "McLeod" cylinder was tested as part of a program of laboratory tests of the Maldev pump head. The performance of the cylinder at the start of the tests was at least comparable with results for conventional pumps, with mechanical efficiencies ranging from 55 percent to 82 percent for depths from 7 meters to 45 meters. After 1,000 hours of endurance testing, however, the outflow from the pump was reduced considerably as a result of wear in the cylinder bore, the sealing edge of the piston, and

Summary: Design Objectives and Constraints

Scope	The project should encompass the complete below-ground assembly, including the pump rods and rising main.
Mode of operation	A simple reciprocating action suitable for use with the Maldev and similar above-ground assemblies.
Capacity	At least 0.5 liter per cycle
Maximum depth	45 meters
Endurance	At least 10 million reversals
Cylinder and rising main	Standard uPVC pipe for both the rising main and the cylinder barrel; the complete below-ground assembly must fit a four-inch well casing.
Seals	The design must be adaptable to a variety of off-the-shelf sealing systems -- leather, urethane, rubber, etc.
Footvalve	To simplify maintenance and repair, the footvalve should be extractable without the need to remove the rising main, but the design must also be viable as a nonextractable system.
Maintenance and repair	The requirements for village-level operation and maintenance must be satisfied: the final design should require the minimum of tools and skills.
Multiutilization of parts	Major components of the piston and footvalve must be identical to reduce initial tool cost, reduce production costs, simplify maintenance and repair, and reduce the number of spares needed on-site.
Performance criteria	To accommodate smaller, weaker users, maximum pump efficiency must correspond to lowest operating speeds. The piston and footvalve must therefore open and close quickly and efficiently at low rates of flow.
Contamination by solids	The flow velocity of the valves should be sufficient to clear suspended particles and prevent contamination of the valve seats.
Potential for high-volume production	Initial prototypes may be produced by small-scale methods, but the finished product must be suitable for volume production in developing countries.

the piston valve. The cylinder barrel was replaced and the piston was repaired, but it wore away rapidly when the test was restarted. This suggested that the combination of HDPE and uPVC was not a favorable one, and the test was terminated.

The initial CRL designs

A basic design was drawn up and adapted to a range of different methods for sealing the piston in the bore of the cylinder, and these sealing options were compared for both performance and endurance.

The main components of the piston and footvalve were identical. Acetal was the material chosen for stress-bearing components because of its strength, stiffness, resistance to creep,[1] and stability in water, although some parts were initially produced in uPVC so that they could be solvent welded. Acetal is extensively used for snap fits, domestic and industrial water fittings, and other applications which exploit its "springy" characteristics. Both the piston and footvalve consisted of a valve seat and two identical body halves. As the halves came together they engaged both the valve seat and two grooves machined in the end of the pump rod. The halves were then secured in position by a collar. The poppet valves were made from acetal, with rubber *o*-ring seals and snap-in legs designed to limit the valve lift. The valve port diameter was 18 mm.

The piston and footvalve were connected by a telescopic link, so that the footvalve could be extracted with the piston. The link was arranged so that it would not interfere with the normal pumping action, but would come into play only when the piston was withdrawn beyond the normal upper point of the pumping stroke. The footvalve was retained in position by a barbed, castellated spigot which snapped into a receiver in the bottom of the cylinder.

Both the cylinder and rising main were standard uPVC pipes of 75 mm outside diameter, the cylinder being Class D pipe and the rising main Class C (BS3505), to enable the piston to be withdrawn for maintenance without extracting the rising main. The pump rods were stainless steel, with acetal connectors. Like the piston body, these connectors consisted of identical halves which engaged grooves machined in the ends of the pump rods, and were secured by collars. All screw threads were thereby eliminated from the design.

This design approach was intended to be compatible with the Maldev pump, which was under development at the same time. The Maldev was designed and made in Malawi, with ease of servicing and manufacture as primary design objectives.

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1 Creep is the name given to the long-term deformation of plastics under sustained stress.

Four sealing techniques were evaluated in the first stage:

- A proprietary urethane hydraulic *u*-seal
- Cup leathers made by Cieco (India) and Climax (UK)
- A rolling lobe diaphragm seal
- Extended tubular piston, without a flexible seal but used in conjunction with close-fitting external polyethylene collars fixed within the rising mains long and short collars were tested)

Comparison of pump performance

Each prototype was tested for pump performance as part of a complete pump assembly, using a Maldev head as the above-ground part. The amount of work done on the pump handle was compared with the useful work done by the pump in raising water, for a range of depths and operating speeds .

The urethane *u*-seal, new or part-worn, worked well.

The rolling lobe diaphragm produced high efficiencies but considerably lower flow rates than other designs. Such performance is inherent in a seal of this type, since the rolling portion of the diaphragm travels only half the distance of the piston.

The leather cup seals achieved performances similar to the urethane *u*-seals. The relatively thin Climax seal produced a higher efficiency and greater outflow than the rather thick Cieco "Meera" seal.

The extended tubular piston with the short external collar was limited in performance by leakage. Better results were obtained from the long external collar, but these were still inferior to the urethane *u*-seal and the better of the cup leathers.

Endurance tests

For endurance testing, prototypes representing the various seal options were mounted on a multistation test rig. Each cylinder was operated at 40 cycles per minute at a simulated head of 45 meters. The target for completion of the test was 2,044 hours, representing five million reversals.

Urethane *u*-seals Two samples were tested. In one sample, the piston body broke after 1,134 hours and could not be repaired. In the second sample, the piston also broke after 1,173 hours, but was repaired. The test continued to 1,647 hours, when wear in the seal had reduced the outflow from the cylinder to a trickle. Wear of both the seals was confined to the lip; the overall diameter was reduced by approximately 1.0 mm and 1.5 mm for the two samples.

Rolling lobe diaphragms Four samples were tested, and all failed rapidly when the diaphragms collapsed on the return stroke, causing them to ruck up rather than roll. The rolling lobe seal was withdrawn from the test at this point, and further investigation was carried out under a separate project (page 33).

Leather cup seals Three samples were tested. Two had to be withdrawn when their pistons broke and could not be repaired. The third completed the test with relatively little wear.

Extended tubular pistons The prototype with the short external collar seized after only 124 hours. However, the prototype with only the long external collar failed to complete the test by 120 hours. It was withdrawn because wear of the collar had reduced the outflow to a trickle.

Field tests

Two prototype assemblies were installed in Malawi. One failed when the legs of the footvalve snap-in feature broke off, mirroring a problem which had been apparent in the laboratory tests. The second survived for 20 months until the piston broke.

Design recommendations

From the results of the laboratory and field test results a series of design recommendations, summarized on the following page, were prepared as the basis for the second stage of the project.

Summary: **Design Recommendations from Stage 1**	
Cylinder and rising main	**75-mm diameter uPVC pipe: cylinder, BS3505 Class D; rising main, Class C**
Pump rods	**12-mm stainless steel**
Piston seal	**A conventional *u*- or cup seal, but this may be either a leather cup washer or a proprietary synthetic seal of urethane or nitrile rubber.**
Piston and footvalve	**Identical components for all the principal parts of both the piston and footvalve; footvalve snap-in redesigned to eliminate excessive stress.**
Valves	**Port diameter 20 mm; molded bobbins fitted with standard rubber *o*-rings; valve lift controlled externally.**
Footvalve seal	**Standard rubber *o*-ring (International Metric, European Metric, or International Inch sizes)**
Materials	**All stress-bearing parts in acetal**
Maintenance	**The only tool required to dismantle the piston and footvalve would be something like a screwdriver to lever the components apart.**

Stage 2: Laboratory tests on prototypes

An improved design was proposed combining the improvements identified in the first stage of laboratory and field testing. The principal components of the cylinder were rationalized to minimize the number of molding tools and the stock of spare parts required, and to eliminate the uPVC components that had proved unreliable. Each molding was designed for simplicity of tooling and ease of manufacture.

The footvalve snap-in feature was redesigned to eliminate excessive stress, and the barbs intended to limit valve lift were removed: many had broken during the tests. The valve orifice diameter was increased to 20 mm. This size was chosen as a compromise between ensuring that water would still flow through the valves relatively quickly, to flush suspended solids in the water and prevent valve seat contamination, while reducing resistance to flow to a level that would not significantly increase the applied force at the handle. Figure B1 illustrates the relationship between head loss and valve diameter for a range of pump operating speeds, based on the dimensions of the experimental cylinder and the stroke of the Maldev pump.

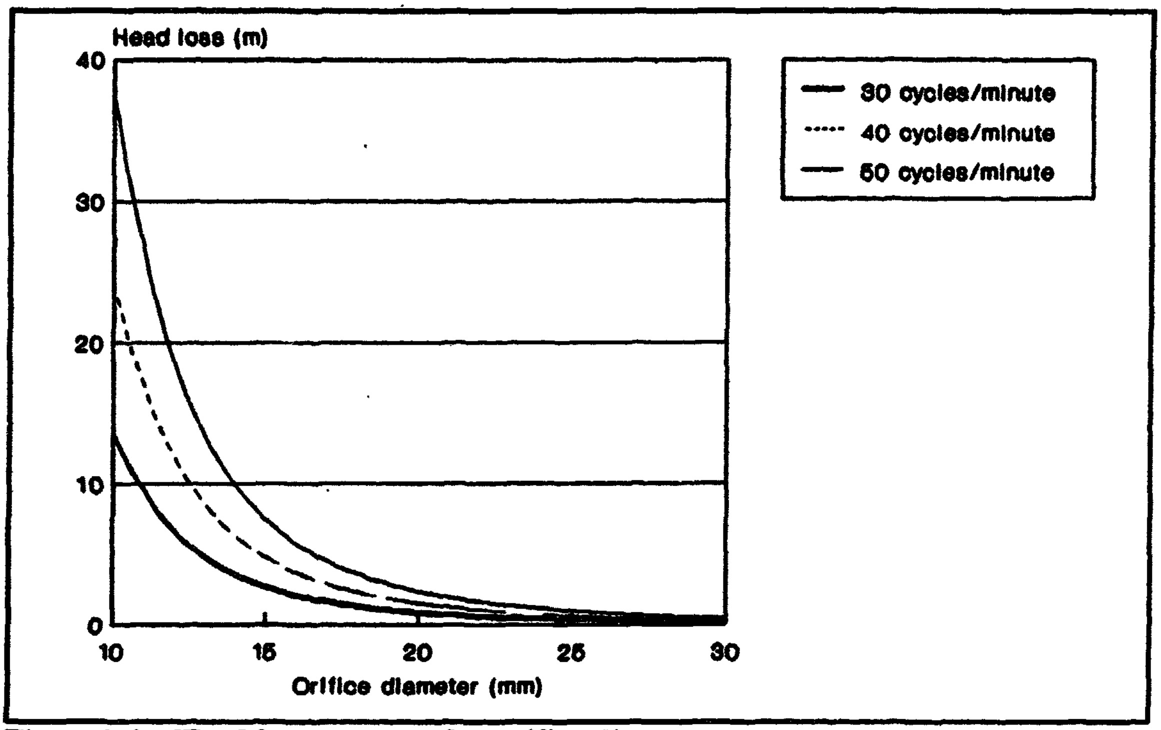


Figure B1. Head loss versus valve orifice diameter

The design is illustrated in Figure B2, page 29. A set of molding tools suitable for a short production run was manufactured, and an initial batch of moldings produced for laboratory testing. Three variants of the basic design were tested for pump performance, to compare with the results obtained in Stage 1:

- Hallite urethane *u*-seal
- Gaco nitrile rubber lip seal
- Cieco cup leather

Performance tests

All the seals provided high levels of pump efficiency, with higher efficiencies corresponding to lower operating speeds. The best results were obtained for the cup leather, followed by the nitrile rubber lip seal and the urethane *u*-seal, but the differences between all the seals were small and unlikely to be significant in practice. For the urethane and leather seals, where comparable results were available from Stage 1, the results for molded Stage 2 pistons and footvalves were consistently better: the required force at the handle of the pump was reduced about 15 percent.

Endurance tests

Four assemblies were tested for endurance:

- Hallite urethane *u*-seal
- Gaco nitrile rubber lip seal
- Cieco cup leather
- A cup leather made in the UK

The test was carried out at 40 cycles per minute at a simulated depth of 45 meters. The water was deliberately contaminated with sand and *Kieselguhr* to induce extra wear. The target time was 2,000 hours, representing about 5 million reversals.

Urethane seal The first seal wore out after 270 hours, reducing the outflow from the pump to a trickle. A fresh seal was fitted in the original cylinder and lasted for a further 324 hours. However, the cylinder wall remained in good condition, with minimal wear, confirming that the seal was the sacrificial element in this configuration.

Nitrile rubber seal The nitrile seal performed well throughout the test, and had the capacity for another 1,000 hours of use under the same conditions at the end. The cylinder bore was polished, and about 1 mm greater in diameter than at the start. These results were consistent with CRL tests of the Tara pump and results obtained by Lund University of Technology.

Cup leathers Both the cup leathers wore out in 620 and 807 hours for the UK- and Indian-made leathers, respectively. In both cases, the cylinder bore was badly scored and worn.

Impact testing of rod connectors

The chosen method of pump-rod connection proved to be reliable in the endurance tests, but a further test was carried out to assess their endurance in response to a repeated shock force of 4,000 Newtons (roughly twice the force in the pump rod during normal pumping).

Connectors immersed in water lasted significantly longer than dry connectors, but all failed. An interesting result was that the original intention that the load would be shared by two shoulders in the couplings engaging a pair of grooves in the rod did not seem to be born out in practice. Clearly, in any such design small dimensional inconsistencies will result in contact being made at one interface before it is made at the other. However, it had been expected that elastic averaging in the plastic coupling would

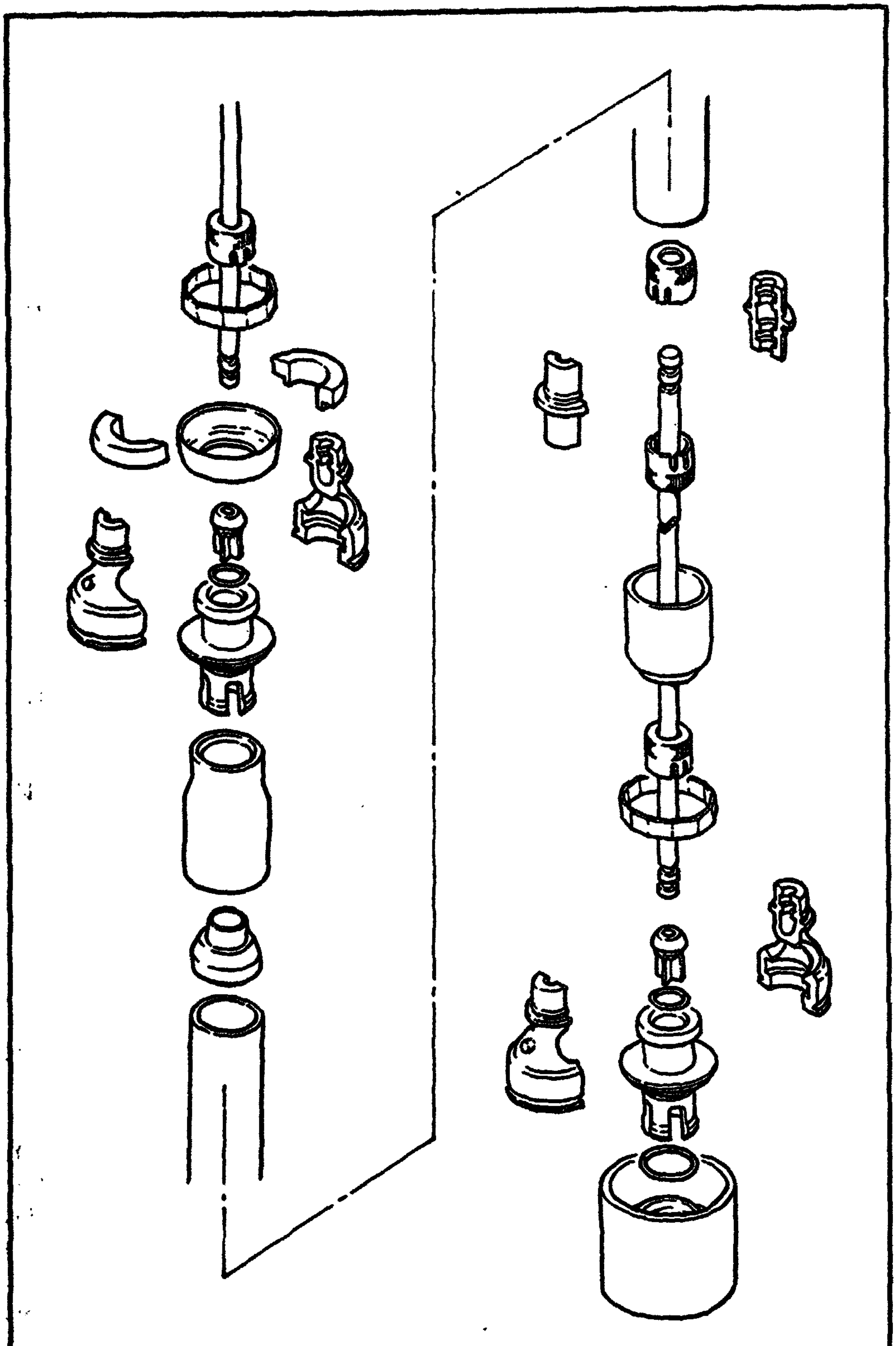


Figure B2. Plastic cylinder components

ensure that once applied the load would be shared. In fact, couplings modified so that they had only a single shoulder survived a similar number of shocks as those with two shoulders.

Stage 3: Field testing

A total of 87 sets of components with a selection of leather, urethane and nitrile rubber seals were sent to field trial centers in East and West Africa, India, China, the Philippines, and Thailand. Pictorial instructions showing how the components should be assembled were also supplied. Reports were received from Kenya, Malawi, Tanzania, and Ethiopia.

***Summary:* Field Test Reports**

Installation	**More detailed instructions would have been helpful; parts should be numbered to correspond to instructions and/or should be molded in different colors; leather cup seals were very difficult to assemble.**
Use	**Satisfactory**
Extraction	**Very difficult to extract pistons with leather seals in working order (easy with worn seals)**
General	**Good design, but too many parts**
Wear	**Urethane and leather seals wear more rapidly than nitrile rubber seals.**

The difficulties encountered when extracting pistons with working leather seals resulted from the seal's expanding so that it continued to support the water column even when the piston was raised beyond the cylinder pipe into the larger-bore rising main.

Assembly difficulties were largely related to the feature of the experimental design that allowed it to be adapted to a variety of types of seals. The design would be simplified substantially if only one type of seal were used.

There was much discussion about the desirability of linking the footvalve to the piston so that the footvalve could be extracted for inspection or repair. If an alternative means of footvalve extraction could be used, nine components and a solvent welding operation could be omitted. It was also pointed out that the link could be a real disadvantage since there would be no point in extracting a footvalve that was working well.

Recommendations and conclusions

The recommendations and conclusions of the CRL research are summarized on the following page.

Development of the Afridev below-ground components

Many of the ideas developed in this project were subsequently put to use in the Afridev pump. The Afridev was designed to be as simple as possible, and to be capable of manufacture in developing countries. To minimize the stresses in the system, a standard cylinder diameter of 50 mm was adopted, combined with a maximum stroke of about 200 mm and a choice of handle ratios (2:1 or 3:1) to accommodate a range of working depths. Below ground, the design objectives were to minimize the number and complexity of components and to arrive at a design suitable for high-volume production.

The Afridev cylinder components were designed and developed with assistance from SKAT and DuPont Plastics. The design carries over the idea of an identical piston and foot valve, molded in acetal, with snap-in legs to retain the foot valve in a receiver incorporated in the rising main. However, the joint between the moldings is at right angles to the cylinder axis, in the plane of the valve seat, in contrast to the CRL design. The moldings are permanently joined by spin welding, thereby creating the interior void for the valve, but avoiding the need for external fastenings or retainers. The valve is of a similar shape to the CRL design, but is molded in rubber to avoid the need for a separate *o*-ring seal, and to give it sufficient flexibility to be inserted and removed through the valve ports. The general wall thickness of the acetal moldings is about 4.5 mm, with external ribs 3.5 mm thick. All the molded components are produced in Kenya, and the molds have also been made available to other developing countries.

While the CRL design was intended to accept a range of seal types, the Afridev was designed from the start to use a proprietary nitrile rubber seal, based on the results of CRL's tests. Because the nitrile seal has a relatively large inside diameter compared to a leather cup washer, it was possible to decrease the overall diameter of the piston to suit the 50-mm cylinder bore without reducing the size of the valve.

Summary: Recommendations and conclusions

Material	Acetal proved to have sufficient strength and toughness to withstand the forces in a deep-well handpump. Care must be taken in design to avoid stress concentrations. Components should be of uniform section and not more than 6 mm thick.
Cylinder	If other aspects of the design are suitable, material standard uPVC pipe can be used successfully as a pump cylinder.
Cylinder size	The project concentrated on a cylinder bore of approximately 63 mm (2.5 inches). For many applications, a 50-mm (2-inch) cylinder would be more appropriate, but there would be no difficulty in scaling the design to other sizes.
Piston seals	Both this project and other handpump tests indicate that nitrile rubber is the best choice for the piston seal.
Footvalve	The concept of a snap-in footvalve, exploiting the stiffness and creep resistance of acetal, was successful. However, the idea of linking the footvalve to the piston had less to commend it, provided that a satisfactory alternative means of extracting the footvalve is found.
Maintenance	The use of plastics was shown to contribute to ease of servicing. The below-ground assembly could be sufficiently light to eliminate the need for lifting tackle, even for installations as deep as 45 meters. Moreover, the use of plastic moldings makes it possible to eliminate conventional tools.
Valves	There was no evidence of loss of efficiency as a result of the relatively small valve port diameter in relation to the cylinder bore.
Pump-rod connectors	Plastic pump rod connections could be viable, although the design used in this research was less than ideal. Specifically, forming a disc on the end of the rod (possibly by "cold-upsetting" the steel) would be better than cutting grooves in the rods.

The Afridev cylinder has a body of standard uPVC pipe lined with brass or stainless steel. The pump rods (mild or stainless steel as required by water quality) have hook-and-eye joints.

The Aquadev pump, made by Mono Pumps, is based closely on the Afridev design. The internal parts of the cylinder are similar, though ultrasonic welding rather than spin welding is used for the piston assembly. The Aquadev uses molded acetal pump-rod couplings. The rods are "upset" at each end into discs, and then linked together by a pair of acetal half-couplings secured by snap-on collars.

Rolling-lobe diaphragms

As a result of the early failures in endurance tests, the rolling-lobe diaphragm was withdrawn from the CRL project. However, because of its potential to eliminate sliding friction in the cylinder, a separate program of development has been undertaken, funded by ODA and using the rig developed by CRL for the original endurance tests.

A series of more refined and developed schemes was devised using multiple diaphragms in opposition to ensure that they remained inflated throughout the pumping cycle. Although the endurance of successive designs has increased, none have been able to achieve results comparable with good-quality, conventional sliding seals.

B2. Plastic Dry Bearings

A pivoting lever, such as the handle of a handpump, must have bearings. In many deep-well pump designs, a second set of bearings is also fitted where the handle is connected to the top of the pump rod. The conventional solution is to fit ball races, but these have serious drawbacks in the context of handpumps. They are expensive, prone to corrosion, designed for continuous rotation rather than restricted angular movement, need accurately machined housings, and tend to be difficult to replace in the field.

Some designs have eliminated at least the second set of bearings by connecting the pump rod to the handle through a flexible link: the India Mark II is a well-known example. But these designs have problems of their own, such as the need to ensure that gravity acting on the pump rods will be sufficient to return the piston on the down-stroke. Plain bearings are also widely used across a broad spectrum of engineering applications. However, most of the materials used require regular, or even constant, lubrication, which is not practical for a handpump.

Plastic bearings have the potential to be inherently free from corrosion, require less stringent standards of manufacture in associated parts, and have no need of lubrication. Their service life may well be considerably less than ball races under ideal conditions, but because they would be cheap and easy to replace they could readily be integrated into a village-level maintenance regime.

Acetal and nylon (polyamide) are plastics widely used for other bearing applications. Both offer good dimensional and mechanical stability, good wear resistance and low friction, are easily machined and also suitable for injection molding. Nylon has a propensity to absorb water, a potential disadvantage in a bearing for a water pump. Acetal, on the other hand, offers low water absorption over a wide temperature range. Other plastics such as PTFE offer very low friction but are much more limited in their mechanical properties.

The first experiments

The first experimental designs for plastic handpump bearings were evaluated in the Consumer Research Laboratory and in the Livulezi Valley Project in Malawi, using Maldev pumps. The initial design was a simple cylindrical bush with an integral thrust washer: a "top hat" bush (Figure B3). Prototypes were machined from solid acetal, but it was recognized from the start that the bearing should be suitable for injection molding.

The same components were used at both the handle fulcrum and the pump rod connection, making a total of four bushes per pump. The bushes were used in conjunction with pivot pins machined to a surface finish of 3.2 μm R_a, and fitted in housings machined to the same standard.

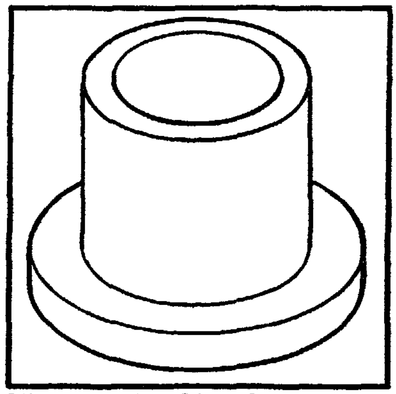


Figure B3. Simple "top hat" bush

For laboratory testing, the bearings were mounted on a purpose-made rig incorporating a Maldev pump handle. The rig imposed vertical, torsional and lateral loads on the bearings, with one bearing carrying a generally higher load than the other. The forces on the pump rod were equivalent to pumping water from 45 meters depth with a cylinder of 50 mm bore, and the operating speed was 60 cycles per minute. The ambient temperature was maintained at approximately 30°C. Wear in the bearings was monitored by measuring the lateral and torsional free play at the end of the handle. The target for completion of the test was 10 million cycles.

The bearings were set up in three configurations:

- fixed relative to the housing, so movement is between bearings and shaft;
- fixed relative to the shaft, so movement is between bearings and housing; and
- free-floating.

Summary: Ball Races Versus Plastic Bearings

	Ball races	Plastic bearings
Cost	Although ball races are widely available, they are universally costly; very few developing countries have the specialized facilities required to manufacture them, so they must usually be imported.	Plastic bushes can be produced very cheaply and to close tolerances using injection molding; transport and storage are also relatively cheap.
Fitting	Ball races need housings and shafts machined to close tolerances. Fitting needs care and effective quality control.	Fitting can be a quick, nonskilled operation; accurage machining and alignment of other pump components is less critical; plastic bushes could be designed to fit stock sizes.
Corrosion	Ball races are liable to corrosion, both in service and during storage. Corrosion will cause a ball race to fail long before it would have worn out.	Corrosion problems in storage and in use would be eliminated.
Replacement	Old bearings can be very difficult to remove, and new bearings need to be treated with care and skill in fitting.	Plastic bushes can be designed for easy replacement iln the field; spares are unlikely to be "borrowed" for other purposes.

These configurations were intended to determine the optimum arrangement for relative movement between the bearings and the associated steel components. The conventional engineering view is that the bearing should be fixed relative to its housing, because an increase in bearing area resulting from running the bush on its outside diameter is likely to be more than offset by greater wear resulting from an increase in sliding velocity. The free-floating configuration was also included because it offered the greatest potential for simplicity in manufacture and fitting.

In fact, both the bearings fixed relative to their housings and the free-floating types produced encouraging results, with an average diameter wear of 0.22 mm per million cycles. Wear was substantially constant throughout the test (see Figure B4). Higher wear rates were recorded for bushes fixed relative to the shaft.

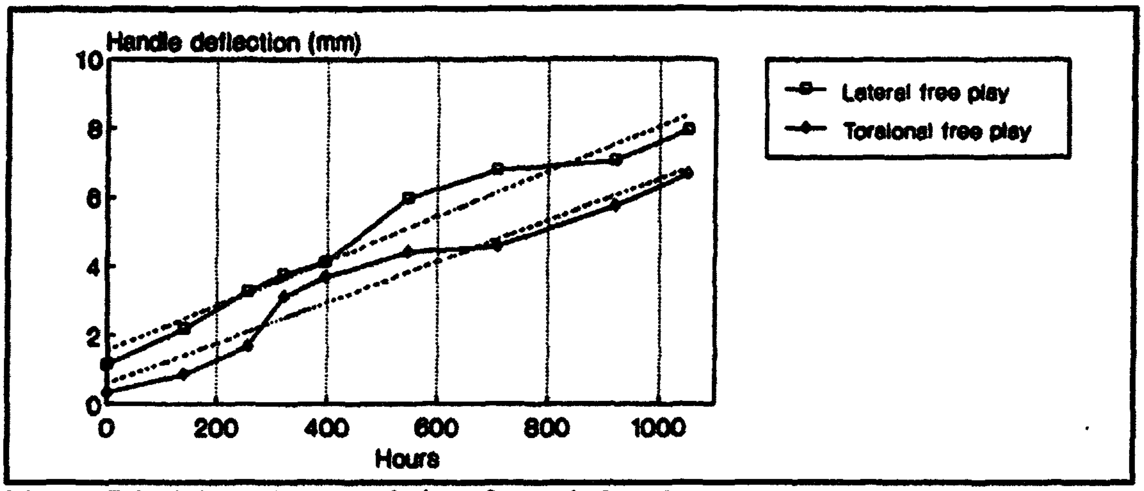


Figure B4. Wear characteristics of plastic bearings

It was clear that the conditions of the test regime were a good deal more severe than actual conditions in the field, however, for which a wear rate of around 0.1 mm per million cycles was indicated. Assuming that wear up to 1 mm would be acceptable on pumps in the field, this yields an anticipated service life of 10 million cycles: equivalent to two years of intensive use. The wall thickness of the bearings would allow the pump to continue to operate with clearances greater than 1 mm, but this could lead to undesirable shock loadings on the bushes and other components of the pump.

A number of bearings were also installed in pumps in the field. Initial results were favorable but inconsistent. There were some indications that these inconsistencies in performance were related to variations in the surface finish on the pivot pins. The test sites also presented different operating conditions in terms of water level, pump use, and exposure to direct sunlight and dust.

Comparative testing of a variety of bearing types

Subsequent research was based on the Afridev pump, and was carried out in consultation with the Afridev design team in Nairobi. A number of different types of bearings were compared:

- One-piece plastic bushes in a variety of materials
- Two-piece plastic bearings in acetal and nylon
- Spherical plain bearings
- Wooden bushes
- Flexural rubber bushes

The test method and regime were similar to that used for the initial research. The target for completion of the tests was 5 million cycles.

One-piece plastic bushes

Five materials were selected for testing:

- Unfilled acetal copolymer (Kematal)
- Acetal copolymer incorporating a lubricant (Railko PV80)
- Unfilled nylon 66 (Zytel)
- Nylon 66 incorporating a lubricant (Nylatron GS)
- Nylon 66 incorporating a lubricant and other fillers (Nylatron NSB)

All were tested as simple top-hat bushes running against a stainless steel counterface machined to a surface finish of 0.4 μm R_a.

Two-piece plastic bushes

The two-piece design was developed in response to evidence from testing in the field that the performance of plastic bushes would be strongly influenced by surface finish on the bearing counterface. The principle of the two-piece bush was that the outer part would be fixed relative to the housing and the inner part fixed relative to the shaft: thus both the bearing and its counterface can be controlled, and both would be replaced simultaneously.

The bearings were designed with assistance from SKAT and advice from DuPont of Switzerland; the outer parts of the bearings were acetal homopolymer incorporating a lubricant (Delrin CL), running on inner bushes of unfilled nylon 66 (Zytel). The molds were manufactured in a workshop in Kenya.

Spherical plain bearings

Spherical plain bearings (SPBs) are widely used in specialist applications such as aircraft and racing cars. They are often referred to as Rose joints, although that name refers to only one of several manufacturers. The bearings chosen for testing were of a type, said to be maintenance free in that they required no lubrication, in which the inner spherical element and the matching housing were separated by a layer of PTFE-impregnated fabric. The bearings were pressed into flanged sleeves machined from stainless steel to enable them to be fitted in the same way as the plastic bearings.

Wooden bearings

Wooden bearings have been used in handpumps in a number of countries. The test bearings were made from Mkarati wood from Tanzania, and were untreated. Taking account of work at the University of Dar-es-Salaam and elsewhere, the bushes were installed so that the bearing loads were carried predominantly along the grain axis.

Flexural rubber bushes

These are commonly used for vehicle suspensions and other applications where isolation of vibration is desirable. There is no sliding contact: the bearing relies on the flexing of the rubber. To enable off-the-shelf components to be used and to achieve the necessary angular movement, bearings were used in pairs, a total of eight per pump.

Results

The results of the laboratory tests are summarized in Table B1. The most encouraging results were obtained for the two-piece plastic bushes. The greatest amount of wear was measured on the Delrin outer bush of the most heavily loaded bearing, at 0.05 mm per million cycles. No measurable wear was found on the inner Zytel bushes. For comparison, the best of the one-piece bushes wore at 0.07 mm per million cycles. The apparent lack of wear in the nylon bushes may have been the result of the bearings' absorbing water, however. Nylon tends to absorb water and expand, and in this case the expansion may have been sufficient to offset any wear. There is some evidence for this: one of the bearings was found to have increased in size during the testing.

The spherical plain bearings developed considerable end float, and the running surfaces were scored. They were considered to have failed. Similar results were obtained from tests in the field. The wooden bearings failed before the wear rate could be established. The flexural rubber bushes failed as a result of fatigue in the rubber.

A number of one-piece bushes machined from Railko PV80 were also tested in field projects in Malawi and Kenya, using brass and stainless steel pins. The results showed a high degree of variation, which seemed to be related to the surface finish on the pins. Pins that had not been machined to a high standard or had deteriorated in use exhibited much higher wear rates.

Table B1: Results of Laboratory Tests on Various Bearing Types

	No. of cycles (x 10^6)	Fulcrum pin temperature (°C)	Bearing temperature (°C)	Maximum wear rate (mm per 10^6 cycles)
One-piece plastic bushes				
Kematal	3.2	53-82	38-54	0.19
Railko VP80	3.2	52-78	36-52	0.17
Zytel	3.5	67-89	41-55	0.34
Nylatron GS	3.5	60-88	46-58	0.69
Nylatron NSB	3.5	35-52	32-41	0.07
Two-piece plastic bushes				
Delrin CL/Zytel	3.7	30-41	30-39	< 0.05
Spherical plain bearings[a]	3.2	35-55	28-44	n.a.
Wooden bushes	0.17	------	not recorded	------
Flexural rubber bushes	4.1	37-61	n.a.	n.a.

a Fulcrum pin and bearing temperatures recorded from inner and outer tracks, respectively.

Testing at elevated temperatures and humidity

The two-piece or composite plastic bearings were subsequently adopted for use in the Afridev pump, with a slot in the inner nylon bush to prevent swelling that might result from water absorption and cause the bearings to seize. However, a number of bearings fitted to pumps in the field recorded wear rates substantially greater than anticipated. Further testing was undertaken by CRL, jointly funded by ODA, UNDP, and the World Bank, to investigate whether the wear was related to the high humidity and elevated temperatures found at many installation sites.

The bearings were tested in two stages. In the first, the dimensions of the bearings were measured for increasing temperatures at 99 percent relative humidity, under no load. The bushes rotated freely at all temperatures. At 40°C, the two parts of the bearing could no longer be separated, though they could easily be removed from their housings. At 55°C, it was no longer possible to remove the bearings from their housings, though this may have been the result of the formation of rust inside the housings in addition to the expansion of the bearings themselves. When the temperature returned to 20°C and the humidity to 55 percent, the bearings could be removed and dismantled easily. The bearings were discolored, but the permanent changes in their dimensions were very small.

In the second phase, the bearings were installed in three Afridev pump handles, and wear characteristics under load at elevated temperatures were assessed. Two of the handle assemblies were contained within a controlled environmental chamber; the third remained in the general environment at an ambient temperature of about 30°C, as a control. All the bearings were initially bedded-in at an ambient temperature of 30°C for 500,000 cycles. The temperature in the environmental chamber was then increased in increments of 10°C to a maximum of 90°C, running the bearings for 125,000 cycles at each temperature. Bearing temperatures of up to 110°C were recorded. On average, the higher-loaded bearings ran 18 percent hotter than the ambient temperature. This observation may prove a useful rule of thumb for estimating maximum bearing temperature for a given ambient temperature.

No significant wear occurred in the bearings fitted to the control assembly, and relatively little wear was recorded in the bearings tested at elevated temperatures. However, in the "hot" bearings, some of the outer bushes split, and it was clear that these problems were associated with residual stresses in the bush around the lug which determined its position relative to the housing. A number of the inner bushes also cracked, but this occurred for both "hot" and "cold" bearings and was attributed to the substantial side loads imposed by the test rig.

Overall, the wear rate of the bearings increased at higher temperatures, but the greater wear was not in itself sufficient to explain the rapid failures observed in the field. Other factors that might be significant include humidity inside the pumpstand, and sand and dust carried by wind or rain. A small sample of dust from a bearing used in the field was found to contain 67 percent debris from the bushes themselves, 16 percent iron oxide, 5.5 percent zinc oxide, and 2.5 percent sand. The significance of these quantities is not known. Even this small amount of sand combined with a few metal particles could cause rapid wear. The Afridev pump was subsequently fitted with stainless steel liners in the bearing housings to eliminate corrosion, and the top cover was modified to offer the bearings better protection from the elements (see Part C).

B3. Sealless Pistons and Diodic Valves

The idea of a piston with no internal moving parts is an attractive one. Solid-state technology has transformed electronics and made possible standards of performance and reliability which would have been completely impractical using mechanical techniques of switching and flow control.

Solid-state control of fluids is also well established and extensively used in applications where mechanical control devices would not be practical: inside nuclear power plants, for example. The Consumer Research Laboratory, in consultation with SKAT and the University of Sheffield, UK, undertook to investigate whether these techniques could be applied to handpumps, both to eliminate flexible piston seals, which have a limited life, and to devise valves with no moving parts. The CRL research was funded by ODA.

A number of handpumps have appeared in which the sealing of the piston has been achieved by means other than a flexible seal. The Ethiopia BP50 -- an early example of a direct-action handpump - had a piston machined from a solid block of high-density polyethylene (HDPE). The piston was machined to provide a clearance of about 0.5 mm to 1 mm within the cylinder bore, with a series of grooves forming a simple labyrinth seal. The Volanta pump uses a sealless piston consisting of a slug of stainless steel which is close fit within a cylinder of glass-fiber reinforced plastic. The fit has to be controlled between 0.15 mm and 0.18 mm. The Pompe UPM has multiple pistons, one at each joint between the 3-meter sections of pump rod. Each piston is molded in rigid plastic, with a cup-shaped piston body. All these pumps have conventional valves, however.

In other fields of engineering, labyrinth seals are widely used where slight loss of fluid is acceptable and the main requirement is for a seal which requires little or no maintenance. They generally consist of a series of square-bottomed grooves combined with a relatively close fit between the mating parts. Other fluid control devices are analogous to electronic diodes and transistors. Fluidic diodes are solid state devices which have marked differences in their forward and reverse flow characteristics, and fluidic transistors are solid state devices which can direct the main flow in a fluidic circuit by adjusting the flow in much smaller control ports.

SKAT research into labyrinth seals for handpump pistons

SKAT has supported a number of research projects in this field carried out at the Hohere Technische Lehranstalt, Brugg-Windisch. One of these compared the leakage across a number of piston shapes with that across a plain cylindrical piston of the same diameter. The best result was obtained for a piston with five simple labyrinth grooves (Figure B5).

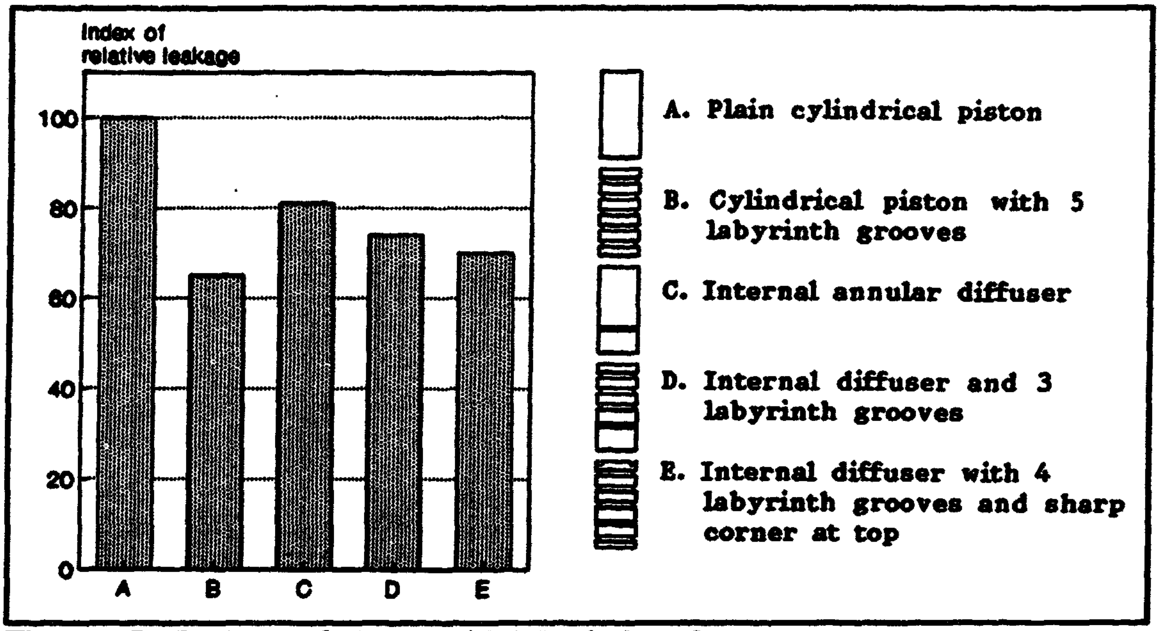


Figure B5. Leakage of pistons with labyrinth seals

A further study confirmed that the reduction in leakage obtained by adding a simple labyrinth seal was maintained across a range of piston speeds from zero to 60 cycles per minute.

Another study concentrated on the shape of the labyrinth groove, comparing square with round-bottomed and tapered forms. Little difference was found between square and round-bottomed grooves, and groove depth also had little effect. However, a conspicuously better result was obtained for a single tapered groove inclined at 6 degrees to the piston axis.

The application of fluidics to handpumps

The piston in a handpump is essentially a diode, with minimum flow across it on the delivery stroke and free flow on the return stroke. In a conventional piston with an efficient seal, there should be zero flow on the delivery stroke, and all the water displaced by the piston will flow across it on the return. A fluidic diode cannot match this performance; there will always be some leakage, and improving the performance in the forward direction must entail some loss of performance in the reverse direction, and vice versa. Moreover, because it exploits dynamic effects, the overall performance of a fluidic diode will be directly proportional to the flow rate and hence to piston speed. Nevertheless, the best fluidic diodes already in use in other applications offer diodicity -- the ratio of forward to reverse flow -- of up to 11, and useful functions can be performed with diodicities of about 5 or 6.

The simplest form of fluidic diode is the conical diffuser (Figure B6). In the forward direction, the pressure loss is reduced due to efficient conversion from dynamic to static pressure in the gradually diverging conical section. In the reverse direction, flow is constricted as the pressure builds up gradually in the conical section, before expanding suddenly in the throat. The diodicity typically has a value between 2.5 and 3.

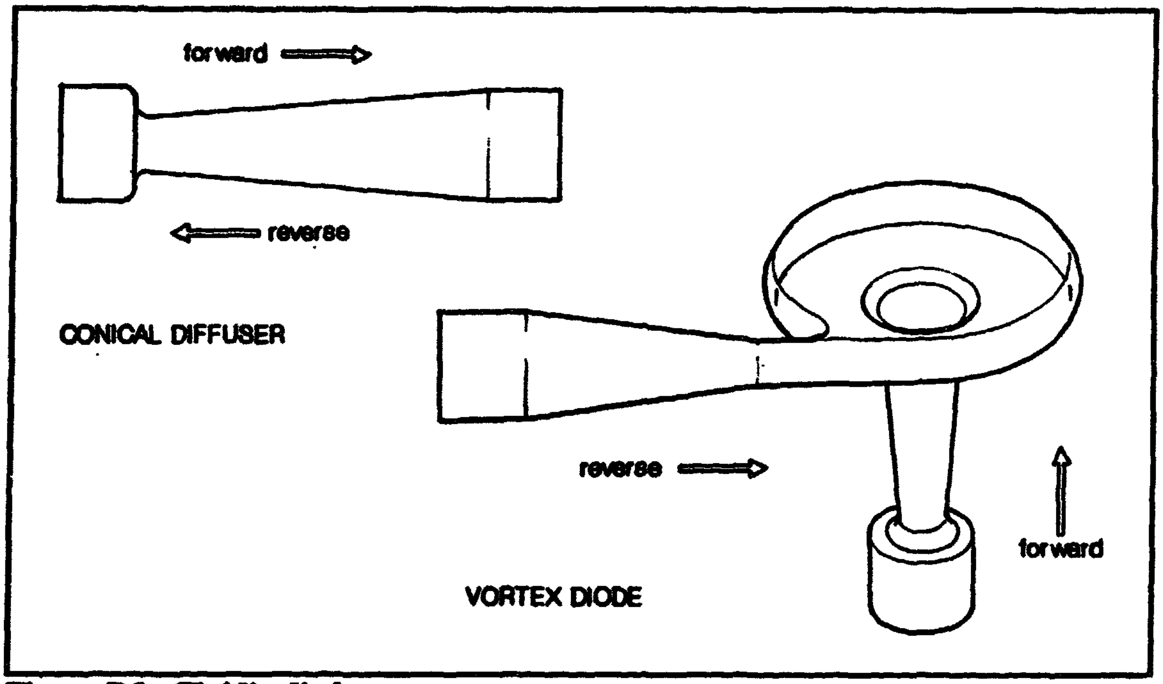


Figure B6. Fluidic diodes

The vortex diode is a solid-state device consisting of a spiral chamber, the vortex, with conical diffusers acting as ports at the center and at a tangent to the scroll. Forward flow is into the center of the spiral and out at the tangential port, and offers relatively little resistance. Reverse flow is restricted by the conical diffusers and by the water being forced from the outside to the center of the spiral. Diodicities up to 11 are possible, depending on flow rate.

A practical design

Applying the concept of a conical diffuser to the piston of a pump, the diffuser might be formed as an annulus around the outside of the piston: between the piston and the cylinder wall (Figure B7). This is a very simple shape to make, though some experimentation may be required to optimize the radius at the lower edge. Tests on an initial prototype also suggested that stabilizing vanes (as shown) may be necessary. Such a piston might be expected to provide about half the output of a piston with a perfect seal at 60 cycles per minute, with the output reducing at lower speeds (Figure B8).

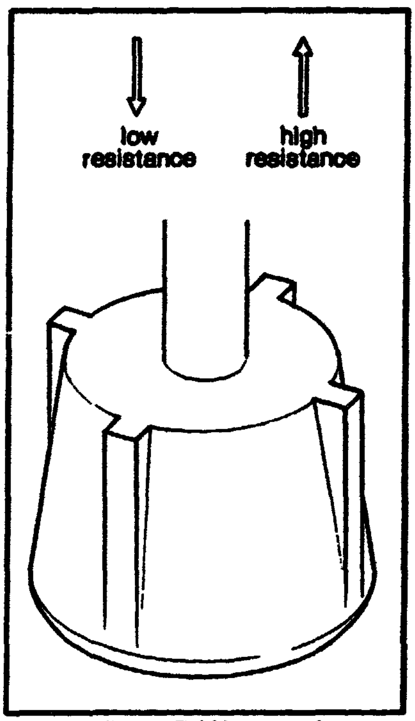


Figure B7. Diffuser piston

Better results could be expected from a piston incorporating a vortex diode, particularly if this were combined with a labyrinth seal between the piston and the cylinder wall. Combining the results of the research sponsored by SKAT with information provided by the University of Sheffield, there is the prospect of a completely solid-state piston capable of providing about 70 percent of the volume flow of a perfectly sealed piston at 50 cycles per minute, and about 50 percent of the volume flow at 30 cycles per minute (Figure B8). Note that the loss of outflow would be compensated by a reduction in the required effort (and of the stresses in the system) on the delivery stroke of at least equal proportions. A given rate of outflow could therefore be achieved by simply increasing the cylinder diameter. There would be some hydraulic friction on the return stroke, but this is unlikely to be greater than the mechanical friction present in a conventional arrangement.

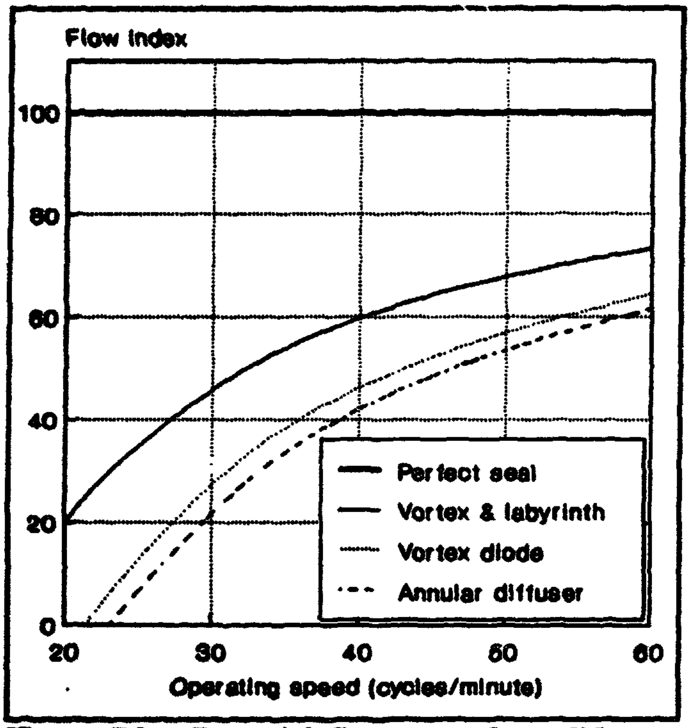


Figure B8. Potential flow rates for solid-state pistons

The rate of outflow would depend strongly on the piston velocity. Piston velocities are generally low in lever-arm pumps, as a result both of the geometry of the system and the inertia of the lever arrangement. However, the piston velocity is inherently greater in direct-action pumps, and users have a better opportunity to apply a rapid acceleration at the start of the delivery stroke. Solid-state pistons might therefore be particularly suitable for direct-action pumps.

A number of possible design schemes were proposed for both single and multiple piston arrangements. An example is shown in Figure B9, which illustrates a solid-state piston incorporating a vortex diode as the valve and a series of grooves acting as a labyrinth seal. The vortex is open to the outside of the piston to enable it to be molded in plastic. In use, the vortex would be enclosed by the cylinder wall.

Some experimentation would be required to optimize the throat diameter of the conical diffuser within the body of the piston and the clearance between the piston body and the cylinder bore.

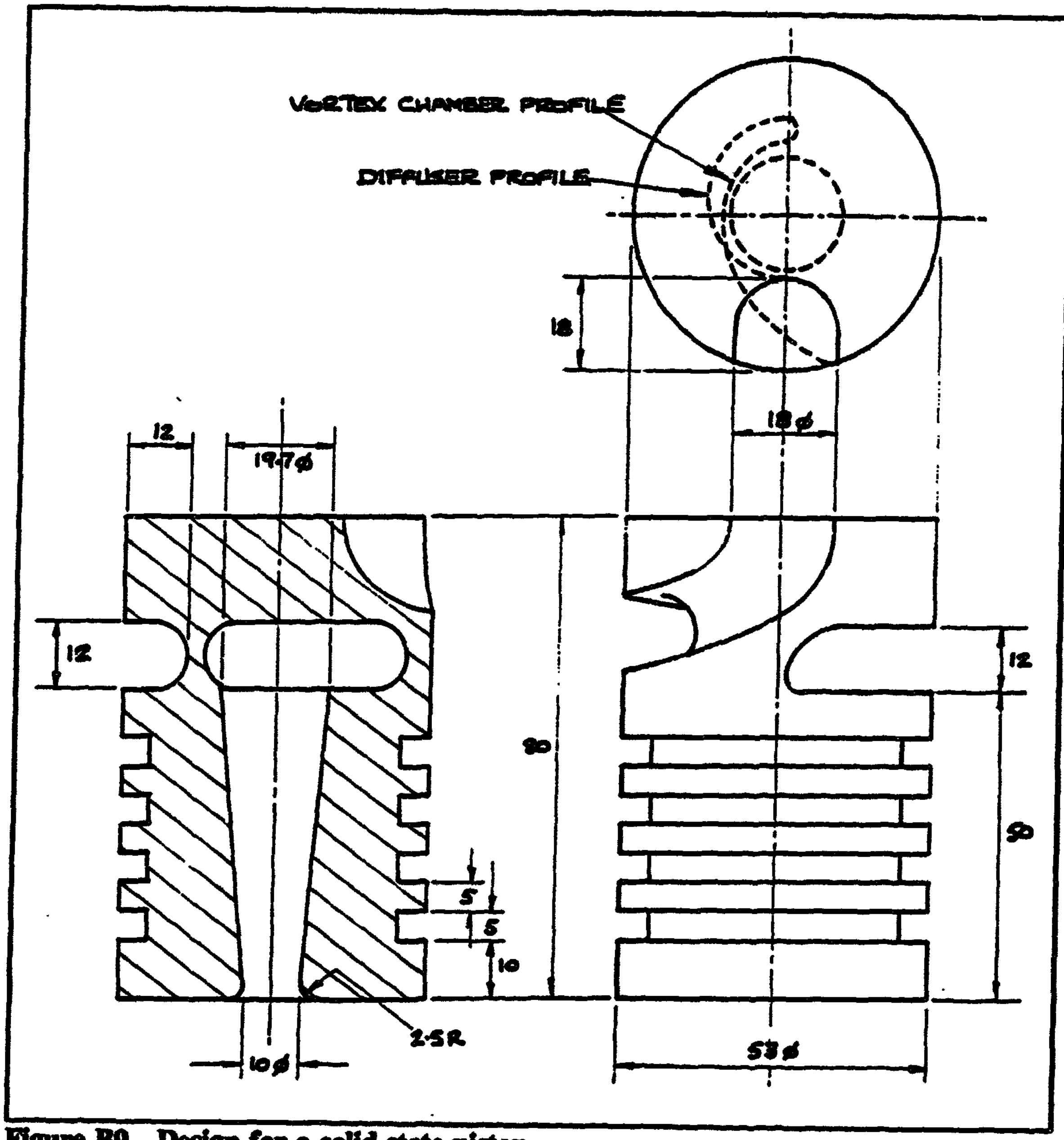


Figure B9. Design for a solid-state piston

B4. Light-Weight Pump Rods for Direct-Action Pumps

Direct-action pumps have much to commend them for water depths to 15 meters or so. A direct-action pump is one in which the conventional operating lever has been replaced by a simple *t*-handle attached directly to the top of the pump rod. Clearly, this eliminates a good deal of the complexity of a conventional lever arm pumpstand, and particularly the bearings, which are susceptible to wear. Direct-action pumps have the potential to be easier to manufacture and to maintain.

Merely attaching a *t*-bar to the pump rod of a conventional pump would result in a very unsatisfactory direct-action pump, however. The user would be required to exert a very strong upward pull during the delivery stroke, while the weight of the rods would send the piston crashing down on the return stroke. In a conventional lever-arm pump, the lever not only provides mechanical advantage, but also reverses the direction of the operating effort, and the weight of the lever helps to counterbalance the weight of the rods.

To achieve a satisfactory direct action design, it is necessary to transfer part of the effort required on the delivery stroke to the return stroke. This can be achieved by using lightweight, high-displacement pump rods. On the upward or delivery stroke, the pump user has to overcome the weight of the rods themselves, plus that of the annulus of water around them, which is supported by the piston. To reduce the lifting force, therefore, it is necessary both to reduce the weight of the rods and to increase their bulk, thereby reducing the cross-sectional area of the annulus of water. The effort that is "saved" is transferred to the return stroke: as the piston travels downwards, the bulky pump rods displace water from within the cylinder and pump it to the surface. By selecting pump rods of appropriate weight and size, the distribution of the total operating effort between the up- and down-strokes can be controlled. Note that there is no inherent requirement for the pump rod to be less dense than water, however. If the weight is low enough and the displacement great enough, the rod will be "buoyant," but this is not a fundamental requirement.

The obvious choice for a lightweight, high-displacement pump rod is a tube, sealed to prevent water getting in. Various materials have been tried: the Tara pump uses uPVC pipe, as does the Wavin, whereas the Pek pump had aluminum tubes and the Nira AF85 uses a polyethylene pipe, for example. Fiberglass and thin-walled stainless steel have also been suggested. The Consumer Research Laboratory (CRL) undertook to identify and test a selection of materials which might be suitable for use as pump rods in direct-action pumps. The project was funded by ODA.

User preference

The first stage of the research investigated how users would respond to different arrangements for distributing the total operating effort between the up- and down-strokes. Five configurations were compared, ranging from maximum force on the up-stroke, via equal forces on both parts of the pumping cycle, to maximum force on the down-stroke, but all the configurations required a total work input equivalent to 50 watts at 30 cycles per minute. Users ranged from 10 years old to adult.

Although average work rates turned out to be very similar for all configurations, the users showed a consistent preference for arrangements where either the up and down forces were equal or the down-force was slightly greater than the up-force.

Computer model

A computer model was devised to examine a wide selection of potential pump materials and dimensions in terms of their effect on the operation of the pump. Inputs to the model were:

- pump rod material
- pump rod form, dimensions, length between connections
- cylinder bore and pump stroke
- cylinder depth below ground
- water depth below ground

The outputs from the model were:

- estimated operating forces on up- and down-strokes
- likelihood of the pump rod's buckling under compression
- stroke rates for a range of work rates
- rate of water outflow
- effect of leaky rods filling with water

The last point was included because the characteristics of hollow rods could change markedly if they leak and fill with water, as has been a problem with some direct-action pumps tested in the laboratory.

Market survey

Market research was undertaken in selected countries to assess the availability of materials approximating to the preferred specifications.

■ uPVC	Widely available: 42 mm-diameter, 2.7-mm wall pipe selected for testing
■ ABS	Less widely available than uPVC; less stiff, hence a relatively thick wall section would be required: 42 mm-diameter, 4-mm wall pipe selected for testing
■ Polypropylene	No suitable materials were found
■ Aluminum	Difficult to find in suitable sizes; tube in the preferred size of 44-mm diameter was only available at great cost: 32-mm diameter, 1-mm wall tube selected for testing, in Grade 6063 alloy (BS 1474:1972).
■ Stainless steel	No suitable materials were found
■ Glass-reinforced	Difficult to find; a suitable material (plastic) was identified, but it was rejected due to very high cost
■ Polyethylene	Readily available as continuous hose: 42-mm diameter, 3.7-mm wall pipe was selected for testing

Performance tests

Prototype pumps were constructed incorporating each of the selected pump-rod materials, and tested in conjunction with a Tara pumpstand and cylinder. No pump-rod guides were used. The pumps were installed at 20 meters depth in a borehole, with the water at 15 meters depth. Joints in the uPVC and ABS pipes were made using solvent cement. The aluminum rods were connected using epoxy resin. The polyethylene hose was installed as a single length with no intermediate connections. The results of the tests are compared in Figure B10.

There was little to choose between uPVC and ABS. For both materials, the results were in close general agreement with the computer model at 20 and 30 cycles per minute. At higher speeds, increased friction suggests that the pump rods were rubbing on

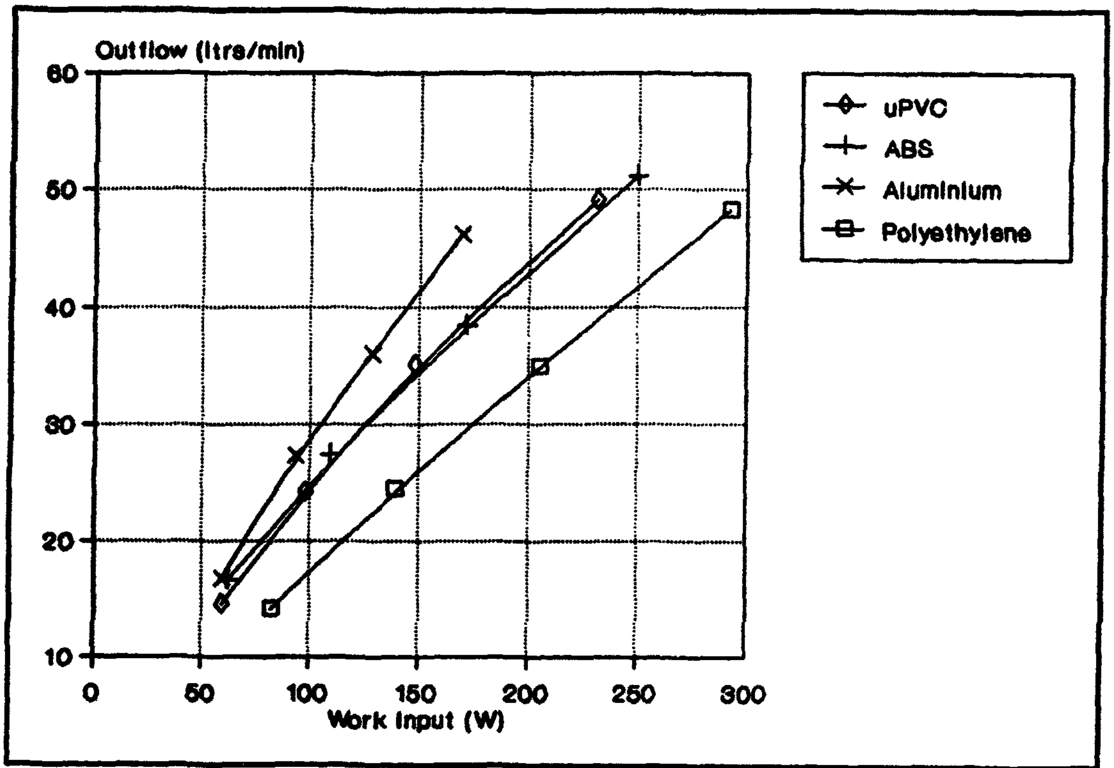


Figure B10. Pump performance with various rod materials

the rising main as a result of the rods buckling under compression. For the aluminum rods, consistently high levels of efficiency were recorded at all operating speeds, suggesting that the greater rigidity of the aluminum tube prevented significant contact between the pump rods and the rising main. The opposite effect was observed for the polyethylene hose, for which the measured efficiencies were consistently lower than for other materials.

Endurance tests

Pumps incorporating each of the rod materials and using Tara pumpstands and cylinders were tested for 4,000 hours at 32 cycles per minute, simulating a water depth of 15 meters and a cylinder immersion of 5 meters.

Out-of-line forces were thought to have contributed significantly to the various failures. In the case of the polyethylene rods, the out-of-line forces were caused by a permanent set in the hose as a result of its having been coiled. In the aluminum rods, the out-of-line forces were transmitted through the handle: the test rig was designed to impose slight out-of-line forces during the pumping cycle, typical of those actually applied by people using direct-action pumps.

Summary: Lightweight pump rods endurance test

uPVC		ABS		Aluminum		Polyethylene	
Hours		Hours		Hours		Hours	
0	Start	0	Start	0	Start	0	Start
						599	Bottom coupling broken
2007	Inspection	2007	Inspection	2007	Inspection	2007	Inspection
				2246	Top section broken		
				3080	Top connection fretted		
				3522	Top section broken		
4006	Final inspection	4006	Final inspection	4006	Final inspection	4006	Final inspection

Each of the pump rods was carefully inspected at the end of the test, and the rising mains were examined internally.

- uPVC — Wear was evident on both the pump rod and the rising main, particularly where lengths of pump rods had been joined. The pattern of wear suggested that it had been caused by the pump rod's buckling during the return stroke. The epoxy cement joint at the top of the pump rod, in an area subjected to relatively high stress, was in good condition.

- **ABS** — Wear was evident on both the pump rod and the rising main, the pattern suggesting that the pump rod had buckled in an S-shape during the return stroke. The maximum wear was not as severe as for the uPVC pump rods.

- **Aluminum** — Very little wear was found on either the pump rods or the rising main, suggesting that the aluminum rods had remained rigid throughout the pumping cycle. However, the rods were corroded, and this had caused a pin hole which had allowed water to enter the pump rod.

- **Polyethylene** — Extensive wear was evident on both the pump rod and the rising main. The pattern of wear suggested that a combination of the original set in the rods and buckling during the return stroke had been responsible. Particles of sand were embedded in the pump rods and had caused accelerated wear of the corresponding areas of the rising main.

Conclusions

All the tubular plastic pump rods seemed to buckle on the return stroke, and any practical design should take account of this. The results for uPVC and ABS were similar; ABS showed a greater tendency to buckle but a lower rate of wear when used with uPVC rising main. An interesting combination might therefore be uPVC pump rod and ABS rising main. This would maximize the stiffness of the pump rod and minimize problems of lack of stiffness in the ABS.

Polyethylene is particularly cheap and naturally buoyant, but it is not as stiff as the other plastic materials and tends to pick up particles of sand that will inevitably accelerate wear. It is normally supplied as a coil so that a complete length can be cut for use in each pump, eliminating intermediate connections. However, the set in the pipe which results from coiling it will exacerbate the tendency to buckle under compression.

Although the aluminum rods were stiff enough not to buckle under compression, their low fatigue resistance made them unable to cope with the flexing which can be expected in a direct action pump, and their corrosion resistance was inadequate. The material tested was chosen after extensive discussions with the manufacturer, and was selected for its combination of mechanical strength and corrosion resistance. Other grades of alloy are available with better fatigue resistance, and anodizing could improve corrosion resistance, but on the basis of this research aluminium cannot be recommended as a material for the pump rods of direct-action pumps.

B5. Stress in Handpump Rising Mains and Pump Rods

The stresses in the below-ground assemblies of handpumps have been the subject of considerable debate. Many attempts have been made to assess theoretically the relative significance of the quasi-static forces (the "dead weight" of the components and of the water), the dynamic forces involved in accelerating the pump rod and the water column, friction at the piston seal, shock loads resulting from the pump handle hitting its stops and other possible factors. Concern centered specifically on the use of plastic rising mains in deep well pumps.

Plastic, particularly uPVC, rising mains have a crucial role to play in making handpumps suitable for village-level maintenance. uPVC pipe is widely available, already manufactured in a number of developing countries, and cheap. It is light in weight (which makes it possible for below-ground assemblies to be withdrawn for maintenance without the need for lifting tackle) and inherently corrosion resistant.

uPVC is already used extensively in water supply, and with success, but applications rarely subject the pipe to significant longitudinal stresses. Existing standards concentrate on the dimensions of the pipe and its ability to withstand pressure.

To develop an understanding of the potential of uPVC pipe to perform reliably as the rising main of a handpump, a knowledge of the working stresses is essential. ODA, UNDP, and the World Bank jointly sponsored a research project by the Consumer Research Laboratory to measure the stresses in a working rising main, and the corresponding stresses in the pump rods, for a variety of pump configurations and for different modes of pumping. A parallel program of research was also undertaken by InterAction Design, sponsored by the Netherlands Ministry for Development Cooperation.

The CRL pilot study

A pilot study was undertaken to establish the best measurement positions, test procedures, and technologies. The work was done in CRL's handpump test tower, and all parts of the system were available for access. Two pumpstands were used: an Afridev and an India Mark II, to compare fixed and flexible connections between the pump rod and the handle. Tests were made using a solid rising main mount and the rubber cone mount from the Afridev pump. A variety of pumping techniques were used, ranging from relatively slow, full strokes of the handle to fast, short strokes. Extra tests were made for full strokes with the operator allowing the handle to bang against its stops.

The rising main on test was 60-mm outside diameter, 3-mm wall Class C uPVC pipe, manufactured in the UK to ISO 727 (materials) and BS 3505/3506 (dimensions). A relatively thin-walled pipe was chosen for the pilot study to ensure that sufficient extension would be obtained in a length of 7 m.

Table B2: CRL Measurement of Stress in Rising Main

Component	Measuring device(s)	Reference (Figure B11)
Handle	Strain gauge measuring force applied by pump operator	7
	Angle displacement transducer measuring handle movement	8
Pump rod	Load cell to measure tensile forces at top of pump rod	6
	Vertical displacement transducer to measure pump rod movement	1
	Accelerometer measuring acceleration of pump rod	2
Rising main	Strain gauge 4-way mounting plate measuring both tensile and bending forces at top of rising main	9-12
	Linear extensometer measuring extension and compression over whole length of the rising main	5
	Strain gauges measuring tensile forces at bottom of rising main, immediately above cylinder	3
	Pressure transducer measuring pressure inside rising main immediately above cylinder	4

A wide range of measuring instruments was fitted. Outputs from the devices were recorded on a high-speed, 12-track UV recorder to enable study of not only the absolute values of the outputs but also their phase relationships. The use of a microcomputer as a multichannel data logger was also considered. It was rejected when it became clear that the available memory would be filled within a few seconds of pumping, as a result of the fast scanning rate required to capture transient effects.

It had been anticipated that the pilot tests would show that some monitoring stations would be producing data of minor significance that could be omitted in subsequent research for which boreholes would be used. This proved not to be the case, however, and it was apparent not only that a fully comprehensive test rig would be required for the borehole tests, but also that a wider range of handpump configurations should be included.

It was also clear that short-term transient effects were important. Even when pumping gently in near simple harmonic motion, the four-way strain gauges on the mounting plate (Figure B11: items 9 to 12) detected relatively high frequency variations in stress in the rising main, and other results demonstrated the additional stresses induced by rapid pumping and by banging the handle against its stops.

CRL's main test program

For the main test program, a wider range of pump configurations was tested, including a Volanta pumpstand in addition to the Afridev and India Mark II types, with cylinders of 50 mm bore (Afridev) and 2.5 inches (India Mark II). The combinations are shown in Table B3. Rising main pipe was Class E, 60 mm outside diameter, 3.9 mm wall. The tests were carried out in a borehole at water depths of 25 meters and 45 meters.

The Volanta pumpstand was included as an example of a pump which moves the pump rod in near simple harmonic motion, and without risk of the handle's being banged on its stops. The elimination of shock loads has often been claimed as a significant advantage of flywheel-type handpumps.

Table B3: Combinations Tested in the CRL Main Test Program

	Afridev stand	India stand	Volanta stand	Afridev cylinder 50 mm	India cylinder 2.5"	Rising main 25 m*	Rising main 45 m*	Rubber cone
1	√			√			√	
2	√			√			√	√
3	√			√		√		
4	√			√		√		√
5		√			√		√	
6			√		√		√	
7		√			√		√	√
8		√			√	√		
9			√		√	√		
10		√			√	√		√

* Water level below ground; cylinders immersed 3 m below water level

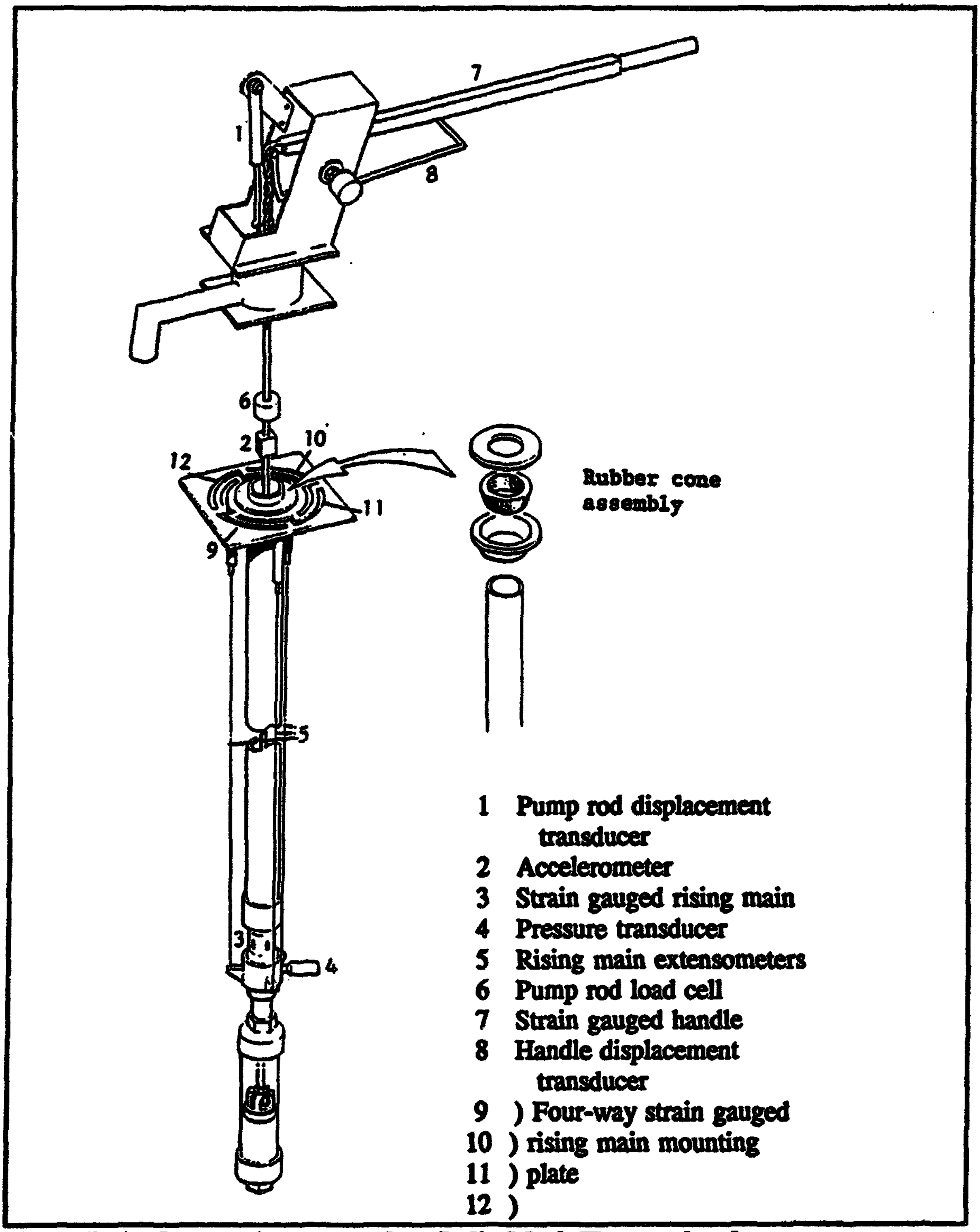


Figure B11. Test equipment used on India Mark II pump head

For each configuration, tests were carried out for three pumping techniques:

- 40 cycles/minute; maximum stroke length without striking the bump stops
- 80 cycles/minute; maximum stroke length without striking the bump stops
- 80 cycles/minute; maximum stroke length including striking the bump stops

For the Volanta pumpstand, tests were carried out at 40 and 80 revolutions per minute.

CRL's main test results

A vast amount of data was generated and stored on magnetic tape for subsequent analysis. Figure B12 illustrates part of one the traces: for pump-rod tension in the Afridev pump, with a solid rising- main mount, operated at 40 cycles per minute from a depth of 45 meters. The trace is typical of the results and shows a good deal of secondary variation superimposed on the primary pumping cycle.

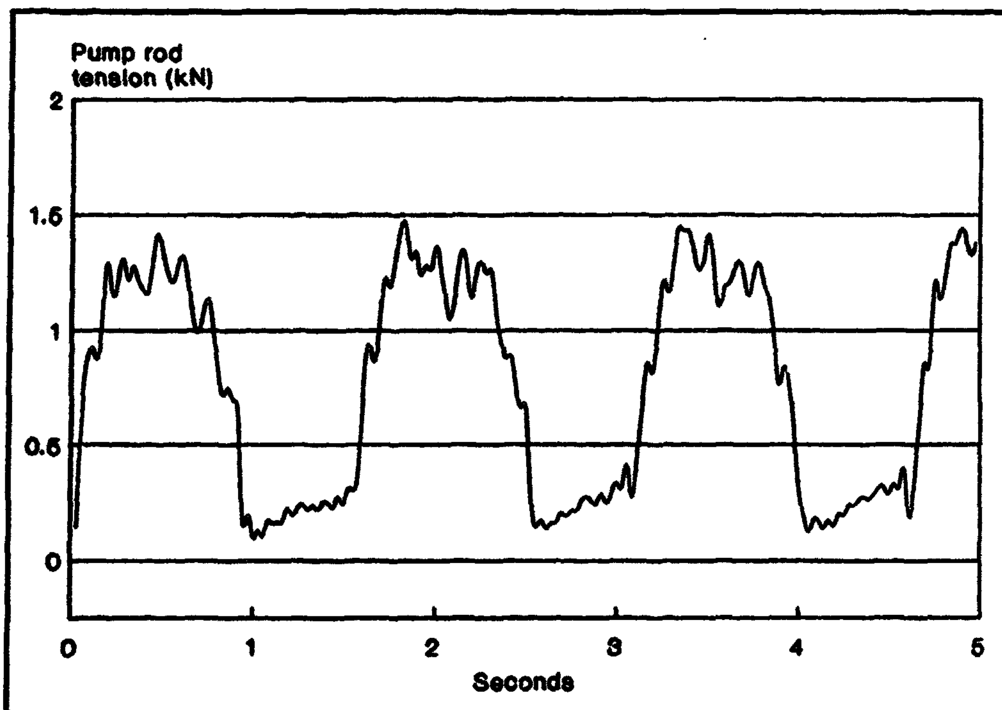
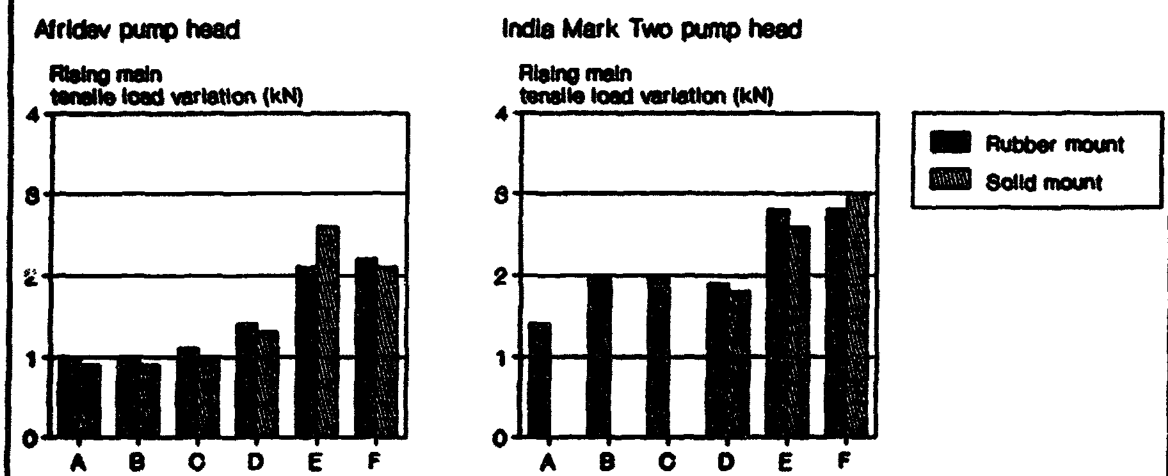


Figure B12. A typical result from CRL's tests

For most configurations, the maximum stress in the rising main occurred at the bottom, as a combination of tensile stress and hoop stress caused by the internal pressure. However, the greatest value recorded in the tests was at the top of the rising main for the India Mark II head with a solid rising main mount, at a stroke rate of 80 cycles per minute and with the handle banging on its stops. The measured maximum load was equivalent to a stress of 7 MPa. This amounts to about 13 percent of the ultimate tensile strength for uPVC (55 MPa at 23°C). Even allowing for notch effects in the rising main, which are almost certain to be present in any practical design, it seems unlikely that uPVC pipe of appropriate size and quality will break solely as a result of the levels of stress imposed on it.

Failure is more likely to be caused by fatigue, and in the determination of the fatigue life of uPVC it is the variation in stress rather than the maximum stress which is significant. Figure B13 illustrates the variations in tensile loads in the rising main measured by CRL for the Afridev and India Mark II test configurations.



Key to graphs:
A = 25m depth, 40 cycles/minute
B = 25m depth, 80 cycles/minute
C = 25m depth, 80 cycles/minute striking bump stops
D = 45m depth, 40 cycles/minute
E = 45m depth, 80 cycles/minute
F = 45m depth, 80 cycles/minute striking bump stops

Figure B13. Variations in axial loads in the rising main

These variations in load translate into variations in stress, shown in Table B4. Note, however, that these stress variations relate only to the particular pipe chosen for CRL's tests, and not to actual Afridev or India Mark II pumps, for which the stress variations will depend on the dimensions of their rising-main pipes.

Table B4: Variations in Rising Main Stress

Water depth (m)	Pumping speed (cycles/min)	Riser mount	Afridev config. stress variation (MPa)	India Mk II config. stress variation (MPa)
25	40	solid	1.2	
25	40	rubber	1.3	1.9
25	80	solid	1.2	
25	80	rubber	1.4	2.7
25	80BS*	solid	1.3	
25	80BS	rubber	1.5	2.6
45	40	solid	1.8	2.4
45	40	rubber	1.8	2.5
34	80	solid	2.7	3.5
45	80	rubber	2.8	3.7
45	80BS	Solid	2.8	3.9
45	80BS	rubber	2.9	3.7

* BS = striking the bump stops.

CRL analyzed the phase relationships between the various measurements to determine the sequence of events in a typical pumping cycle: an example, for the Afridev head operating at 40 cycles per minute, is shown in Figure B14. At the start of the cycle, the handle moved down, the piston moved up and the piston valve closed. This caused an extension of the pump rod, which then sprung back and oscillated briefly. The pressure in the cylinder reached a maximum as the column of water was accelerated. The rising main shortened as the weight of water was taken off the footvalve and friction at the piston seal increased. The system then oscillated at about 6 Hz. On the return stroke, the foot valve closed, the pump rod decelerated and oscillated at about 20 Hz. The oscillations in the pump rod can be seen in Figure B12. During the return stroke, the rising main lengthened and oscillated at about 2 Hz.

CRL's conclusions

It is difficult to predict the likely fatigue life of the rising main. The fatigue characteristics of a particular pipe will depend on the formulation of the raw material, the method of manufacture, the degree of quality control, the addition of stabilizers and lubricants to assist in processing, and of fillers and rubbery materials to improve the impact strength.

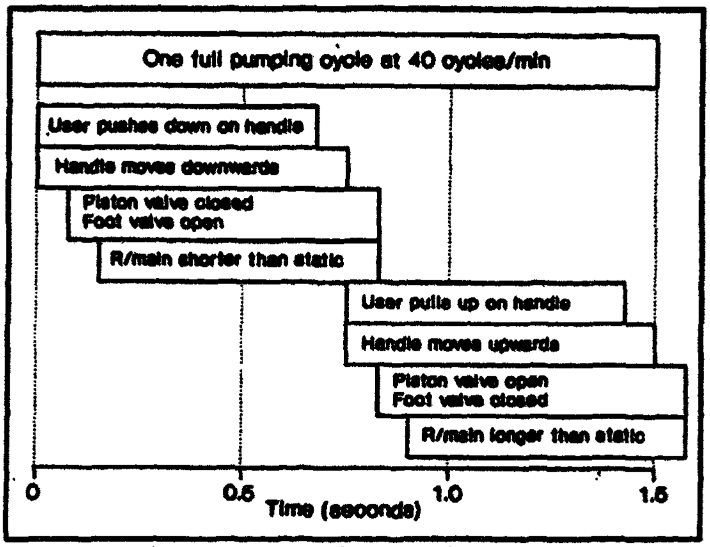


Figure B14. Sequence of events in a pumping cycle

Creep, long-term elongation of the pipe under continuous load, is unlikely to be a problem provided that pumps are installed with a clearance between the piston at top dead center and the top of the cylinder. The static stress is relatively small, and will give rise to a strain of between 0.1 and 0.2 per cent per year at 20°C, equivalent to an extension of 7 mm per year for a 47 m below-ground string.

The maximum stress induced in the pump rods as a result of the tensile loads was 27.8 MPa, considerably greater than the stress induced by acceleration. Since the ultimate tensile stress for stainless steel is around 800 MPa, there would seem to be little risk of pump-rod breakage. However, stress will be concentrated at the roots of the threads, especially where these are cut rather than rolled. A typical stress concentration factor for cut threads is three, though considerably higher figures are possible for badly cut threads, or where threads are not cut square with the axis of the rod.

There is no specific information on the fatigue performance of threaded pump rods, but data is available for steel nuts and bolts. This indicates that the stress should not exceed 50 MPa for badly cut threads and 150 Mpa for rolled threads to give a fatigue life of ten million cycles. It is therefore recommended that rolled threads be used wherever possible, and particularly for 10-mm pump rods, to ensure a satisfactory fatigue life.

Other factors in CRL's tests

The **rubber cone rising main mount** had the effect of damping the oscillations in the rising main, but increasing their amplitude. The overall effect was generally to reduce the maximum stress at the top of the rising main (particularly with the India Mark II configuration) though not the variation in stress. The rubber cone also tended to reduce slightly the output of the pump by shortening the effective pump stroke.

The **rotary** configuration (Volanta pump head) gave the lowest values for pressure above the piston and for deflection of the rising main, but the levels of stress were generally similar to the other configurations.

Checking pipe quality

Many people working in handpump projects continue to have serious reservations about uPVC as a rising main material. It is not clear to what extent these reservations are based on direct experience of failures in uPVC rising mains, however, as opposed to worries about the poor quality of some pipes manufactured in developing countries. There are indications that at least some difficulties associated with uPVC rising mains have resulted from inappropriate jointing methods rather than shortcomings in the pipes themselves.

ODA of the UK and GTZ of Germany are collaborating in research into connectors for uPVC rising mains, and agreed to extend this work to include the examination of samples of pipes manufactured in developing countries. The objectives were to give a general indication of quality and to suggest a simple quality control test which could be carried out by manufacturers. Chemical analysis was carried out by the Open University, UK, and mechanical assessments by CRL. Samples of pipe were obtained from Ethiopia, India (three manufacturers), Kenya (two manufacturers), Malawi, and Pakistan (two manufacturers). For comparison, the same tests were performed on samples of the UK-made pipe used by CRL for their measurements of rising-main stress.

All but one of the pipes was found to have been inadequately processed, to varying degrees, leading to incomplete fusing of the uPVC particles. However, poor gelation, as this is known, can be readily detected during manufacture by a relatively simple test.

It is recommended that manufacturers should extrude rising main pipes in specific batches, with extra supervision and testing of pipe quality. Below-specification pipe need not be totally rejected, but can be set aside for less demanding uses such as wastewater disposal. Gelation should be routinely tested using a nonsolvent immersion test in methylene chloride (CH_2Cl_2) or acetone. The test is easy to perform, requiring only a lathe to turn a taper on the end of a sample of the pipe. Very little interpretative skill is needed, and the test can be carried out quickly near the extrusion line which minimizes the effect on production.

Poor gelation is generally caused by inadequate die-head temperatures during the extrusion process. In extreme cases, the full thickness of the pipe may be adversely affected. In less severe cases, the poorly gelated material may only be in the central part of the pipe wall, the inner and outer skins being relatively well consolidated. The quality of solvent-welded joints in poorly gelated pipe is also likely to be adversely affected, due to solvent penetration between the inadequately fused uPVC particles.

Testing by InterAction Design

InterAction Design (IAD) of the Netherlands set out to investigate the stresses in PVC rising mains used for handpumps for depths down to 100 meters. Their tests were based on the SWN 81 and Volanta pumps, and included a "hybrid" pump combining the Volanta below-ground assembly with the SWN pumpstand. Tests of the SWN pump were carried out for water depths ranging from 20 meters to 96 meters; the Volanta and hybrid pumps were tested at 78 meters. A number of other factors were also investigated (Table B5).

The instrumentation used is illustrated in Figure B15 on page 75. The outputs were processed by two AT-compatible computers. Strain was measured using groups of four strain gauges glued at 90 degree intervals around the PVC rising main and pump rod, to permit both axial strain and bending stress to be calculated. At the bottom of the rising main, additional tangential strain gauges were applied to compensate for contractions caused by pressure fluctuations inside the rising main.

IAD test results

IAD drew a sharp distinction between conventional "stiff" rising mains and PVC "elastic" rising mains. The elasticity of conventional steel pipes is slight, but for PVC rising mains the effect of the pipe stretching and relaxing under load is sufficient to reduce considerably the actual stroke of the piston in relation to the cylinder, and therefore the amount of water delivered. Moreover, the resonant frequency of a typical PVC rising main is sufficiently low that resonance may occur at normal pumping rates.

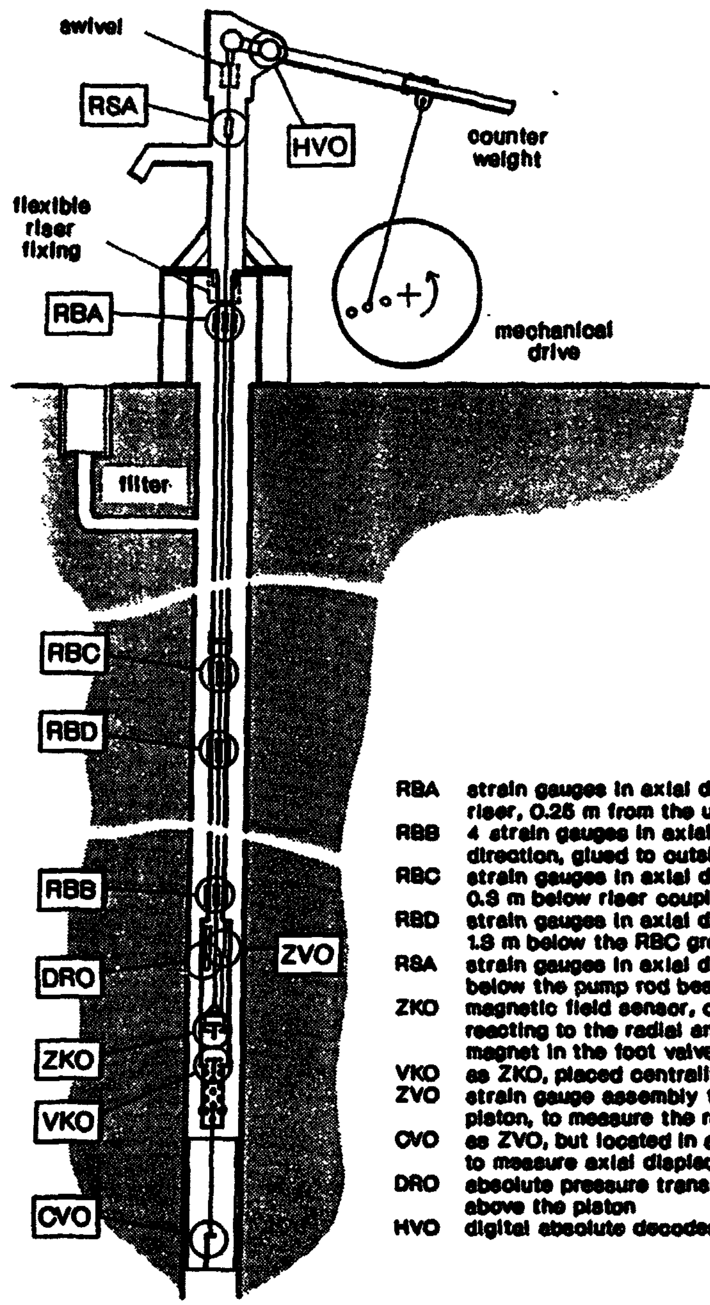
Table B5: Combinations Tested in the IAD Test Program

	SWN 81					Volanta	Hybrid
Water depth (m)	20	40	60	80	96	78	78
Effect tested							
1. Rising main centralizers				√			
2. Cylinder support					√		
3. Flexible riser fixing	√	√	√	√	√		
4. Stand out of plumb	√	√	√	√	√		
5. Swivel (on rod hanger)	√	√	√	√	√		√
6. Mechanical and hand drive	√	√	√	√	√	√	√
7. Flywheels 1.5 m and 0.75 m diameter						√	
8. Flywheel and pump handle						√	
9. Immersion depth	√	√	√	√	√		
10. Piston valve weight						√	
11. Piston valve lift						√	

Loss of output

Figure B16 is taken from IAD's report, and shows calculated and actual results for the volumetric efficiency of the SWN 81 pump (50-mm cylinder bore, 165-mm stroke), for depths down to 100 meters. Although the effect if not very significant at 45 meters depth (the experimental results in particular holding up well, at over 90 percent volumetric efficiency), a marked loss of output is indicated at 100 meters depth.

IAD's explanation for this loss of output is illustrated in Figure B17. At the start of the upward or delivery stroke, the pressure generated by the "head" of water in the rising main is gradually transferred from the rising main to the piston. The rising main contracts and the piston and cylinder move upwards together, without any significant movement of the piston relative to the cylinder (Phase 1). Only when all the pressure has been transferred to the piston does it move relative to the cylinder, opening the footvalve and drawing water into the cylinder (Phase 2). On the return stroke, pressure is gradually transferred from the piston to the rising main, causing the rising main to lengthen. Again, the piston and cylinder move together (Phase 3), with no significant relative movement until the rising main has been fully extended (Phase 4). The effective stroke of the piston is therefore reduced by the extension of the rising main.



RBA	strain gauges in axial direction, glued to outside of riser, 0.25 m from the upper end
RBB	4 strain gauges in axial direction plus 1 in tangential direction, glued to outside of pipe 0.2 m from lower end
RBC	strain gauges in axial direction, glued to outside of riser 0.3 m below riser coupling
RBD	strain gauges in axial direction, glued to outside of riser 1.8 m below the RBC group, midway down the riser
RSA	strain gauges in axial direction, glued to pump rod 0.2 m below the pump rod bearing
ZKO	magnetic field sensor, centrally under the piston valve, reacting to the radial and axial displacement of a bar magnet in the foot valve
VKO	as ZKO, placed centrally under the foot valve
ZVO	strain gauge assembly fitted in the cylinder, above the piston, to measure the relative piston displacement
CVO	as ZVO, but located in a PVC tube under the cylinder, to measure axial displacement of the pump cylinder
DRO	absolute pressure transducer, placed in the cylinder above the piston
HVO	digital absolute decoder, connected to pump handle

Figure B15. Test equipment used with the SWN 81 pump

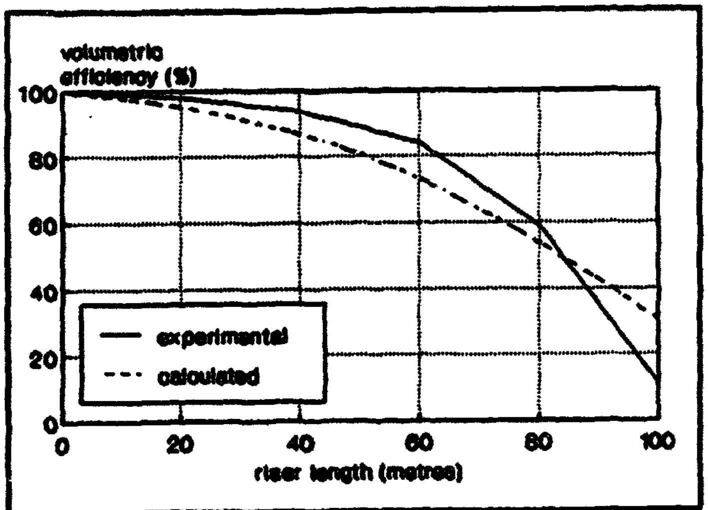


Figure B16. Loss of output due to rising main elasticity

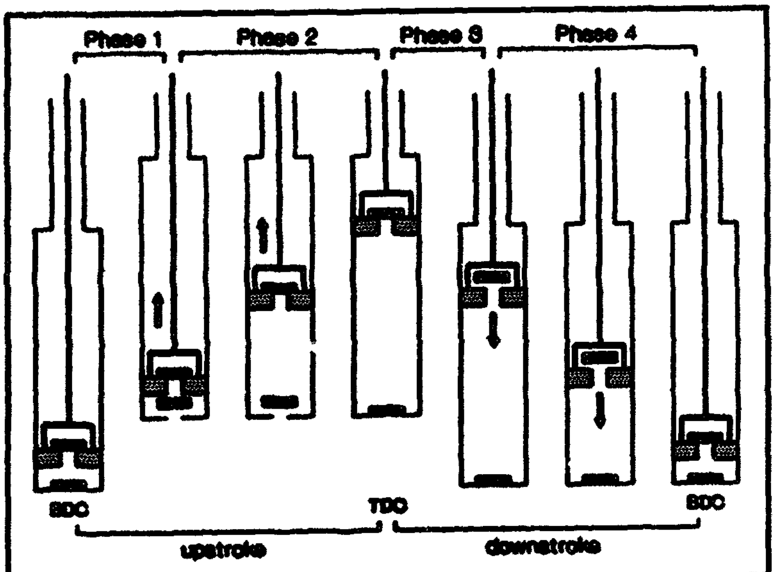


Figure B17. Sequence of events in a pumping cycle for a pump with a PVC rising main

Resonant effects

At low pumping speeds, IAD concluded that the stresses on the pump rods and rising main could be accurately predicted by relatively straightforward quasi-static approximations. At higher speeds, however, dynamic effects added considerably to the total stress. The most significant dynamic effects were pressure fluctuations caused by resonance of the water column and rising main.

At the start of the upstroke, the water immediately above the piston is compressed. The pressure is localized by the inertia of the system, and the rising main expands to accommodate it (water being virtually incompressible). This pressure front moves up the system at a speed determined by the dimensions of the pipe and its elasticity, about 400 meters/second for typical rising main pipes, and is reflected back down at the top.

After a few pumping cycles, a complex pattern of pressure waves is set up within the rising main, as newly produced waves interact with reflected waves. Resonance occurs when the waves reinforce one another, that is, when a reflected wave arrives at the moment a new wave is produced. This depends on the length of the rising main, as illustrated in Figure B18.

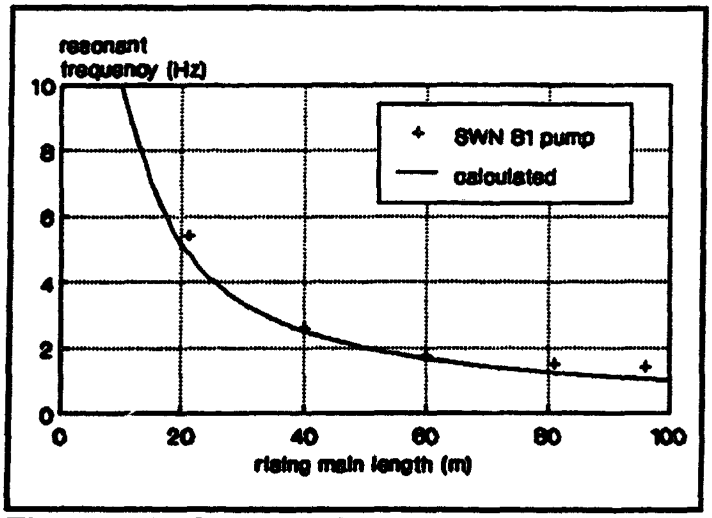


Figure B18. Resonant frequency versus length of rising main

At other frequencies, the effects of interactions of the pressure waves will still be present, appearing typically as pressure fluctuations at approximately the resonant frequency superimposed on the basic pressure cycle. IAD analyzed this effect in detail and got good agreement between the theory and their actual results, both for measurements of pressure and of the resultant stresses in the rising main and pump rod.

IAD found that experiments with the valves of the Volanta pump (halving the valve lift from 10 mm to 5 mm and reducing the mass from 80 g to 25 g) had no material effect on the strains and stresses in the rising main or pump rod.

IAD developed formulas relating the stresses in the rising main and pump rods to the physical characteristics of the pump and conditions of use. These formulas have been used to produce the figures shown in Table B6.

Table B6: Variations in Rising Main Stress

Pump	Water depth (m)	Stress variations for pumping rates: 20	40	60	80	100
		(cycles/minute)				
SWN 81	35	0.8	0.9	1.0	1.0	1.1
	55	1.3	1.5	1.7	1.9	2.5
	73	1.8	2.1	2.5	3.0	2.4
Volanta	73	1.2	1.4	1.7	2.0	1.6

IAD's conclusions and recommendations

- Significant differences exist between pumps with PVC rising mains and conventional rising mains, because of the greater elasticity of PVC.
- The most likely cause of failure of pump rods and PVC rising mains is fatigue.
- The pump yield will be reduced by the loss of effective piston stroke that results from a PVC rising main stretching under load.
- At low frequencies, the stress and strain fluctuations in the rising main and pump rods can be accurately predicted by quasi-static approximations.
- At pumping frequencies greater than about half the resonant frequency of the rising main, dynamic effects due to interfering pressure waves in the rising main become significant.
- The reduction in output from stretching of the rising main and the stresses in the rising main and pump rod can be reduced by maximizing the ratio of pump stroke to piston diameter.

IAD advises that the stress fluctuations in PVC rising mains should not exceed 5 MPa, and in stainless steel pump rods should not exceed 50 MPa. Stress concentrations should be minimized by making changes in section (at joints and couplings, for example) as smooth as possible. Joints must be accurately aligned. Rolled threads in pump rods are preferred to cut threads.

Rising main centralizers will minimize the bending stress fluctuations caused by swinging and snaking, though they will not prevent buckling when compressive stresses occur. Allowance must be made for long-term creep, particularly in deep installations, to prevent the piston "topping out" in the cylinder.

Overall conclusions and recommendations

The stress variations measured by CRL and IAD confirm that uPVC pipe has the capability to perform adequately as a handpump rising main, provided the pipe is of good quality and the overall design takes account of the specific properties of uPVC. The maximum values of stress established in this research are well within the maximum tensile strength of uPVC pipe. The predominant cause of failure is therefore more likely to be fatigue.

Pipe quality is important: the fatigue life of poor-quality pipe may be as little as one sixth that of good-quality pipe. The tests on samples of actual pipes suggest that a large proportion of commercially available pipe may be of less than satisfactory quality, and that pipe made in the developed world cannot be assumed to be superior to pipe made in developing countries. However, relatively simple techniques are available for monitoring pipe quality during manufacture: specifiers should insist that these techniques be used and a satisfactory level of quality achieved in pipe intended for use as handpump rising mains.

Features of handpump design which will tend to maximize the effectiveness and fatigue life of a handpump with a uPVC rising main include:

- A relatively small piston diameter. The dynamic forces in a handpump are dependent on the square of the piston diameter: a 30 percent reduction in piston diameter will more than halve the dynamic forces, and hence the stresses.

- A relatively long stroke. This offsets the effect of the relatively small piston and ensures that the loss of stroke which results from the stretching and contraction of the rising is a relatively small proportion of the total stroke.

- Rolled, rather than cut, threads on the pump rods. Care must be taken to ensure that the threads are accurately aligned.

It is also important to minimize external damage to the pipe and the pump rods during installation and repair. Any dent or scratch can act as a focus for stress concentration, from which a fatigue crack may propagate and eventually cause failure.

This research has confirmed that an "unsympathetic" pumping technique, banging the handle on its stops at the ends of the stroke, will have the effect of increasing the stresses in the system. The increases are modest, however, and there is no evidence that this could be the predominant cause of the failure of plastic rising mains in the field. Similarly, there is no evidence that rotary operating systems (which have no fixed stops) offer significant reductions in stress.

Figure B19 illustrates the likely relationship between fatigue life and stress variation for uPVC rising mains, for a range of stress variations typical of those measured in the CRL and IAD test programs. The heavier shading indicates the likely fatigue life of good-quality pipe; the lighter shading represents pipe of inferior quality.

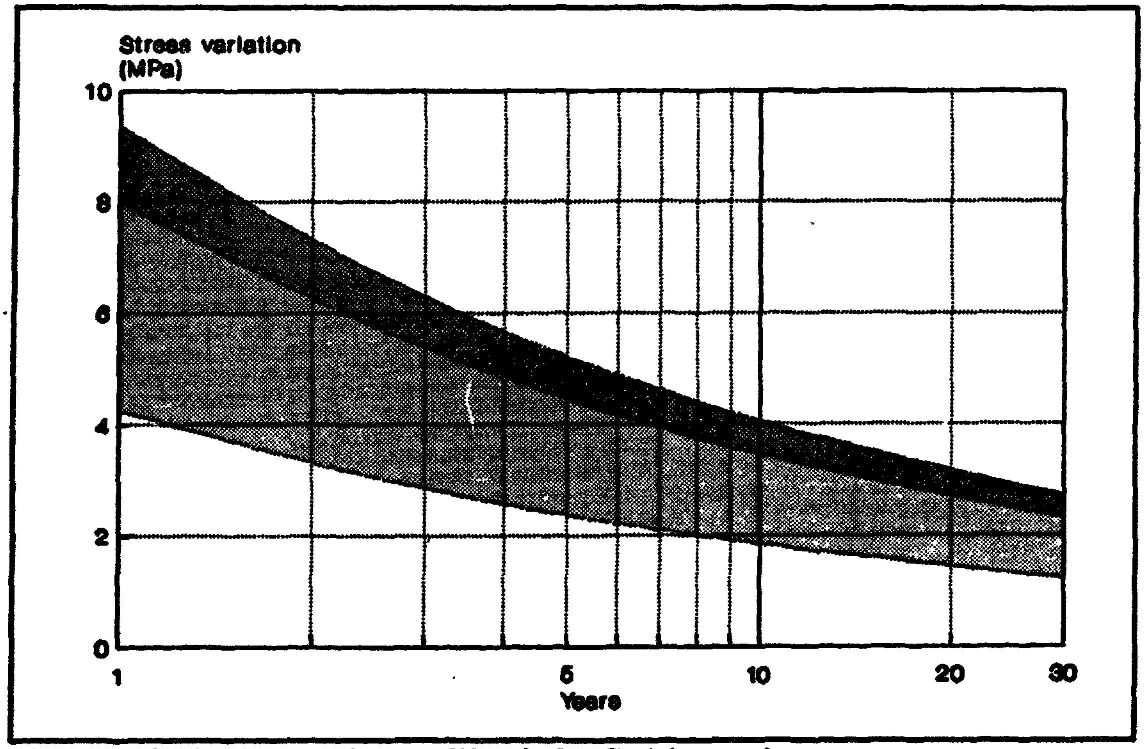


Figure B19. Estimated fatigue life of uPVC rising main

B6. Ongoing Research: Rising Main and Pump-Rod Connectors

Following the research into the stresses in the below-ground assemblies of handpumps described in section B5, CRL has undertaken further research and development into the design of VLOM connectors for plastic rising mains, sponsored jointly by ODA and GTZ, and connectors for pump rods, sponsored by ODA, UNDP, and the World Bank. This research is ongoing, and the information in this report therefore represents the interim results.

Rising main connectors

This is a project in several phases, intended to develop easy-to-use couplings for plastic rising mains. The research has progressed to the point where a number of potential connector concepts have been identified, market research into suitable adhesives has been carried out, and a number of adhesives have been tested. The next phase of the work will consist of the manufacture of prototype molded connectors for testing in the laboratory and the field. The design objectives are summarized on the following page.

The research has been based on connectors suitable for DIN 8062 (BS3505) uPVC pipe, 63-mm outside diameter, 53-mm inside diameter, used as a handpump rising main at settings down to 50 meters. A limit of 85 mm was placed on the outside diameter of the connector to allow for a 6-mm security rope and provide some slack when fitted in a 100-mm borehole casing.

Selection of designs for testing

Initially, ten design concepts were devised, from which six were selected for further evaluation:

- a threaded connector, with female-threaded collars solvent-cemented to the pipe and a loose male-threaded coupling
- an eccentric coupling, relying on the friction generated between "interfering" eccentrics, engaged and disengaged by twisting
- a split collar coupling, using collars solvent-cemented to the pipe locked together by snap-on external split half-collars

Summary: Design objectives for rising main connectors

- Simple to use, needing no tools to assemble or dismantle, and an obvious mechanism that cannot be assembled incorrectly
- Should fail safe, by leakage rather than breakage, so that failure does not cause the rising main to fall down the borehole, but should not leak significantly until the point of failure is reached.
- Suitable for manufacture in developing countries: designed for maximum local material and processing content. If plastics are used, they should be injection molded or extruded.
- Target cost about $5 per assembly in medium-scale production
- Should incorporate, or be capable of incorporating, a rising main centralizer
- Should be designed to minimize points of stress concentration, especially where notch-sensitive materials such as uPVC are used
- Ideally the components should be supplied factory-assembled to the pipe, avoiding on-site assembly
- Must be self-cleaning and have adequate flow characteristics
- Should be designed to outlast the rising main pipe and be capable of withstanding typical storage and handling conditions such as exposure to ultraviolet radiation and accidental abuse

- two versions of bayonet couplings, with lugs in one part engaging L-shaped recesses in the second part, engaged and disengaged by twisting
- a compression coupling relying on friction generated by compressing rubber rings onto the outside of the rising main pipe

The relative merits of these designs are compared in Table B7.

Models were made of these six designs to give a clearer idea of what each would be like to make and use. The eccentric coupling and the two types of bayonet coupling were rejected at this stage. The eccentric coupling would require very close tolerances and might therefore be susceptible to contamination from particles of dirt or sand, and could tempt maintenance staff to use pipe wrenches which would damage the rising main. The bayonet connectors would require complex molds, and it would be difficult to make the couplings easy to operate without making them insecure in service. Three designs were therefore selected for further development, leading to prototype manufacture and testing:

Table B7: Comparison of Connector Designs

Connector type:	1 Threaded coupling	2 Eccentric coupling	3 Split collar coupling	4 & 5 Bayonet couplings	6 Compression coupling
Easy to assemble	-	+	0	+	-
Can be fastened without tools	-	+	+	+	-
Durable in unskilled hands	-	0	+	+	-
Does not rely solely on friction	+	-	+	+	-
Requires little further development	+	-	0	-	0
Incorporates a sacrificial element	+	-	+	-	+

Key: + Positive attribute
- Negative attribute
0 Neutral or indeterminate

- split-collar coupling
- threaded coupling
- compression coupling

Of these, it was recognized that the compression joint had a number of potential drawbacks, but it also had the unique advantage of accepting the bare end of the rising main pipe. It could therefore be retrofitted in the field, for example, without solvent cement or other adhesives. However, further investigation revealed that it would not be possible to make a practical compression joint capable of withstanding the tensile loads in a rising main, and the design was therefore withdrawn.

Adhesives for uPVC pipe

Adhesives for uPVC are generally based on volatile solvents (typically cyclohexanone or tetrahydrofuran) which attack the uPVC and form a weld when the solvent evaporates. CRL was unable to obtain data on the shear strength of solvent-welded joints from adhesive manufacturers. This information is crucial in the design of couplings, however, to determine the area of the bond which in turn determines the dimensions of the coupling. CRL therefore carried out a series of simple tests to determine the shear strength of solvent-welded joints in uPVC.

The results revealed a wide variation which could not readily be explained in terms of differences in the area of the joints or the conditions under which they were made. However, it was clear that joints left to cure for 72 hours were approximately twice as strong as joints left to cure for 24 hours, and that simply increasing the bonded area of the joint did not necessarily result in an increase in strength.

CRL also surveyed 65 adhesive manufacturers to identify sources of adhesives which were not based on solvents. Only two were able to offer products which they considered would meet the requirements: the first was a rubber-toughened epoxy and the second an acrylic adhesive. Both were two-part adhesives which have to be mixed immediately prior to use. Joints made with these adhesives were tested alongside solvent-welded joints, using values of force variation drawn from CRL's measurements of the stress in handpump rising mains (section B5 of this report).

Both the nonsolvent joints and one of the solvent-cemented joints performed well. The second solvent-cemented joint failed rapidly, however, even though the same procedures were used to make all the joints. Examination of the failed joint showed poor contact between the pipe and the connector, with only a small portion of the total area bonded securely. Since similar failures are known to occur in the field, CRL feels that this result may have much wider significance.

The problem appears to be related to the formation of solid or "gelled" material in the adhesive, as a result of solvent evaporation, prior to the joint being brought together. Gelled adhesive cannot bond effectively with the uPVC, and gaps are therefore created within the joint. Because the solvents are very volatile, and some time must elapse between the application of the adhesive and bringing the joint together, a certain amount of gelation is inevitable. The problem will be exacerbated by high ambient temperatures, and virtually impossible to detect because there is no external evidence of it once the joint has been made.

Initial testing of prototype rising main connectors

Prototypes of the two remaining connector designs were produced and subjected to an endurance test regime based on forces measured in CRL's tests on uPVC rising mains (section B5). The target for completion of the test was 115,200 cycles. For each joint, components to be bonded to the pipes were made in uPVC and other components in acetal, which was chosen for its combination of strength, fatigue resistance and negligible water absorption.

Split collar The first sample failed rapidly (after 3,387 cycles) at the coupling solvent cemented joint between the socket and the pipe. Examination revealed that only 50 per cent of the available area had been bonded. A second sample lasted somewhat longer (9,829 cycles), but failed in a similar way. In this case, bonding had occurred over about 75 percent of the available area. The variance in these two joints prepared with care under identical conditions highlights the inherent difficulties in achieving consistent solvent-welded joints.

A further test sample was prepared, using epoxy adhesive to secure the collars, which required a small modification to the outer half-collars. This lasted 90,870 cycles, when failure occurred in the pipe immediately above the epoxy joint. There were no signs of failure in the acetal outer half-collars.

Threaded Following the experience with the split collar coupling, the coupling threaded connector was attached to the pipe with epoxy adhesive.

The first sample was tightened by hand and failed after only 50 cycles. It was remade using strap wrenches and completed the full 115,200 cycles. The test was continued to failure, which occurred after 124,000 cycles due to shear separation in the epoxy adhesive. Examination revealed that catastrophic failure of the pipe would have occurred shortly thereafter. There were no signs of failure in any of the coupling components.

Final designs for both joints have been drawn up with a view to the manufacture of molded prototypes for testing in the laboratory and at selected sites in the field. These designs are illustrated in Figure B20. Note for the split collar coupling that no clips or straps are shown for securing the outer half collars: it is intended that in a production version of this coupling, the half collars would have an integral retaining feature.

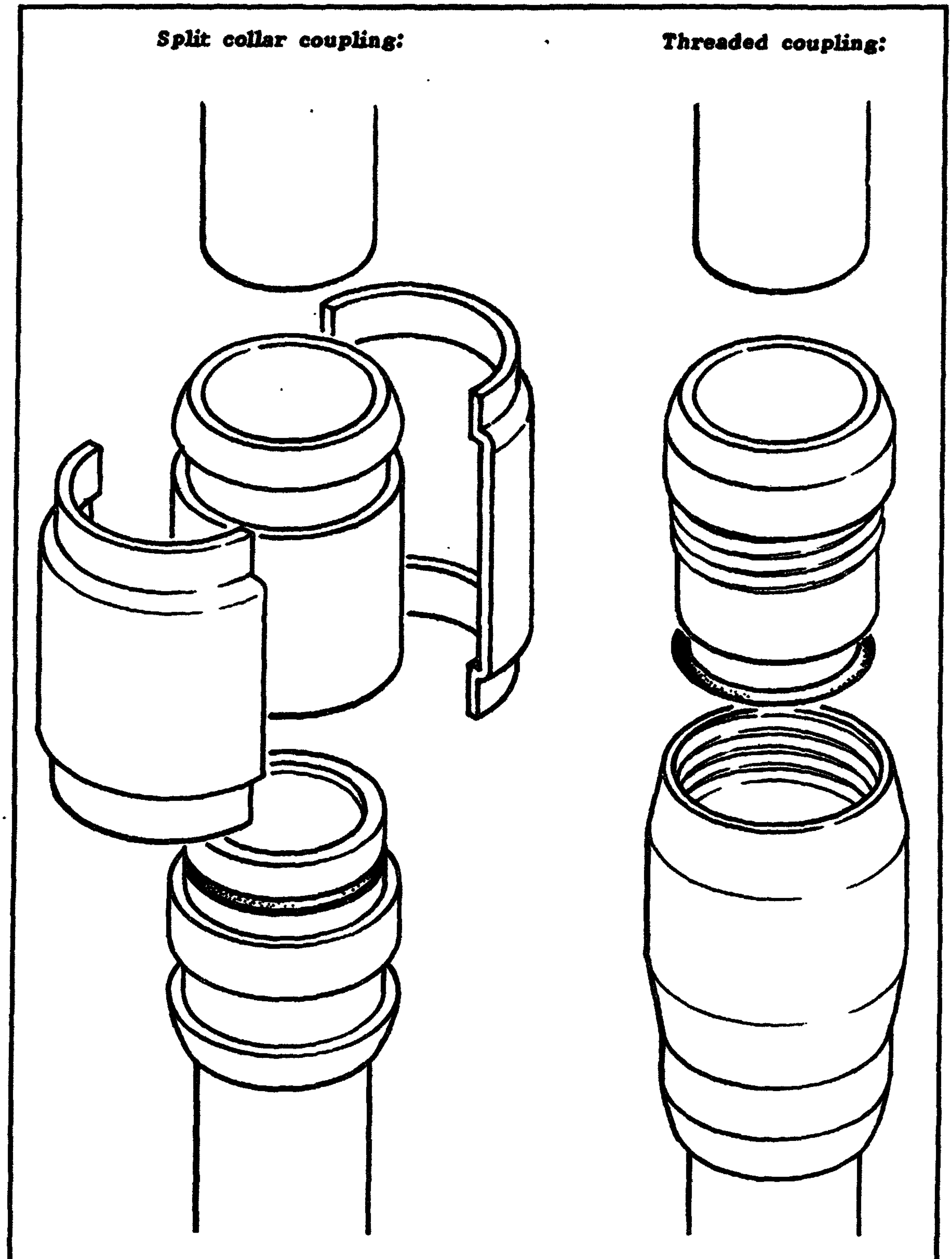


Figure B20. Selected connector designs

Pump-rod connectors

This is an ongoing project to compare existing designs for pump-rod connectors which need no tools, and to develop improved designs.

Existing connector designs that were evaluated are:

- Afridev hook-and-eye connector, in mild steel and stainless steel
- Indian forged connector (from Inalsa), in mild steel and stainless steel
- Afridev pin-and-plate connector, in carbon steel and stainless steel
- Aquadev acetal connector (from Mono Pumps)

These were compared by setting up five connectors of each type in a rod string. The test consisted of lifting a weight equivalent to a 45-meter water column, then lowering it to allow the string to collapse slightly. Testing was carried out at 40 cycles per minute, and the target for the test was 10 million cycles. Each rod string was connected to the rig using one of the Afridev hanger connectors. A string failed if three similar or four dissimilar breaks occurred. Results are illustrated in Figure B21.

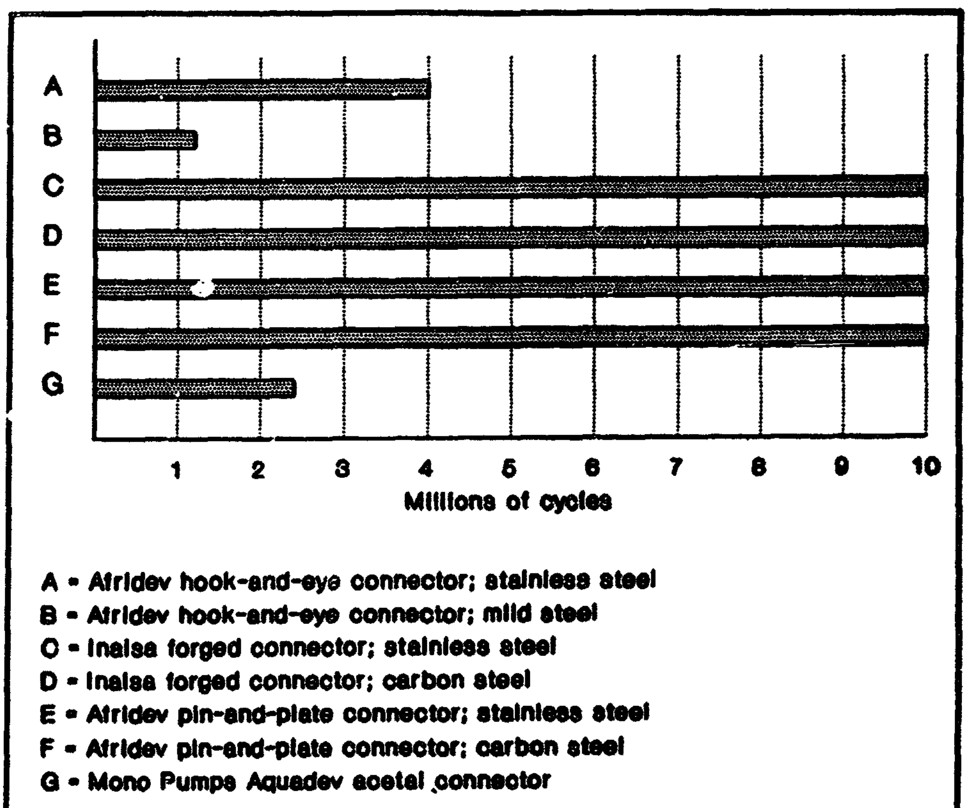


Figure B21. Endurance tests on rod connectors

Afridev hook-and-eye connectors	All the galvanized mild steel connectors failed in less than 1.2 million cycles. Four of the stainless steel connectors failed within 4 million cycles. Most broke at the joint between the hook and the pump rod, probably due to stress concentration induced by welding. A few broke within the bent hook section. CRL has recommended that this connector be modified so that the hook is formed directly from the rod, eliminating the need to weld on the hook.
Inalsa forged connectors	All the test samples completed the allotted 10 million cycles without failure, and with relatively little wear.
Afridev pin-and-plate connectors	Most of the test samples completed the allotted 10 million cycles. Two of the stainless steel connectors failed, one at the joint between the plate and the pump rod, the other at the joint between the pin and the plate.
Aquadev acetal connectors	Four of the samples failed within 2.4 million cycles, due to breakage of the acetal. This connector has subsequently been modified by Mono Pumps.

C. Handpump Research in the Field

Field trials in 17 countries -- nine in Africa, seven in Asia and one in South America -- were coordinated by the UNDP-World Bank Handpumps Project. Over 2,500 installations representing about 70 different pump types were monitored. The field trials were reported in detail in *Community Water Supply: The Handpump Option.*

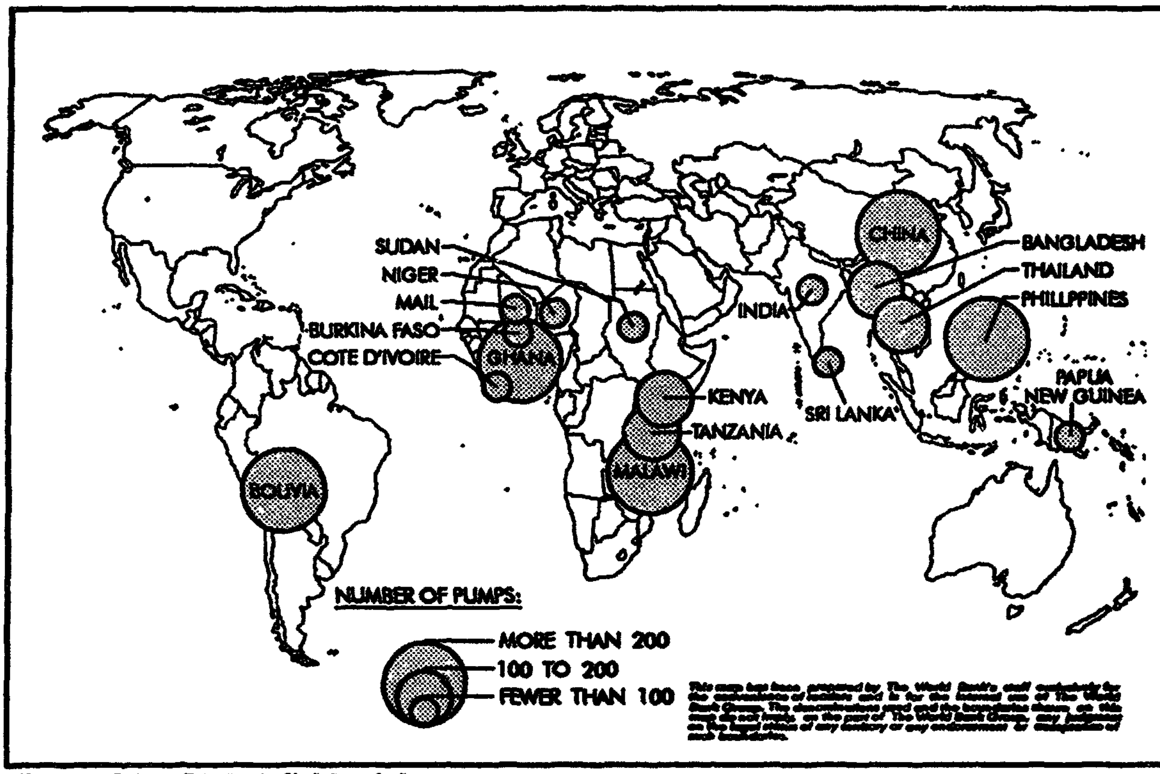


Figure C1. Global field trials

Since 1986, active research on the Afridev, India Mark II, and Tara handpumps has continued in Kenya, India, and Bangladesh.

C1. Kenya -- The Afridev Handpump

The Afridev handpump was developed from the Maldev concept, and was designed from the start with ease of maintenance as a top priority. The initial field experiments with plastic below-ground assemblies and plastic dry bearings were carried out in the Livulese Valley Project in Malawi, using the Maldev pump, and this early experience was used in planning the research into these topics described in Part B of this report.

Production of the Afridev pump began in Kenya in 1985. The main problems encountered with the first pumps were erratic wear of the two-part handle bearings and internal damage to the rising main where the polyethylene pump-rod guides rubbed it. The erratic wear of the handle bearings was not easily explained. Some bearings wore slowly, suggesting potential lives of well over one year; others had to be replaced in a few weeks. A number of experiments were carried out to compare various potential bearing materials and to assess the significance of high temperature and humidity (see Part B). But the most likely causes of high wear rates seemed to be distortion caused by corrosion inside the bearing housings, and the ingress of corrosion products and of wind- and rain-born dust, particularly in the handle fulcrum bearings.

Modifications were introduced in 1987:

- Stainless steel liners were fitted to the housings for the handle and rod hanger bearings .
- The pumphead cover was extended to prevent the ingress of external dust.
- A stainless steel plunger rod was fitted to stabilize the piston in the cylinder.
- The polyethylene rod guides were replaced by nitrile rubber guides.

These modifications were also incorporated in the Afridev Specification published by SKAT in 1987.

Field testing of modified pumps

The pumps were tested in the Kwale Water and Sanitation Project (KWSP), with assistance from the Kenya Water for Health Organisation (KWAHO). Kwale is a coastal area southwest of Mombasa, characterized by high temperatures and high humidity. Aggressive groundwater is common. Nineteen pump installations were monitored, with static water levels ranging from 13 meters to 45 meters and pump settings from 16 meters to 50 meters (Figure C2). All the field trials were carried out while the pumps were providing water to the local communities, and the monitoring procedures were therefore designed to obtain field data with minimum disruption to normal use. The results as they stood at March 1990 are shown in Table C1.

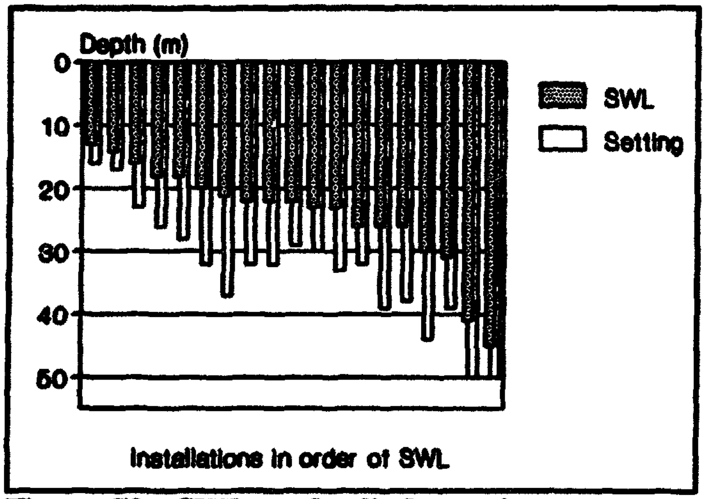


Figure C2. SWLs and cylinder settings

The plastic handle bearings performed well, and in most cases lasted over one year. Fulcrum bearings tended to wear more rapidly than rod hanger bearings: this was expected since the fulcrum bearings carry generally higher loads and have to resist any side loads applied to the handle. The stainless steel bearing housing liners were successful in eliminating corrosion.

The nitrile rubber pump-rod centralizers were a marked improvement over the earlier polyethylene type. Wear was concentrated on the centralizers rather than the rising main.

The uPVC rising mains in the sample were up to four years old. There were no instances of rising mains failing under load, even in rising mains that had been badly worn internally by the polyethylene pump-rod centralizers.

Cylinders performed well. A few footvalve leaks were encountered on early pumps, due to excessive flash on the valve bobbin moldings which was eliminated by improving the molds. The stainless steel plunger rod eliminated instability in earlier cylinders that allowed the piston body to contact the cylinder wall. Piston seals wore relatively slowly, as the results for volumetric efficiency confirm, but a few showed a tendency to stretch or swell after several months of use, and on two pumps the seals rolled off the piston while it was being extracted for maintenance. Wear on the valve bobbins was very low.

Table C1: Afridev Handpumps in KWSP, Kenya

	SWL[a] (m)	Setting (m)	Water pH	Minimum bearing life[b] (months)	Minimum efficiency[c] (%)	Age of rising main (months)
Mrima camp	23	30	7.2	11[F]	85	45
Kigombero 1	45	50	5.8	10[F]	89	39
Kigombero 2	31	39	5.7	21[F]	64	36
Kigombero 3	26	32	5.9	19*	82	33
Milanani 2	13	16	7.7	35[F]	96	35
Mwaebe	14	17	6.7	27*	94	51
Mrima Ndooni 1	18	26	6.4	24[B]	98	21
Perani Primary	20	32	7.0	23[B]	96	26
Msambweni Police	16	23	7.1	27*	97	27
Kivuleni 2	21	37	5.8	15[F]	96	40
Kilulu 1	23	33	7.3	22*	96	32
Mivumoni Primary	22	32	5.3	18[F]	98	33
Ndengwa Primary	26	39	5.3	23[F]	99	26
Mtituni 1	22	32	5.6	n.a.	98	39
Mwachande 3	22	29	6.8	28*	98	29
Nguluku Mwalimu	26	38	6.8	19*	95	19
Nguluku Mwamzandi	41	50	5.8	19[B]	81	19
Vwivwini	18	28	5.6	11[F]	94	33
Mkala Nguluku	30	44	6.7	20[F]	n.a.	22

a Static water level
b F = fulcrum bearing wore out first; H = hanger bearing wore out first; B = both wore out at the same time; * = bearings did not need to be replaced.
c Volumetric efficiency

Corrosion of the galvanized mild steel pump rods was considerable, in some cases after only six months, and tended to be concentrated at the hook-and-eye couplings. In one sample a hook connector broke after being weakened by corrosion. The hot-dip galvanizing on the pumpheads was very effective in resisting corrosion.

The rubber rising main centralizers, fitted to center the rising main in the borehole, showed a tendency to "migrate" along the pipe, in some cases allowing contact between the rising main and the borehole casing.

Maintenance

Throughout the trial, pumps were progressively handed over to their user communities, and by March 1990 all but three of the monitored pumps had been transferred. To follow up the monitoring process, however, a questionnaire was introduced to obtain relevant data when spare parts were purchased from stores. The questionnaire covered the following points:

- why spare parts were being purchased
- which parts were required
- the current condition of the pump being repaired
- whether an attempt had been made to repair the pump before purchasing spare parts
- the extent to which the community was satisfied with the pump

It emerged that communities were generally satisfied with pumps, though there were complaints about unpleasant taste effects caused by corrosion of the mild steel pump rods. There were signs that routine replacement of parts (planned at intervals of one year) was not taking place. Rather, users were tending to carry out maintenance when problems became apparent: when the pump failed to produce water or when it started squeaking, for example. In some cases, spare parts were being replaced unnecessarily because faults had been incorrectly diagnosed. It was also clear that there was a need to decentralize spare-parts distribution, as some users had to travel considerable distances to the existing distribution center.

Recommendations

For the pump:

- Stainless steel pump rods should be used where the groundwater is aggressive. This will increase the cost of the Afridev pump by around 40 percent, but the long-term costs will be lower and the water quality will be improved; moreover, the improvement in the taste of the water will encourage people to use it in preference to traditional water sources.

- Piston seals and valve bobbins wear out in a "fail-safe" mode, but not handle bearings. There is evidence that users cannot be relied on to change the bearings yearly. A visual or audible warning built into the bearings would alert users that the bearings are almost worn out.

- A method of locating the rising main centralizers on the pipe would be beneficial. This should be considered in the ongoing research into detachable rising main connectors (see section B6, page -?-).

For maintenance:

- Further information is needed to confirm early indications that annual maintenance is not performed by users. If it is not, a strategy to ensure that wearing parts will be replaced before the basic structure of the pump is damaged should be developed and incorporated into training procedures.

Other topics

Other topics included in the Kenya field trials were:

- The development of low cost concrete pedestals designed to avoid contamination of the aquifer by the seepage of water around the base of the pump.
- An analysis of user preferences regarding apron design and water point facilities such as basins for washing clothes.
- Field testing of an installation manual and a scheduled maintenance card for the Afridev pump.

C2. India -- The India Mark II and Mark III (VLOM) Handpumps

The India Mark II has an admirable record of community service dating back to the late 1970s. By 1983, more than 800,000 India Mark II pumps had been installed in India; in 1989 the total reached 1.3 million pumps serving an estimated 360 million persons in rural and periurban areas. The basic design predates the VLOM concept, however, and the India Mark II relies heavily on a centralized maintenance regime.

In 1983, the UNDP-World Bank Handpumps Project set up a field testing project in Coimbatore, in southern India, working with the National Drinking Water

Mission of the Government of India, the State Government of Tamil Nadu, UNICEF, and Richardson & Cruddas (1972) Ltd.

The objectives were:

- to make improvements to the India Mark II pump, increase the mean time between failures (MTBF), and simplify maintenance; and

- to document consumption of spare parts and interventions for maintenance and repair.

Coimbatore is characterized by relatively deep water tables and high use of handpumps. Nearly 80 handpumps were included in the project, of which 48 were standard India Mark II pumps and 32 were fitted with experimental components. The range of static water levels recorded when the pumps were installed between 1984 and 1986 (from 4.6 meters to 38 meters) is illustrated in Figure C3, which also shows the cylinder settings (ranging from 21 meters to 49 meters). The populations served by individual pumps varied from 100 to 560. Modifications tested on the pumps included:

- different types of piston seals
- pump rods with different materials and types of coatings
- PVC rising mains with various types of connectors
- PVC cylinders
- the addition of a bottom intake pipe
- the incorporation of a sand trap
- plastic handle bearings
- 50-mm, brass-lined, cast iron cylinders
- pump-rod centralizers
- special tools
- different platform designs

In addition, a VLOM derivative of the Mark II, the India Mark III, was developed. This model uses an open-topped cylinder and 2.5-inch galvanized pipe for the rising main, to enable the piston to be withdrawn for maintenance without extracting the rising main. An intermediate plate was also added to the pump head to give easier access to the below-ground assembly. Other modifications incorporated in the India Mark III include:

- a mechanism to lift the valve guide when the piston is connected to the footvalve for extraction, dumping the column of water when the footvalve is raised a few millimeters
- a conical receiver and *o*-ring seal for the footvalve

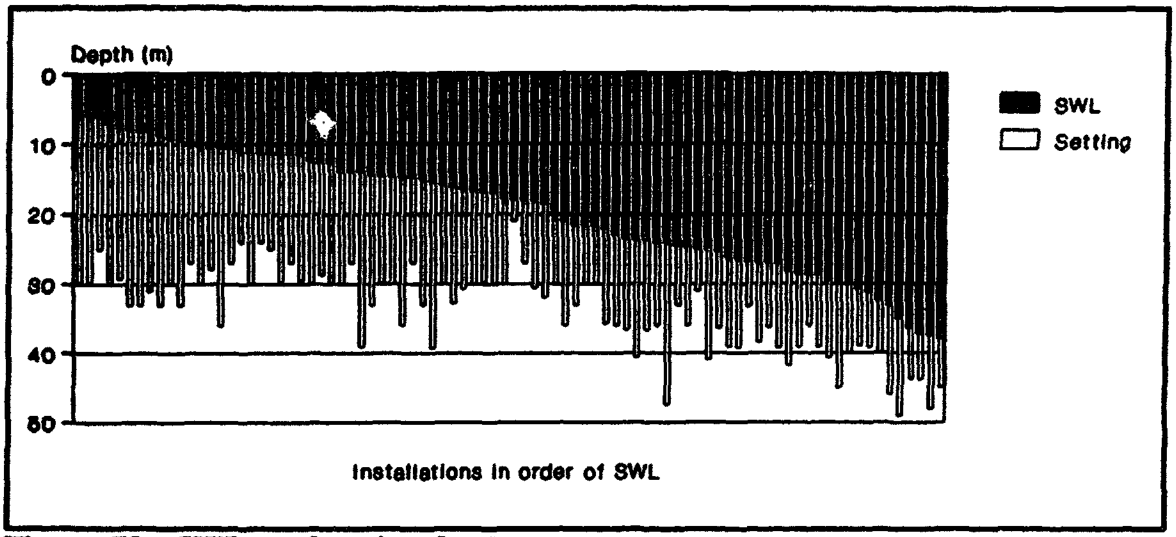


Figure C3. SWLs and setting depths

- nitrile rubber piston seals rather than leather
- a two-piece upper valve, to eliminate failures due to disconnection of the threaded joint, and a two-piece foot valve
- a square rather than round bearing housing on the handle, to increase rigidity and minimize distortion during welding and increase the service life of the bearings
- a deeper water tank, to eliminate splashing during fast pumping
- a reduction in the overall pumpstand height, to reduce banging of the handle on its lower stop

Several of these modifications were also tested on India Mark II pumps.

Comparing the India Mark II and Mark III (VLOM) pumps

On average, repairs to India Mark III pumps took just one third of the time needed to carry out similar repairs to Mark II pumps. The differences are illustrated in Figures C4 and C5. The Mark II pump requires a minimum of four semiskilled workers with a mobile van and special tools to repair the below-ground components. By contrast, a mechanic, carrying all the necessary tools on a motorbike, can extract the piston and footvalve of the Mark III with the assistance of the pump caretaker or another member of the user community. A mobile team is required only for the relatively infrequent replacement of the rising main or cylinder body.

The work of the mobile team was reduced by a factor of 10, and most repair work on the Mark III was shared between mechanics equipped with two-wheelers and local caretakers, as illustrated in Figure C5.

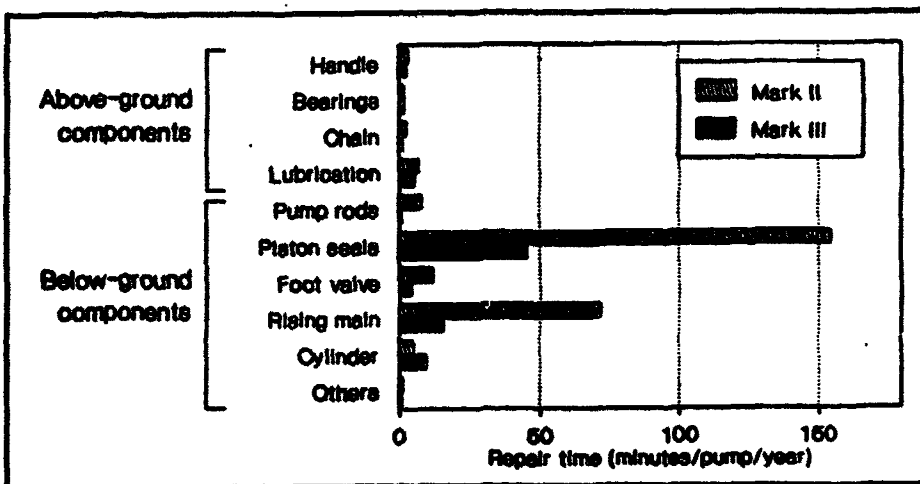


Figure C4. Active repair times, India Mark II and Mark III pumps

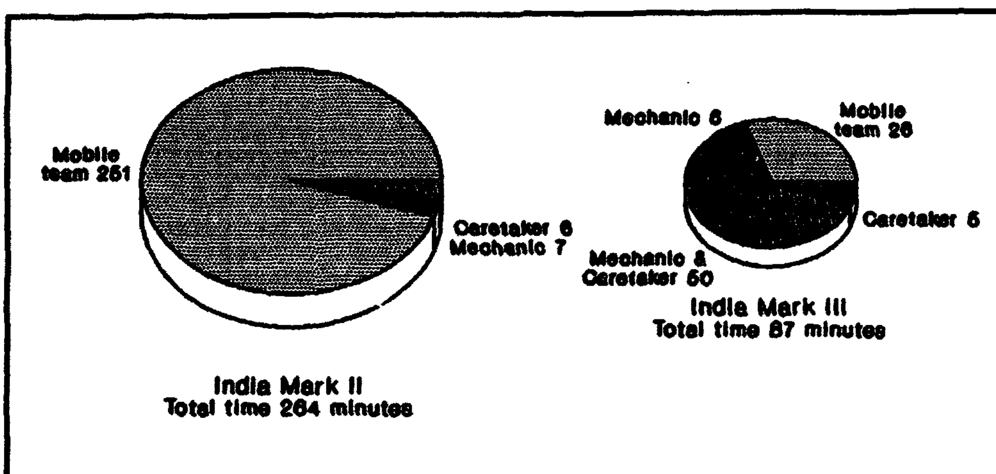


Figure C5. Maintenance regimes, India Mark II and Mark III pumps

The overall reduction in the average annual repair times, from 264 to 87 minutes per pump, arose in part from the relative ease of servicing the piston and footvalve of the Mark III, and also from improvements in reliability.

Figure C6 compares the average numbers of components replaced annually for the two types of pump. Of particular interest are piston seals and rising mains. The numbers of piston seals which had to be replaced in the two types of pump were roughly equal; the reduction in service time was achieved by eliminating the need to extract the rising main to service the piston in the Mark III pump. With the rising main itself, however, there was a marked reduction in the number of components that had to be replaced. The larger-diameter rising main of the Mark III pump reduced abrasion between the pump rods and the inside of the rising main, helping to keep the galvanizing intact and increasing the life of both the rising main and the pump rods. Another factor was that the rising main was less prone to damage from wrenches and clamps, which can cause corrosion, since it did not have to be removed to service the piston or footvalve.

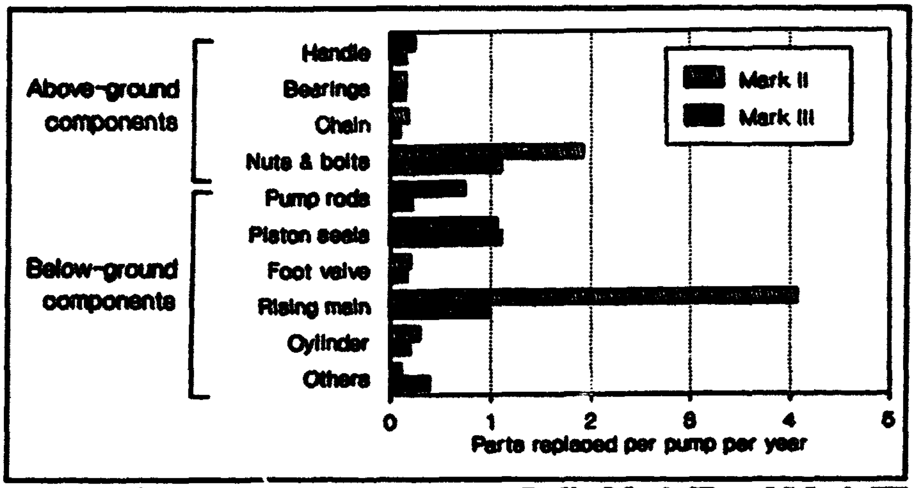


Figure C6. Parts replaced per year , India Mark II and Mark III pumps

Another consideration of this research was to compare the performance of various types of piston seal, particularly leather versus nitrile rubber seals. Of the leather seals tested, vegetable-tanned lasted longer than semichrome- or chrome-tanned seals, but nitrile rubber seals out-performed them all.

The average life expectancy for nitrile seals was in excess of 2.5 years, assuming 25 m depth and seven hours of use per day. With leather piston seals, it has been necessary to replace the brass cylinder liners at internals of four or five years, due to abrasion of the liner from sand particles embedded in the leather. The nitrile seals showed a markedly lower tendency to embed sand particles, however, which is consistent with results obtained both in other field research projects and laboratory tests. It is therefore estimated that, with nitrile seals, the brass liner can be expected to last at least seven to eight years.

The average life of handle bearings was 2.8 years.

Conclusions and recommendations

Minor modifications to existing India Mark II handpumps could improve reliability substantially. The costs of modification would be fully offset by reduced maintenance costs in less than two years.

The design modifications which have been shown to be successful in the Coimbatore project have therefore been incorporated in Indian Standard IS:9301. An Indian Standard for the Mark III handpump has also been published, IS:13056, 1991.

The Mark III design dramatically reduces the dependence on a mobile team for the majority of repairs. A mechanic with a two-wheeler can carry out 90 percent of repairs with assistance from a user or local caretaker. The additional capital cost of the Mark III over the Mark II will be more than offset by the lower maintenance costs in less than three years. It is recommended that a National Standard be prepared for the Mark III handpump.

To make possible greater self-reliance in user communities, research should concentrate on ways to simplify maintenance requirements even further and ways to build capability at village level to carry out maintenance and repairs.

C3. Bangladesh -- The Tara Direct-Action Pump

The Tara is a simple, low-lift, direct-action pump designed for both manufacture and village-level maintenance within the very limited resources available in Bangladesh.

The development of the Tara is fully described in *The Tara Handpump: The Birth of a Star*. Work has included both field trials and laboratory tests, and by the end of 1988 it was estimated that 5,000 Tara handpumps had been installed throughout Bangladesh. The Bangladesh government's Department of Public Health Engineering (DPHE) plans to install up to 60,000 Taras by the end of 1993.

A sample of 148 Tara pumps have been monitored since their installation in the mid-1980s. In addition, UNICEF, DPHE, and the UNDP-World Bank Handpumps Project have extended the monitoring to include up to 2,000 additional pumps. The most significant findings of this research and development effort are summarized below.

- A cheap, effective, and reliable direct-action pump can be produced using standard uPVC pipes for both the rising main and pump rods. Internal pump-rod couplings minimize wear between the pump rods and the inside of the rising main since the assembled pump rod has a smooth surface and a constant diameter.

- The Tara uses standard uPVC pipe as the cylinder, without any special processing. However, cylinder pipes are selected from normal production for good internal finish and minimum variation of wall thickness. The life of a cylinder in the field has been estimated conservatively at 12 years under typical Bangladesh conditions.

- Various piston seals have been tried, including some synthetic materials. For a period, a nitrile seal was used, but the tight tolerances needed for efficient operation were incompatible with the pipes available locally. Leather has the ability to conform to a wider range of cylinder bore sizes, and subsequent attention has therefore centered on optimizing the dimensions and improving quality control of leather seals.

- Simple rubber flap valves, for which spare parts can be cut from old inner tubes, have proved successful. Nylon has replaced aluminum as the material for the piston. The foot valve is made from high-density polyethylene using rudimentary injection molding equipment.

The Tara is a true VLOM pump which enjoys very high user acceptance. It can be installed at low cost and sustained at a cost of about $0.10 per user per year.

D. Laboratory Tests

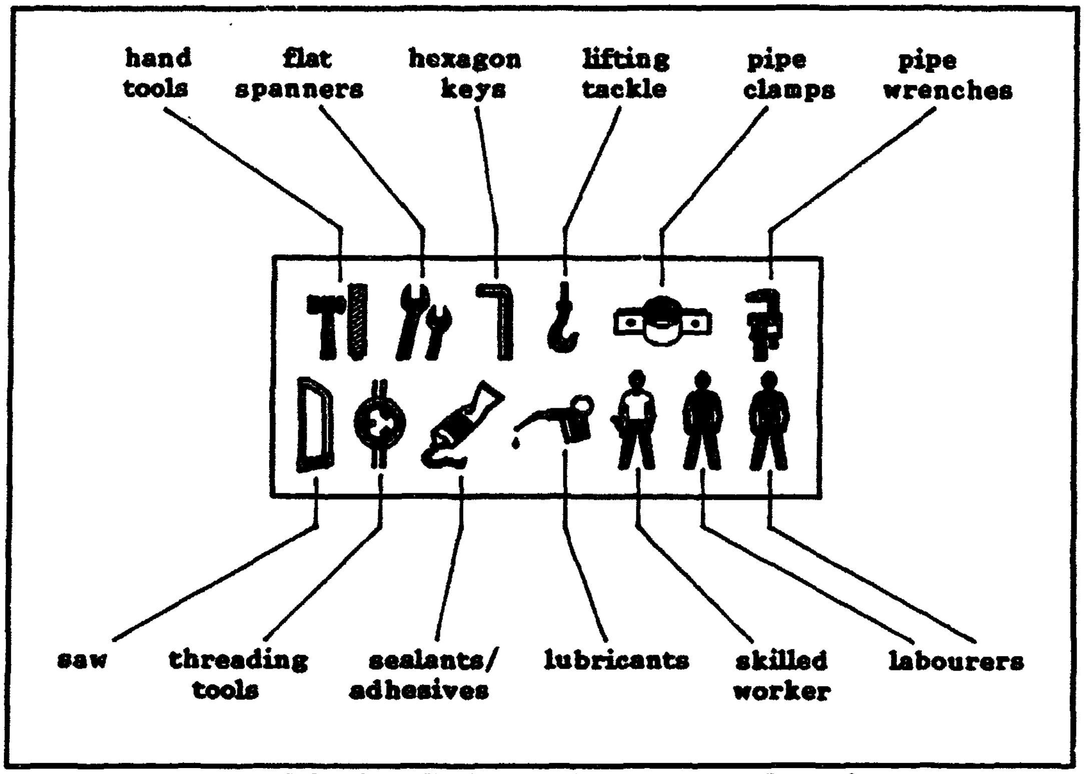
The Consumer Research Laboratory (CRL), based in Harpenden, UK, has been testing handpumps since 1977. These laboratory tests were never intended to be a substitute for testing in the field, but rather to provide reliable and comparative information under controlled laboratory conditions that could be used in conjunction with field data. The results of tests carried out up to and including 1985 have been published in previous World Bank Technical Papers and Applied Research and Technology Notes, and were incorporated in *Community Water Supply: The Handpump Option*.

This report summarizes the laboratory's findings for eleven handpumps tested between 1986 and 1989:

- **Wavin:** a direct-action pump from the Netherlands designed to work at depths of 10 meters to 15 meters
- **India-Mali:** a version from Mali of the well-established India Mark II deep-well handpump
- **Bestobell Micro:** a deep-well handpump from Zambia
- **Abi-ASM:** a hydraulic pump combining a pumpstand manufactured in Côte D'Ivoire and a pumping element made in France; no longer in production. It has been included because of continuing interest in pumps using this principle of operation.
- **Pumpenboese:** a derivative of the India Mark II made in Germany
- **Knebel:** a cable-operated handpump from Denmark designed for depths to 25 meters
- **Aquamont:** a deep-well handpump from the UK
- **Atlas Copco 111:** a deep-well pump employing a stretching rubber hose as the pumping element, from Sweden
- **Atlas Copco 122:** a deep-well handpump combining the pumpstand of the Atlas Copco 111 with a conventional piston and cylinder

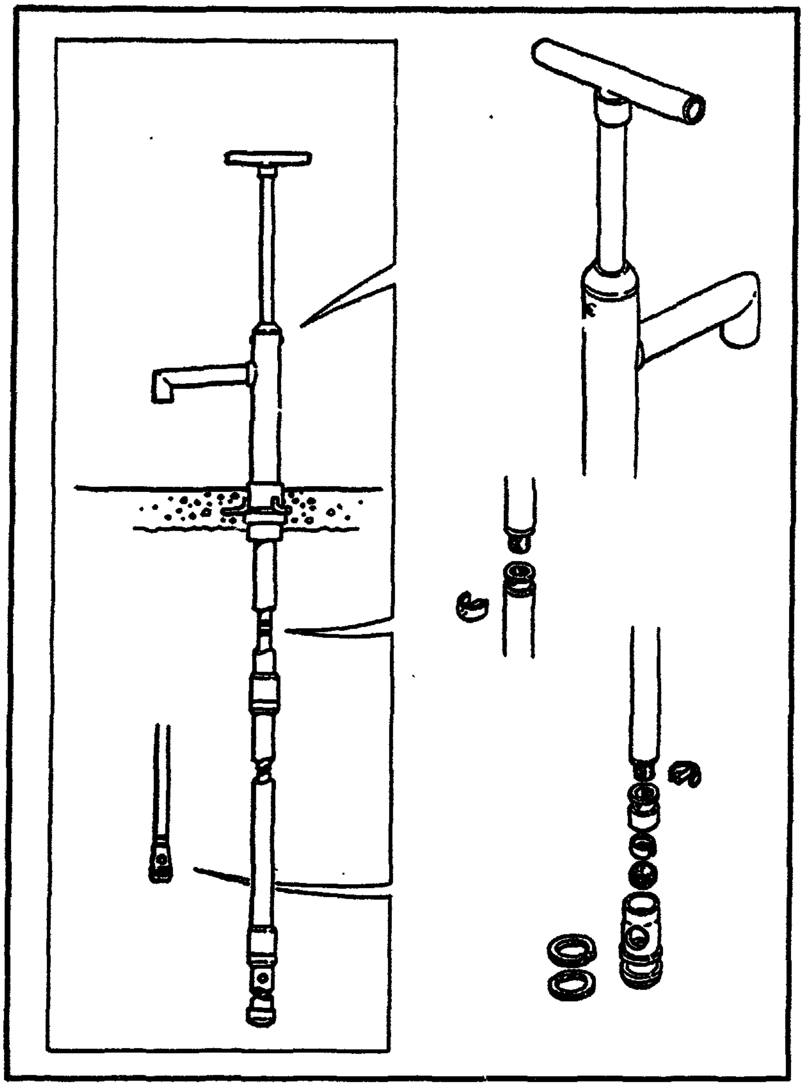
- **Aquadev: the first pump based on the Afridev concept in full-scale production, made by Mono pumps in the UK**
- **Afridev: a deep-well handpump designed with particular stress on ease of maintenance and repair, from Kenya**

All pumps were tested in accordance with procedures developed by CRL in consultation with the UNDP-World Bank Handpumps Project and others. Test procedures are summarized in the Appendix.



Key to symbold used for installation, maintenance, and repair

D1. Wavin handpump



Construction
The Wavin pump used standard uPVC pipe for the rising main and as a lightweight pump rod. The pumpstand and handle were fabricated from steel sections, galvanized, with a polyethylene bush for the emerging pump rod. The piston and footvalve were plastic, with rubber valve balls. The piston seal was ramie cord. Spare cord and valve balls were supplied attached to the dip tube, the intention being that in the event of failure spares would be readily available when the pump was removed from the borehole. The piston acted directly on the bore of the rising main: there was no separate cylinder. The sections of the pump rod and rising main were joined using threaded connectors epoxy-cemented to the pipe.

The test sample was taken from an initial production batch of pumps. Results obtained from initial inspection, design assessment and performance tests were used to refine the design before embarking on the endurance test.

The Wavin is a direct-action pump intended to operate at water depths between 10 meters and 15 meters. It was designed to be easy to manufacture, operate, and maintain. It was tested in 1986; the CRL reference is A9113.

Manufacturer	Wavin Overseas b.v. P O Box 158, 7700 AD Dedemsvaart, Netherlands
Price (October 1990)	Complete for installation at 25 m depth (the maximum design depth), in lots of 50: $530 each

Weights

Pumpstand:	7.3 kg	Rising main, per meter:	0.6 kg
Cylinder assembly:	1.4 kg	Pump rod, per meter:	0.2 kg

Dimensions

Maximum handle height:	1,365 mm	Nominal cylinder bore:	45.2 mm
Minimum handle height:	585 mm	Maximum stroke :	785 mm
Spout height:	325 mm	Maximum diameter of below-ground assembly:	59 mm

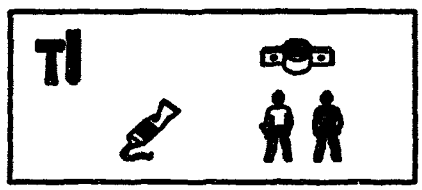
Manufacturing

Above-ground assembly:	Steel fabrication, basic machining, galvanizing
Below-ground assembly:	uPVC extrusion and fabrication, basic machining, rubber molding

Good quality control is essential to make satisfactory joints for both the rising main and the pump rod, but in general the pump is potentially suitable for manufacture in developing countries with established pipe extrusion capabilities.

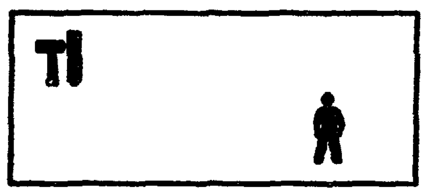
Installation and major repairs

The lightness and simplicity of the pump make it easy to install or extract, with no need for special tools or lifting tackle. Some care was needed to avoid damage to the uPVC pipe and joints.



Routine maintenance

Very straightforward. Maintenance of the pumpstand is limited to replacement of the top bush, an easy task. The piston can be extracted through the rising main by simply removing the top bush in the pumpstand.



Installation and maintenance information

An installation and maintenance manual was provided, in English. It was well illustrated and included details of the construction of a suitable wellhead apron and comprehensive instructions for installation and maintenance of all below-ground parts. The latter included various means of renewing the portion of the rising main used as the cylinder, to compensate for wear.

Resistance to contamination

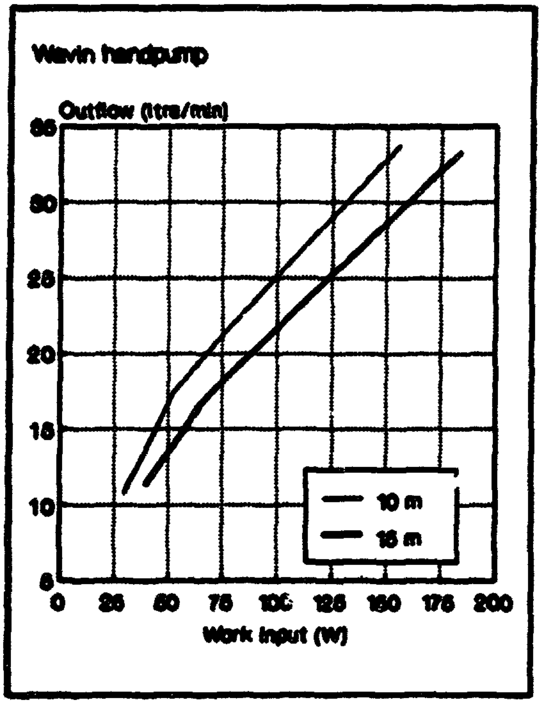
Generally good; the spout could be easily modified to prevent fecal contamination, if required.

Resistance to abuse

The handle may be susceptible to impact since it tends to rise to its uppermost position as a result of the buoyancy of the pump rods.

Pump performance

The ramie cord piston seal tended to be stiff, but after bedding-in for 24 hours, the work required to achieve a given outflow was reduced by approximately 30 percent.



In the course of the endurance test, a number of modifications were made to the pump in consultation with the manufacturer. The results of the test of pump performance after endurance are therefore not strictly comparable with those for the new pump. Since the pump after endurance is more representative of the final design, the results after endurance are illustrated. The pump produced water at a rate of 18 liters per minute for a work input of 75 watts, from a depth of 15 meters. The efficiency was distinctly better at lower operating speeds, the best result being 70 percent for 20 cycles per minute at 15 meters depth.

Endurance

The pump did not break during the endurance test. However, the pump seized several times when particles of uPVC lodged between the piston seal and the cylinder. In the first failure the uPVC debris appeared to have been caused by sharp edges on the piston body rubbing against the cylinder bore. In consultation with the manufacturer, the piston body was modified, and the problem with this apparent cause did not recur.

Test record (failures set in Italic type)

Hours:				
	754	2,000	*3,772*	4,014
Start	*Pump very stiff to operate; excessive uPVC debris in outflow*	Inspection	*Piston siezed in cylinder*	*Piston siezed in cylinder* Final inspection

During the second phase of the test, when sand and Kieselguhr had been added to the water, the pump seized a second time. Once again, particles of uPVC debris were packed around the piston seal. However, in this case the debris had not resulted from contact between the piston body and the cylinder, but seemed to have been generated by the pump rods rubbing against the rising main. In consultation with the manufacturer, a filter was added. The pump seized again, however, and the test was stopped at this point.

The final inspection confirmed that the debris had originated from contact between the pump rod and rising main in the first 2 meters or so of below-ground assembly beneath the pumpstand.

Abuse tests
The pumpstand body was undamaged by side impacts. Because of the tendency of the handle to rise while unattended, a side impact test was carried out on the protruding handle. The handle was slightly bent by lateral impacts but could be straightened by hand and continued to be serviceable.

The handle was tested by repeatedly banging against its lower stop, from which it emerged undamaged. A similar test of the upper limit of handle movement was not carried out, since it would be most unlikely that the handle would ever strike the upper stop in actual use.

Verdict
The Wavin pump incorporated some interesting innovations, principally the use of epoxy cement for joints in uPVC pipes and of ramie cord as a piston seal. The pump completed the endurance test with no failures in the rods or rising main. The ramie cord appeared to be a durable seal, but it was susceptible to contamination by debris, resulting in seizure of the piston.

If the pump's durability can be improved, it has the potential to be easy to operate, install, maintain, and repair, and therefore to satisfy the requirements for village level operation and maintenance in developing countries. Some developing countries would also have the capability of manufacturing the pump.

Further information

A number of modifications have been introduced following the CRL tests:

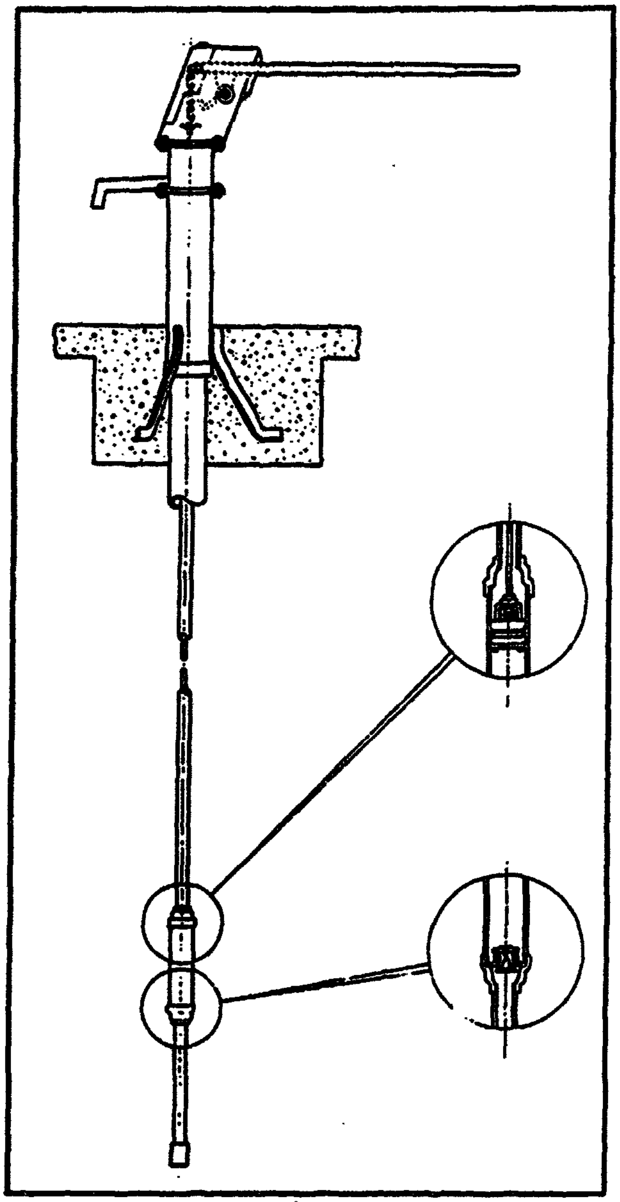
Piston and footvalve. These are still based on similar components, but are no longer identical. The footvalve has a rubber sealing ring, in contrast to the rameh cord rings on the piston.

Pump-rod guides. The collars on the pump-rod connectors have been modified to act as spacers or guides between the pump rod and the inside of the rising main. These are molded in polyacetal and are fitted at every pump-rod coupling at 2.5-meter intervals.

Handle. The polyethylene buffer block beneath the handle tee-bar has been replaced by a steel plate. The connector by which the handle is attached to the pump rod is now molded in polyacetal rather than PVC.

In addition to these modifications, an alternative pumpstand, made of cast iron and galvanized, is now available.

D2. India-Mali Handpump



Construction
The India-Mali followed closely the established India Mark II design. The pumpstand was fabricated from steel, with a chain and quadrant linking the handle to the top of the pump rod. The handle fulcrum bearings were proprietary ball races.

The pump was supplied with cylinders of 68 mm, 80 mm and 105 mm diameter, to suit both the depths and the required rates of delivery for different installations. The 105-mm cylinder was intended for use at a maximum depth of 20 meters. Cylinders of all three sizes were similar in construction, with barrels of stainless steel pipe and cast iron end caps. The pistons and footvalves were cast gunmetal, and the pistons were fitted with leather cup washers.

The pump was designed to use galvanized steel rising main of 1.25-inch nominal bore. The size of the pump rod should be chosen to suit the depth at which the pump is to be used.

The India-Mali is a version of the familiar India Mk II deep-well handpump, made in Mali and intended for use at depths between 7 and 45 meters. The pump was tested in 1986; the CRL reference is A9123.

Manufacturer	**Emama-Sikasso** **B.P. 68, Sikasso, Mali**
Price (November 1990)	**Complete for installation at 30 meters depth, in lots of 50: price per pump, $685 with galvanized pump rods and rising main; $1,385 with stainless steel pump rods and rising main.**

Weights

Pumpstand assembly:	41.7 kg	Rising main per meter:	2.9 kg
Cylinder assembly:	7.3 kg (not supplied)		

Dimensions

Maximum handle height	1,117 mm	Cylinder bore:	68	80	105 mm
Minimum handle height:	420 mm	Maximum stroke:	100	100	100 mm
Handle length:	1,055 mm	Volume per cycle:	363	503	866 ml
Angular movement:	42 deg	Maximum diameter			
Handle ratio:	7.7 : 1	of below-ground			
Spout height:	445 mm	assembly:	100	110	115 mm

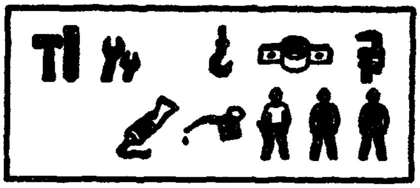
Manufacturing

Above-ground assembly:	Steel fabrication, general machining
Below-ground assembly:	Iron and gunmetal foundry, general machining, galvanizing, leather craft

The pump is suitable for manufacture in many developing countries, although those without established foundry facilities would have to find another way to produce the piston, footvalve, and cylinder end caps. Rigorous quality control is essential, particularly to ensure that the handle bearing housings are accurately machined and properly aligned, and to provide an adequate internal finish on the cylinder barrel.

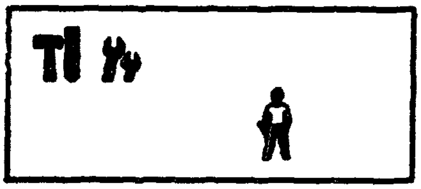
Installation and major repairs

Lifting tackle will be essential unless plastic rather than galvanized steel rising main can be used. In other respects both installation and extraction should be straightforward.



Routine maintenance

A single 19-mm spanner will fit all the fastenings in the pumpstand. Replacing the handle fulcrum bearings requires a high degree of skill and understanding to ensure that the new bearings are not damaged.



Installation and maintenance information

The test samples were supplied with no information on installation, maintenance, or repair. Without this information, installation and maintenance in the field could be carried out only by well-trained, experienced personnel.

Resistance to contamination

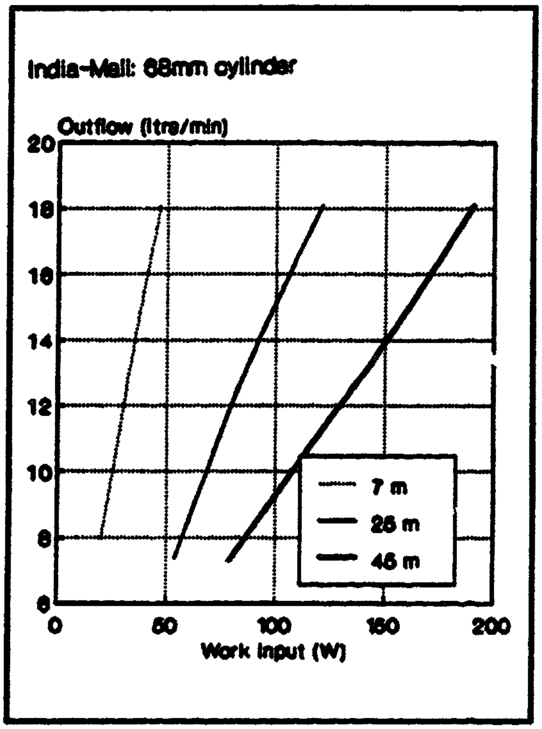
Good. It would be difficult to push sticks and stones into the spout. The design of the pumpstand allows for the well casing to protrude above ground level, ensuring that the well will not be contaminated by surface water.

Resistance to abuse

Good. The pumpstand body was generally robust. However, the short handle stroke may mean that users will be more likely to bang the handle on its stops at the ends of the stroke, which may damage the pump in the longer term.

Pump performance

The pump was tested with each of the cylinder sizes supplied. The results illustrated (right) are for the 63-mm cylinder used for the endurance test.



With the 68-mm cylinder, the pump was capable of providing water at approximately 9 liters per minute from a depth of 45 meters, for an input of 100 watts. The efficiency varied from 45 percent at 7 meters to approximately 68 percent at 45 meters depth.

Similar results were obtained after the endurance test. The rate of delivery was maintained, and in most cases the required work inputs were slightly lower, suggesting a small reduction in friction.

Leakage

Insignificant for the 68-mm cylinder, at all depths tested. For the 80-mm and 105-mm cylinders, some leakage was observed around grub screws in the lower cylinder end caps, though there was no leakage from the footvalves themselves.

Endurance

Test record

Hours:	2,081	4,123
Start	Inspection and volume check	Final inspection and full performance test

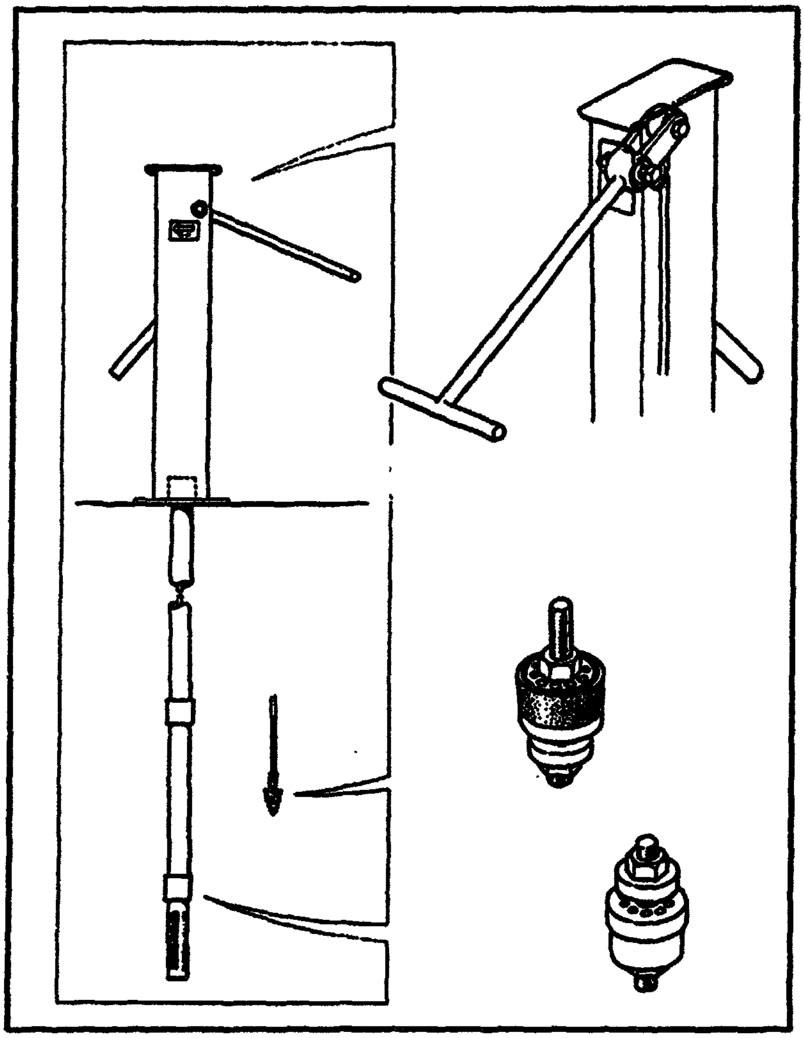
The pump completed the endurance test with no failures. In the final inspection, a good deal of wear was evident in the pumpstand. The handle bearings were in good condition, but the rod guide was badly worn, and there was wear of the chain and the pumpstand body where the handle rubbed on it as a result of misalignment of the pivot holes during manufacture.

Below ground, there was a good deal of corrosion, particularly at the joint between the piston and the pump rod. The cylinder bore was polished but only lightly scored, and the cup seals were found to be still serviceable. The footvalve seal was worn but still serviceable.

Abuse tests
The pump was undamaged by side impacts on the body and by lateral impacts on the handle, and no damage resulted from repeatedly banging the handle against its stops.

Verdict
A strong, generously proportioned design, of which this derivative manufactured in Mali proved to be sturdy and reliable. However, its potential for application is limited by serious drawbacks in manufacturing and maintenance. Manufacture requires relatively well- developed industrial and engineering skills. Maintenance also demands a high degree of skill, and lifting tackle is required unless a plastic rising main can be used. The requirements for both manufacturing and maintenance could be eased by appropriate modifications.

D3. Bestobell Micro Handpump



Construction

The pumpstand and *t*-shaped handle were fabricated from steel. The handle bearings were proprietary open-ball races. A single spanner fits all the fastenings in the pumpstand.

The manufacturer envisaged that the rising main and pump rods would normally be purchased locally, and these were not supplied. The pump was designed to use uPVC rising main, and provided that pipe of sufficient diameter (at least 2 inches) is used, the piston can be withdrawn for maintenance or repair without removing the rising main from the well. However, it is still necessary to extract the entire below-ground assembly to gain access to the footvalve. The pump was designed for 12-mm steel rods with threaded connectors.

The cylinder is a length of heavy-duty, 2-inch uPVC pipe. The piston and footvalve are also uPVC. The initial piston seals were leather, but these were replaced by a molded rubber seals during the test.

The Bestobell Micro is a deep-well force pump designed for a maximum depth of 60 meters. The test samples were manufactured in Zambia, and the pump was tested in 1986; the CRL reference is A9170.

Manufacturer	**Bestobell Zambia Limited** **875 Zambia Road, P O Box 230003, Ndola, Zambia**
Price (November 1990)	**Complete for installation at 30 m depth, in lots of 50: $365 per pump.**

Weights

Pumpstand assembly:	20.8 kg
Cylinder assembly:	3.8 kg

Dimensions

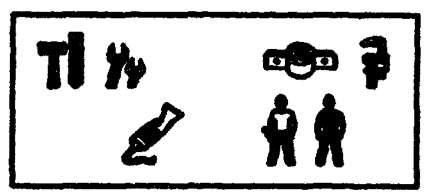
Maximum handle height:	1,350 mm	Nominal cylinder bore:	48 mm
Minimum handle height:	550 mm	Maximum stroke:	152 mm
Handle length:	520 mm	Nominal volume per cycle:	275 ml
Angular movement:	100 deg	Maximum diameter of below-ground components:	75 mm
Handle ratio:	6 : 1		
Spout height:	470 mm		

Manufacturing

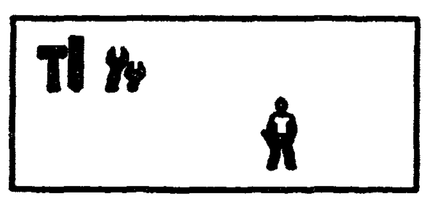
Above-ground assembly:	Steel fabrication, general machining
Below-ground assembly:	General machining, screwcutting, rubber molding

Manufacture of the pumpstand could be undertaken in many developing countries. Below ground, the piston and footvalve could be injection molded or extruded for volume production. The cylinder assembly is potentially suitable for manufacture in some developing countries, though care will be needed in cutting the screw threads in the cylinder barrel.

Installation and major repairs
Lifting tackle would not be required if uPVC rising main were used. If rising main of at least 2-inch diameter is used, the piston can be withdrawn for maintenance without extracting the rising main.



Routine maintenance
Only one spanner is required for all the fastenings in the pumpstand. Care is required in replacing handle bearings.

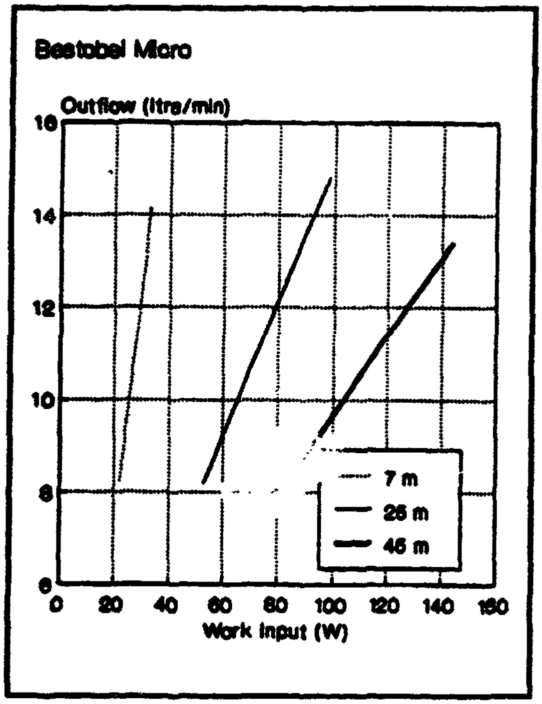


Installation and maintenance information
Instructions in English were supplied with the pumps. They were comprehensive and useful, though a presentation relying more on illustrations than text would be an advantage.

Resistance to contamination
Poor. Care is needed to provide an adequate seal at the base to ensure that the well is not contaminated by surface water. It would be easy to push sticks and stones into the spout.

Resistance to abuse
Although the pump was, in general, fairly robust, the handle fulcrum and the pumpstand baseplate are susceptible to damage from persistent abuse or severe impacts.

Pump performance
The pump was tested with both the original leather seals and with a molded rubber seal fitted midway through the endurance test when the original piston failed (see Endurance, below). Substantially better results were obtained from the rubber seal, and these are shown in the diagram. When new, the pump provided water at approximately 9.5 liters per minute from a depth of 45 meters, for an input of 100 watts. The efficiency varied from around 45 percent at 7 meters to over 70 percent at 45 meters depth.



At the end of the endurance test, the performance of the pump at 7 and 25 meters depth had deteriorated slightly but had improved at 45 meters depth, with a typical efficiency of 75 percent.

Leakage
Insignificant at all depths tested.

Endurance (failures are shown in italics) (wordgraff)

No failures were apparent in the first 2,000 hour stage of the test, using clean water. However, when the cylinder was dismantled for inspection, the piston body was found to have broken between the two leather seals. The piston was replaced by a piston of the same design. The pump failed again after 47 hours of the second phase of the test, when sand and Kieselguhr were added to the water. Sand embedded in the leather seals caused severe wear to the cylinder bore.

Test record (failures set in Italic type)

Hours:	*2,138*	*2,185*	*2,425*	4,257
Start	Inspection and volume flow check *Piston broken and one seal missing*	*Severe wear of cylinder and footvalve leaking due to contamination by sand; new piston and Socla footvalve fitted*	*Bearings collapsed at connection of handles to top of pump rod*	Final inspection and pump performance test

After discussion with the manufacturer, a new piston was made using a rubber seal provided by Bestobell, and the footvalve was replaced with a proprietary "Socla" valve. This new piston and footvalve completed the test and were in good working order at final inspection.

Considerable wear was observed in the inspection after 2,000 hours in the diecast zinc alloy bearings at the connection between the handle and the top of the pump rod. After 2,425 hours, the bearings collapsed. The second test sample was supplied with ball races at this point. They were fitted for the remainder of the test and were in good condition at final inspection.

Abuse tests

The handle was not damaged by side impacts, but a heavy impact on the pumpstand body produced distortion of the baseplate and a crack in one of the welds. When the handle was repeatedly banged against its stops, the fulcrum bracket fractured at the weld to the body of the pumpstand after 32,666 cycles.

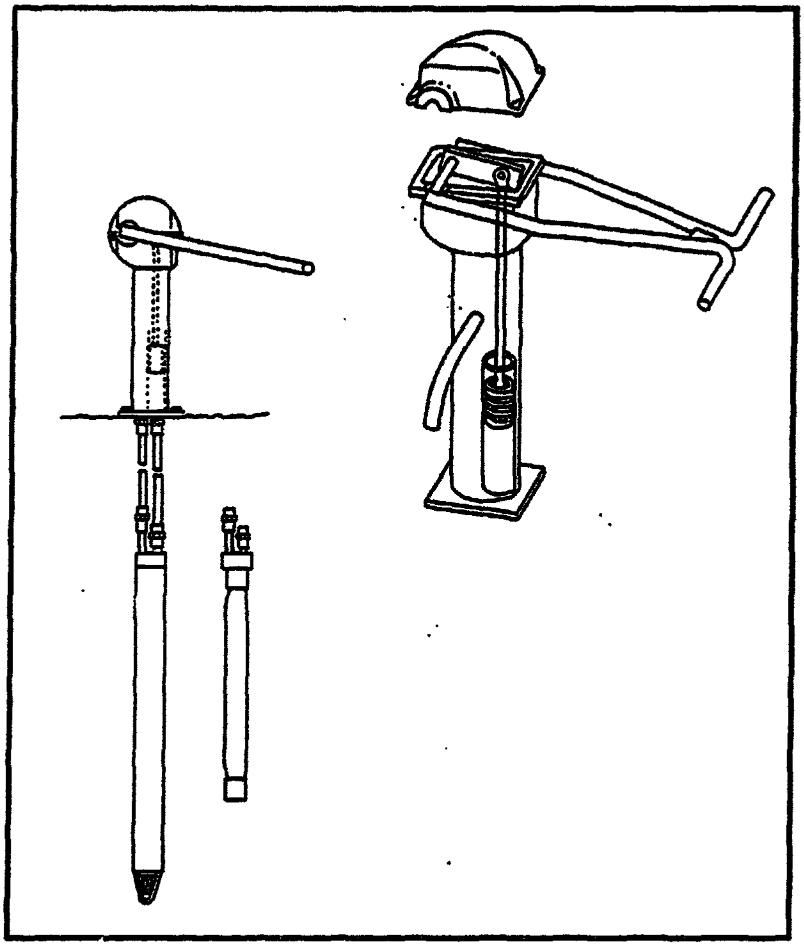
Verdict

A design with good potential for manufacture, maintenance, and repair in developing countries, but it requires considerable additional development before it could be considered for large-scale application.

Additional information

The manufacturer has subsequently strengthened the pumpstand, and the baseplate is now made from a single piece of steel.

D4. ABI-ASM Handpump



Construction
The ABI-ASM is a hybrid handpump working on hydraulic principles. Two polyethylene hoses are the only connections between the pumpstand and cylinder assemblies.

The pumpstand is part cast iron and part fabricated steel. The main handle bearings are molded nylon, with a proprietary spherical plain bearing at the connection between the handle and the piston rod. The primary cylinder inside the pumpstand is drawn brass tube brazed to a cast gunmetal baseplate; the piston is also gunmetal, fitted with three leather ring seals. By lifting the handle fully, the primary cylinder is automatically replenished from the delivery water.

Below ground, the motion of the primary piston is transmitted via a polyethylene command hose to a flexible rubber tube encased in a stainless steel vessel. The alternating dilation and contraction of the rubber membrane pumps water to the surface via a polyethylene rising main.

The ABI-ASM consists of an above-ground assembly manufactured in Côte d'Ivoire and a cylinder assembly manufactured in France. An earlier version of the pump was tested in 1983/84, and the results published in UNDP Project Management Report No. 3 (World Bank Technical Paper No.19). A number of modifications to the pump were implemented subsequently, both above and below ground, and this second test was carried out in 1986; the CRL reference is A9127.

Production of the pump ceased while the laboratory test was under way, and the testing was stopped at that point. CRL's report does not therefore contain results for the user trial, abuse tests, or some parts of the engineering assessment.

Manufacturer	Groupement Abidjan Industrie Z.I. de Vridi, 01 BP 343 Abidjan 01, Côte d'Ivoire

Weights

Pumpstand assembly:	62.5 kg
Cylinder assembly:	9.4 kg

Dimensions

Maximum handle height:	1,075 mm	Primary cylinder bore:	60 mm
Minimum handle height:	155 mm	Maximum stroke:	120 mm
Handle length:	750 mm	Nominal volume per cycle:	340 ml
Angular movement:	80 deg	Maximum diameter of below-ground assembly:	91 mm
Handle ratio:	8.7 : 1		
Spout height:	390 mm		

Installation, maintenance, and repair were not assessed.

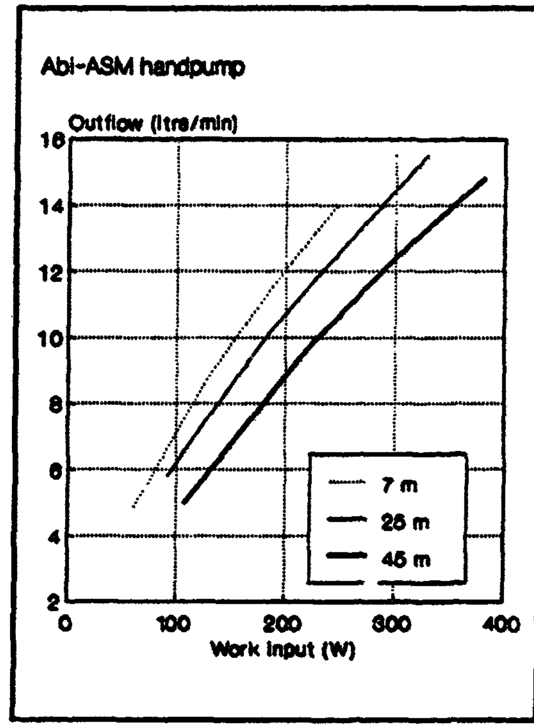
Installation and maintenance information
A manual, handwritten in French, covered both installation and maintenance of the pump. It was clear and neat, though a presentation relying more on illustrations than on text would be more appropriate for use in developing countries.

Resistance to contamination and abuse were not assessed.

Pump performance

The pump required relatively high levels of work input to achieve even modest outflows, at all depths. For a depth of 45 meters, an input of 100 watts produced a flow of less than 5 liters per minute. Efficiency varied from less than 10 percent at 7 meters to around 32 percent at 45 meters depth.

The cause of the high operating effort was thought to be excessive friction in the primary piston. Experience with other pumps of this type suggests that this friction would decrease as the pump "bedded in" with use.



Endurance (failures set in Italics)

Test record

Hours:	*139*	*338*	*481*	*984*	*1,633*	2,007
Start	*Handle bearings worn out*	*Primary piston seal worn out*	*Handle bearings worn out; journals polished* / *Primary piston seal worn out*	*Piston hanger bearing badly worn; replaced*	*Piston hanger spigot sheared off*	Inspection and volume flow check / *Pumping element split*

The handle journals were supplied in a poor condition. They were pitted with rust and covered with a patchy coating of paint, and their poor surface led to premature failure. After cleaning and polishing in the workshop, the second set of bearings lasted substantially longer, although wear rates were still comparatively high.

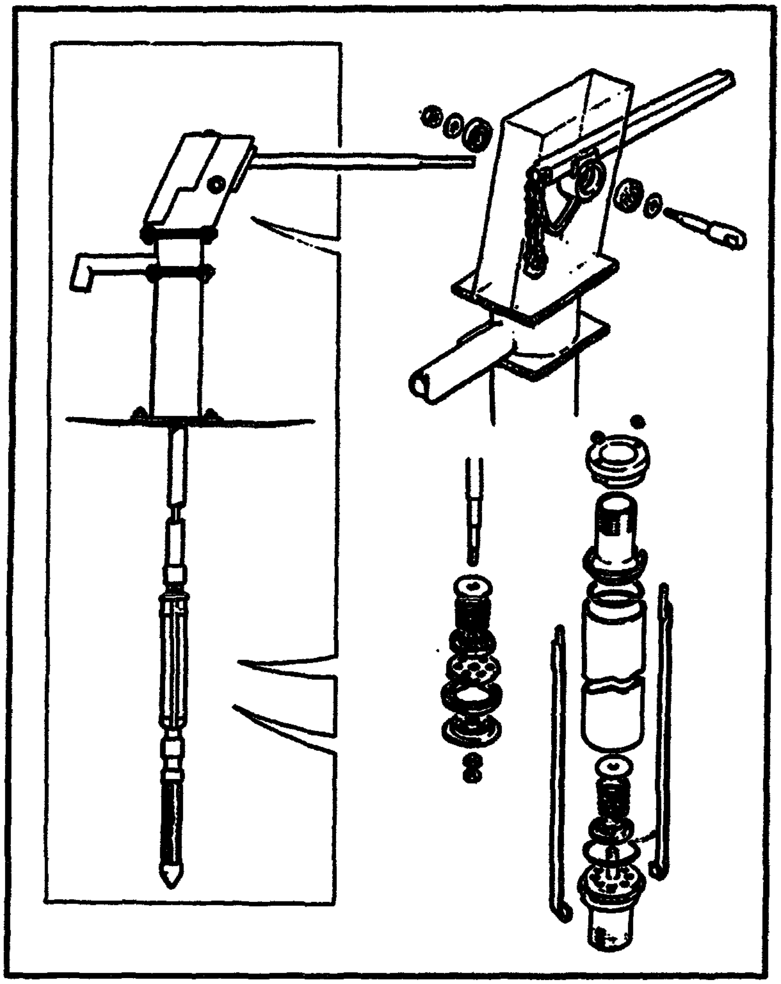
Premature failure of the piston seals was caused by a sharp edge on the replenishing hole in the side of the primary cylinder.

The piston hanger bearing wore rapidly and had to be replaced. This was an inappropriate application for a plain spherical bearing because of the high loads being applied while the bearing was rotating.

The spigot carrying the piston was poorly fitted in the handle, with clearance of approximately 0.1 mm. The forces were therefore taken by the end weld. The weld was of poor quality and not to the full depth.
After 2,000 hours, the rate of outflow from the pump was greatly reduced: the pumping element was found to be split. The endurance test was discontinued at this stage.

Verdict
Interest persists in pumps working on this principle because the connection between the above- and below-ground parts is simply a pair of flexible hoses, which makes the pumps potentially very easy to install and maintain. However, the pumping element is a specialized item that would have to be imported, and as this example showed, sound design and good quality control will be essential if a suitable pumpstand is to be manufactured in a developing country.

D5. Pumpenboese PB-Mk II Handpump



Construction
The pb-Mk II retained all the essential features of the India Mark II in the above-ground parts, including the galvanized steel pumpstand, the proprietary ball-race handle bearings, and the chain and quadrant. The cylinder was not of the type normally found on the India Mk II, however. The sample had a stainless steel cylinder barrel of nominal internal diameter 63 mm, with end caps also made of stainless steel, sealed to the barrel by rubber *o*-rings and held in place by two stainless steel straps. The piston was also stainless steel, with rubber valves and seals. Rising main and pump rods were available in either galvanized or stainless steel. At time of testing, manufacturers were also working on a polyethylene rising main.

The Pumpenboese pb-Mk II deep-well handpump is a derivative of the well-established India Mark II design, and is intended for use at depths between 15 meters and 50 meters. The test samples were made in Germany, and the pump was tested in 1987; the CRL reference is A9101.

Price (October 1990)	Complete for installation at meters, in lots of 50: with galvanized rods and rising main, $759; with stainless steel rods and rising main, $1,390.

Manufacturer	Pumpenboese KG Raiffeisen Str 2, D-3006 Burgwedel 1, PO Box 1250 Germany

Weights

Pumpstand assembly:	48.2 kg	Rising main, per meter:	3.2 kg
Cylinder assembly:	3.3 kg	Pump rod, per meter:	0.9 kg

Dimensions

Maximum handle height:	1,190 mm	Nominal cylinder bore:	63 mm
Minimum handle height:	415 mm	Maximum stroke:	104 mm
Handle length:	1,175 mm	Nominal volume/cycle:	324 ml
Angular movement:	44 deg	Maximum diameter of below-ground components:	73 mm
Handle ratio:	7.7 : 1		
Spout height:	455 mm		

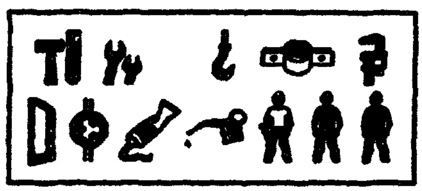
Manufacturing

Above-ground assembly:	Steel fabrication, machining, galvanizing, electroplating
Below-ground assembly:	Pressing, rolling, drawing and general fabrication of stainless steel, rubber molding

The manufacture of the cylinder requires sophisticated facilities and rigorous quality control, and has little potential for manufacture in developing countries. Some developing countries may have sufficiently developed industrial resources to make the pumpstand, though care must be taken with the dimensional accuracy of the bearing housings, spindle and the locating holes in the pump head.

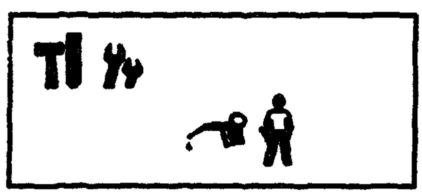
Installation and major repairs

The below-ground assembly is heavy, and lifting tackle will be required in deep settings, for both installation and below-ground repairs. The design is not suited to village-level maintenance.



Routine maintenance

Replacing the handle bearings requires a high degree of skill to ensure that the new bearings and the spindle are not damaged. All the fastenings on the pumpstand can be removed using 17-mm and 19-mm spanners.

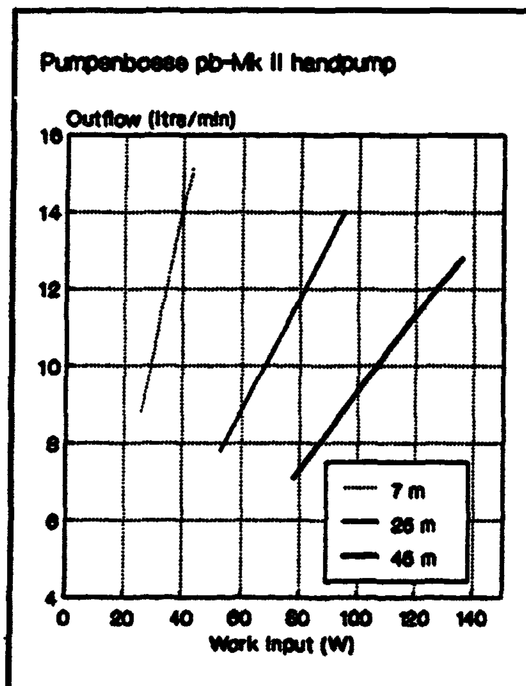


Installation and maintenance information
A manual was supplied for each test sample dealing with installation and maintenance. The installation instructions were comprehensive and well illustrated but could be confusing. There was no clear division or heading for the methods of installing each type of rising main. A quick-reference fold-out page was provided for pump part numbering and a list of tools with codes used in the text. Instructions for maintenance were limited to an engineering diagram of the cylinder and instructions for disassembly of the pump cylinder.

Resistance to contamination
Fair. It would be difficult to insert sticks and stones into the spout, but the design of the spout allowed it to be easily blocked, with a consequent risk of contamination. The retaining bolts for the inspection hatch are easily pilfered which could give direct access to the well and lead to possible pollution.

Resistance to abuse
Fair. The pumpstand is generally sturdy, in spite of some departures from the Indian Standard. None of the fastenings on the pumpstand were pilfer resistant.

Pump performance
When new, the pump was capable of providing water at a rate of approximately 9.5 liters per minute from a depth of 45 meters (see illustration, right). The efficiency varied from about 40 percent at 7 meters to approximately 67 percent at 45 meters depth.



In the endurance test, the outflow from the pump was reduced markedly when the strainer clogged with contaminants suspended in the water. When the strainer was removed, however, the pump provided more water than in the original performance tests, with a consequent improvement in efficiency. Considerable ovality had been noted in the cylinder at the start of the test, and at the end it was noticeable that this had resulted in uneven wear of piston the seal.

Leakage
Insignificant at all depths tested.

Endurance

Test record

Hours:	2,105	4,106
Start	Inspection and volume check	Final inspection and full performance test

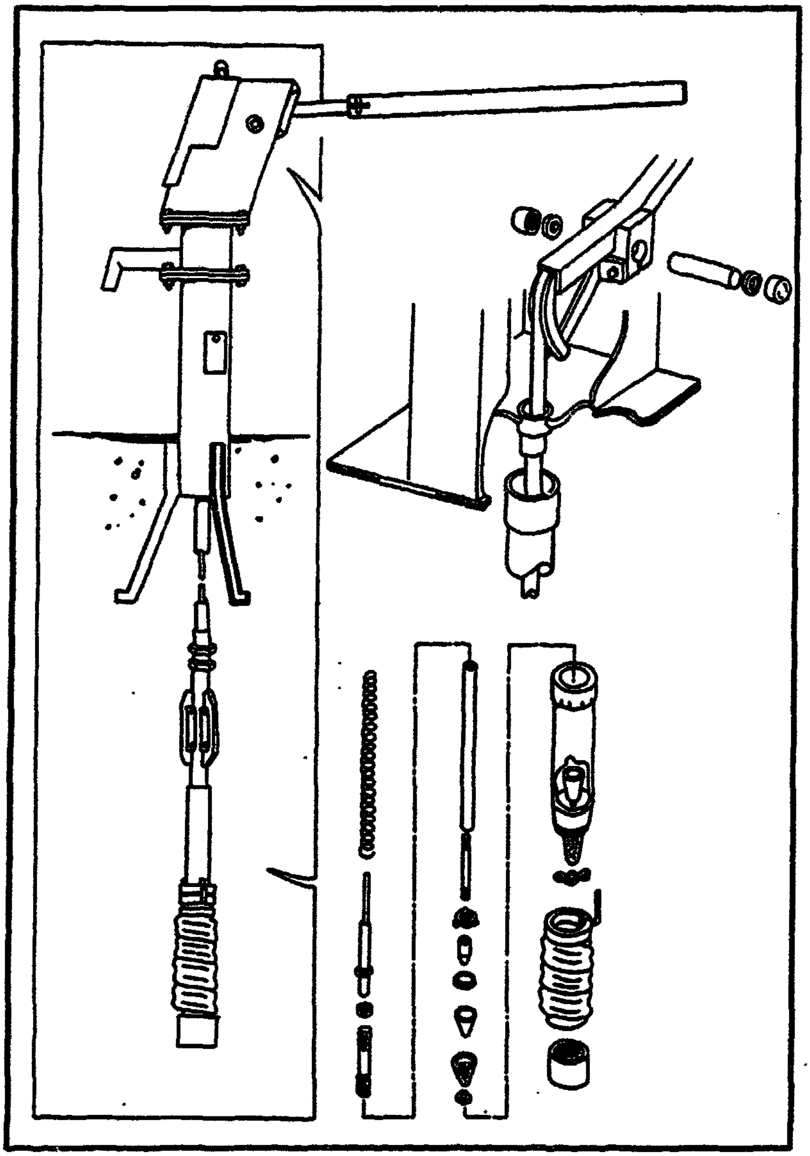
There were no failures in the endurance test, although the output of the pump fell off substantially toward the end of the test as a result of clogging of the strainer. The piston seal was worn to the point where contact had been made between the cylinder and the metal plate supporting the seal, with some scratching of the cylinder as a result. However, both the cylinder and the seal were still serviceable at the end of the test.

Abuse tests
The pump was undamaged by side impacts. In the test where the handle was struck repeatedly on its stops, some cracking appeared at the lower edge of the handle exit hole in the pumpstand. This has been noted on some other India Mark II pumps tested in the same way.

Verdict
The Pumpenboese Mk II proved to be as strong and reliable as other India Mk II derivatives tested by CRL. However, the laboratory felt that the potential for its application was limited by maintenance and manufacturing drawbacks. With its stainless steel cylinder, it was only suitable for manufacture in developed countries, and maintenance demands a high degree of skill and knowledge. The strainer supplied could not be recommended for applications where sand or silt might be present.

Further information
Pumpenboese subsequently made a change to the diameter of the metal plate supporting the piston seal. From June 1987, all support plates have been 61 mm in diameter rather than 62 mm, to avoid damage to the cylinder wall as the seal wears. An internal stiffener has been added to the suction tube to prevent distortion of the footvalve seating face during installation.

D6. Knebel Handpump



Construction
The pumpstand, water tank, and head were all manufactured from galvanized steel. The plastic-sheathed steel operating cable ran through a guide bush in the base of the pump head, around a quadrant attached to the handle, and then through the hollow square section of handle.

The rising main was supplied in one continuous length of high density polyethylene (HDPE) hose. The cylinder was fitted with an inflatable reinforced rubber expansion collar connected by a small-bore plastic tube to a bicycle valve attached inside the pumpstand. The top section of the cylinder was formed from stainless steel pipe and was sealed to the lower half of the cylinder by a rubber *o*-ring. The lower half of the cylinder was formed from stainless steel, with a nominal bore of 64 mm. The cylinder employed a forced spring return for the piston. The piston and footvalves were rubber, sealing against perforated stainless steel cones. The proprietary piston seal was formed from plastic.

This handpump from Knebel Drill of Denmark is designed for depths downs to 25 meters. It is outwardly similar to the India Mark II, but uses a cable rather than a pump rod, with the cylinder anchored in the borehole by an inflatable collar. The pump was tested in 1989; the CRL reference is A9204.

Manufacturer	Knebel Drill International A/S Industrivej 20, DK-8550 Ryomgaard, Denmark
Price (October 1990)	Complete for installation at 30 meters depth, in lots of 50: $1,095 per pump

Weights

Pumpstand assembly:	45.4 kg	Rising main, per meter:	0.5 kg
Cylinder assembly for 4.5 inch borehole:	6.5 kg	Operating cable, per meter:	0.2 kg
Cylinder assembly with adaptor for 6.25 inch borehole:	9.8 kg		

Dimensions

Maximum handle height:	1,450 mm	Nominal cylinder bore:	64 mm
Minimum handle height:	360 mm	Maximum stroke:	108 mm
Maximum handle length:	1,510 mm	Nominal maximum volume/cycle:	347 ml
Angular movement:	47 deg	Maximum diameter of below-ground assembly	100 mm
Maximum handle ratio:	10.1 : 1		
Spout height:	450 mm		

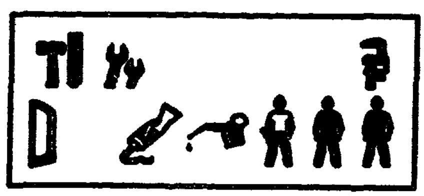
Manufacturing

Above-ground assembly:	Steel fabrication, galvanizing, general machining, plastic moldings
Beow-ground assembly:	Stainless steel fabrication, plastic pipe extrusion, wire spinning, rubber/plastics moulding, general machining, spring manufacture, crimping

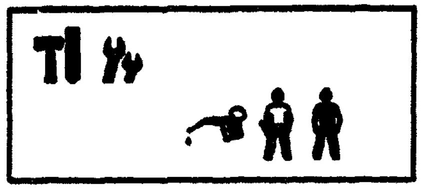
Only the basic components of the pumpstand are likely to be suitable for manufacture in developing countries. The cylinder is a complex assembly requiring a high degree of skill and costly facilities.

Installation and major repairs

Lifting tackle is not required for installation, though lifting the rising main full of water is difficult. Some experience is necessary to inflate the collar and to tension the operating cable correctly.



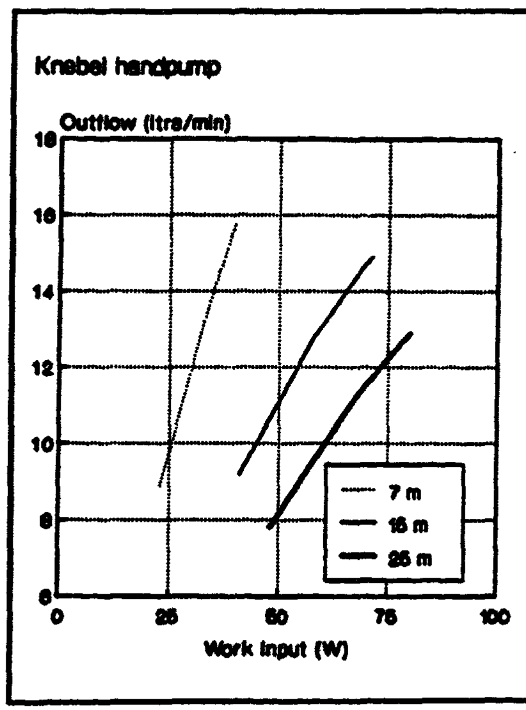
Routine maintenance
The handle bearings are difficult to replace and not suited to typical conditions in the field. Two people are required to tension the cable. The pump is not suitable for a VLOM maintenance regime.



Installation and maintenance information
A looseleaf ring binder containing information on spare parts, installation and maintenance was supplied with each pump. The instructions for installation were almost entirely pictorial with only a few words of English. Each step of installation was numbered and depicted in clear, uncomplicated diagrams, so that the installation instructions could be followed by persons with little literacy. The instructions also gave details of a suitable pump surround and soakaway. Maintenance details were also given in a pictorial format dealing with the checking and replacement of the handle bearings.

Resistance to contamination
Poor. Although it would be difficult to push sticks or stones into the spout it could easily be blocked off to build up water in the water tank, with a consequent risk of contamination. The inspection hatch which houses the valve for the expansion element was positioned low on the pumpstand: this hatch also gives direct access to the well for chlorination but may lead to contamination of the well by surface water.

Resistance to abuse
Poor. The nuts and bolts of the pumpstand were unprotected from pilferage. Although the pumpstand was generally sturdy, the leverage available at the handle could make the pump susceptible to damage from side impacts.



Pump performance
At the request of the manufacturer, the performance tests were carried out in a borehole rather than the CRL test tower.

When new, the pump produced over 12 liters per minute from a depth of 25 meters, for an input of 75 watts. At 15 meters and 25 meters and a stroke rate of 50 strokes per minute, water was forced up through the guide bush into the pump head and was wasted. The efficiency varied from 45 percent at 7 meters to 66 percent at 25 meters depth.

At the end of the endurance test, the pump produced no output for stroke rates less than 50 cycles per minute, due to a badly worn piston seal.

Leakage
Insignificant at all depths tested.

Endurance (failures set in Italic)

Test record

Hours:	889	2,000	2,206	3,783	3,922	4,010
Start	*Operating cable broken*	Inspection and volume flow check	*Operating cable broken*	*Rising main perforated*	*Pump rod in cylinder sheared*	Final inspection and full performance test

The operating cable proved to be unreliable, breaking twice in the course of the test. The inflatable collar was found to be deflated at both the 2,000-hour inspection and the final inspection at the end of the test, with considerable abrasion having resulted from contact with the well casing. The rising main wore through as a result of contact with the operating cable. At the end of the test, the piston seal was worn down to its support plate, with the cylinder bore badly scored as a result.

Abuse tests
The body of the pumpstand was undamaged by side impacts. Lateral impacts on the handle produced a offset which restricted the handle's movement, preventing a full stroke. The pump was undamaged by repeated impacts of the handle against its stops, however.

Verdict
Overall, CRL concluded that the pump was generally well made but had a number of design flaws that led to problems in the test. The design of the cylinder and the choice of materials did not lend themselves to manufacture in developing countries. Maintenance problems also made the pump unsuitable for VLOM applications. A number of design changes would therefore be needed before the pump could be considered for community use in rural water supply programs.

Further information

Following the CRL test, the manufacturer has introduced a number of modifications, including:

Cable. The stranded operating cable has been replaced by a single- strand 6 mm stainless steel wire which will not rotate under tension, connected to a stranded cable within the pumpstand.

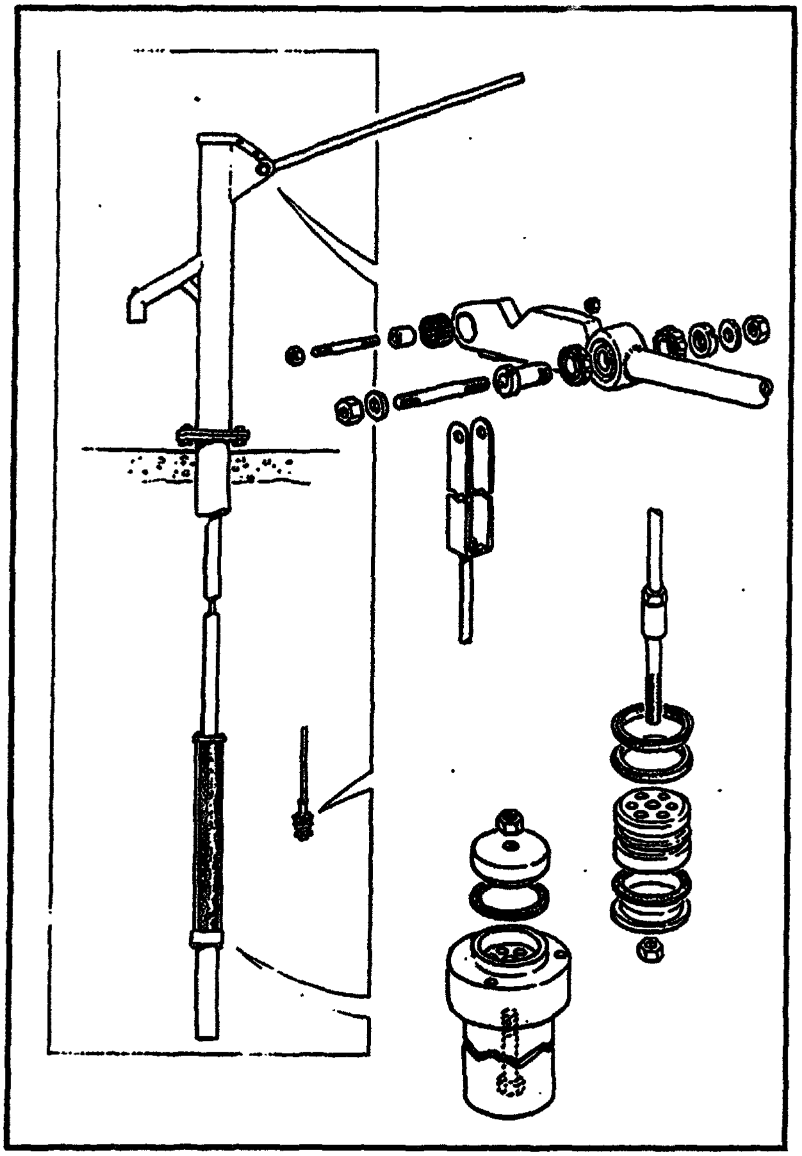
Rising main. The HDPE hose is now allowed to cool before being made into rolls for transport, to ensure that there is no permanent set.

Handle bearings. The design has been changed to make it easier to remove and replace the bearings.

Inspection hatch. The inspection hatch has been eliminated. The air valve has been repositioned within the pump head with access via the top cover.

Handle. This has been reinforced close to the bearing housing to ensure any bending due to side loads will not impair the operation of the pump.

D7. Aquamont Handpump



Construction
The pumpstand and handle were galvanized steel and could either be mounted on a protruding well casing or bolted to a concrete plinth. The main handle bearings were taper roller bearings, with a needle roller bearing at the connection to the pumprod. As a direct result of problems in the endurance test -- and following a further test at CRL -- the manufacturer replaced this needle roller bearing with a more simple and reliable hardened steel bush and stainless pin that were evaluated in a separate test.

Below ground, the cylinder was formed from glass-reinforced epoxy resin, with a coating of PTFE on the bore. The acetal piston was fitted with rubber seals: the original was nitrile rubber, but it was replaced with Hytrel during the test. The cylinder and pumpstand were threaded to suit 1.25-inch rising main, and the pump rods were 10-mm stainless steel.

The Aquamont is a conventional deep-well force pump, intended by the manufacturers in the U.K. to be suitable for depths down to 90 metres. It was tested in 1988; the CRL reference is A9108.

Price (October 1990)	Complete for use at 30 meters, in lots of 50: $-?- per pump

Manufacturer Eurafric Trading Company Ltd.
Cunard Building, Water Street, Liverpool, L3 1HR, UK

Weights

Pumpstand assembly:	54.7 kg	Rising main, per meter:	1.2 kg
Cylinder assembly:	3.4 kg	Pump rod, per meter:	0.7 kg

Dimensions

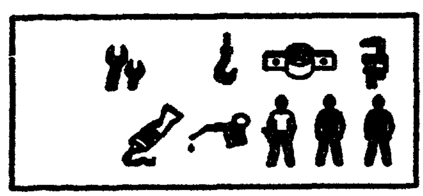
Maximum handle height:	1,350 mm	Nominal cylinder bore:	50 mm
Minimum handle height:	430 mm	Maximum stroke:	225 mm
Handle length:	1,074 mm	Nominal maximum volume/cycle:	442 ml
Angular movement:	61 deg	Maximum diameter of below-ground assembly:	82.5 mm
Handle Ratio:	5.5 : 1		
Spout height:	430 mm		

Manufacturing

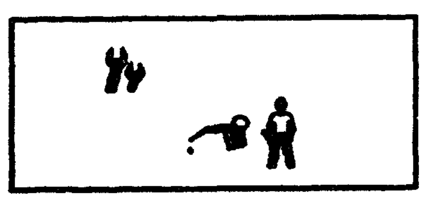
Above-ground assembly:	Steel fabrication, general machining, galvanizing
Below-ground assembly:	Plastic moldings, glass-fiber-reinforced epoxy resin forming, general machining

Only the above-ground assembly would be suitable for manufacture in developing countries.

Installation and major repairs
The weight of below-ground components makes lifting tackle essential. Major repairs could not be carried out at village level and would require a centralized or regional maintenance regime.



Routine maintenance
It would not be practical to replace the handle bearings under field conditions, and a complete new handle will be required when the bearings are worn out. The cylinder must be extracted to service the piston and footvalve.

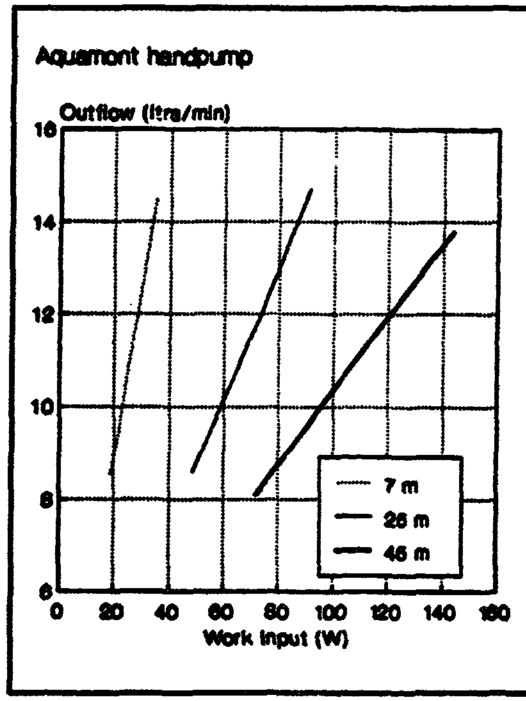


Installation and maintenance information
Supplied in French and English. Clear and well-illustrated, but with no instructions or schedules for maintenance.

Resistance to contamination
Poor. The design of the spout allowed it to be easily blocked, with a consequent risk of contamination. The well-head seal was unsatisfactory when the pump was installed on a concrete plinth.

Resistance to abuse
Poor. The pumpstand was generally sturdy, but the handle was not. Nuts and bolts could be pilfered easily.

Pump performance
The cylinders supplied for testing varied in performance, due to dimensional inconsistencies. Using the cylinder selected for endurance testing, the pump was capable of providing water at over 10 liters per minute from a depth of 45 meters, for an input of 100 watts (see illustration, right). The efficiency varied from 54 percent at 7 meters depth to over 80 percent at 45 meters.



The performance was retested at the end of the 4,000-hour endurance test. The rate of outflow was unchanged, but the required work input was slightly reduced, with a consequent small improvement in efficiency. This suggests a reduction in friction as a result of bedding-in.

Leakage
Insignificant at all depths tested.

Endurance (failures set in Italic)

Test record

Hours:	*2,000*	*2,216*	4004
Start	Inspection: *Bearing at handle-to-pump-rod connection failed*	*Lower piston seal rolled off, jammed cylinder*	Final inspection

The principal problem encountered in the endurance test was failure of the bearing at the handle-to-pump-rod connection. Replacing this bearing by a more suitable arrangement was one of several design improvements suggested by CRL.

Abuse tests
The pump stood up to side impacts with only minor damage. In a test where the handle was repeatedly struck against its stops, the handle broke when one of the piston seals jammed in the cylinder.

Verdict
The Aquamont pump achieved very good efficiencies for cylinders that were within specification, and showed a small improvement in efficiency at the end of the endurance test, but its overall performance was marred by lack of quality control. If these problems can be overcome the pump may prove to be efficient and reliable in service. The materials used in the cylinder make it generally unsuitable for manufacture in developing countries, however.

The new arrangement at the connection between the handle and the pump rod, with a hardened steel bush and a stainless steel pin, has been tested separately (see Further information, below).

Further information
Following the original test by CRL, the manufacturer arranged for the laboratory to evaluate a number of alternative designs (including the use of plastics) for the handle bearings, and particularly for the connection between the handle and the pump rod.

The most successful arrangement retained the original taper rollers for the fulcrum bearings, with a plain, hardened, proprietary bush and stainless steel pin at the pump-rod connection. This was tested using a severe regime originally developed for testing Afridev handle bearings, and the bearings were still in working order after 10 million reversals.

This new bearing arrangement was therefore adopted immediately in place of the original needle roller bearings.

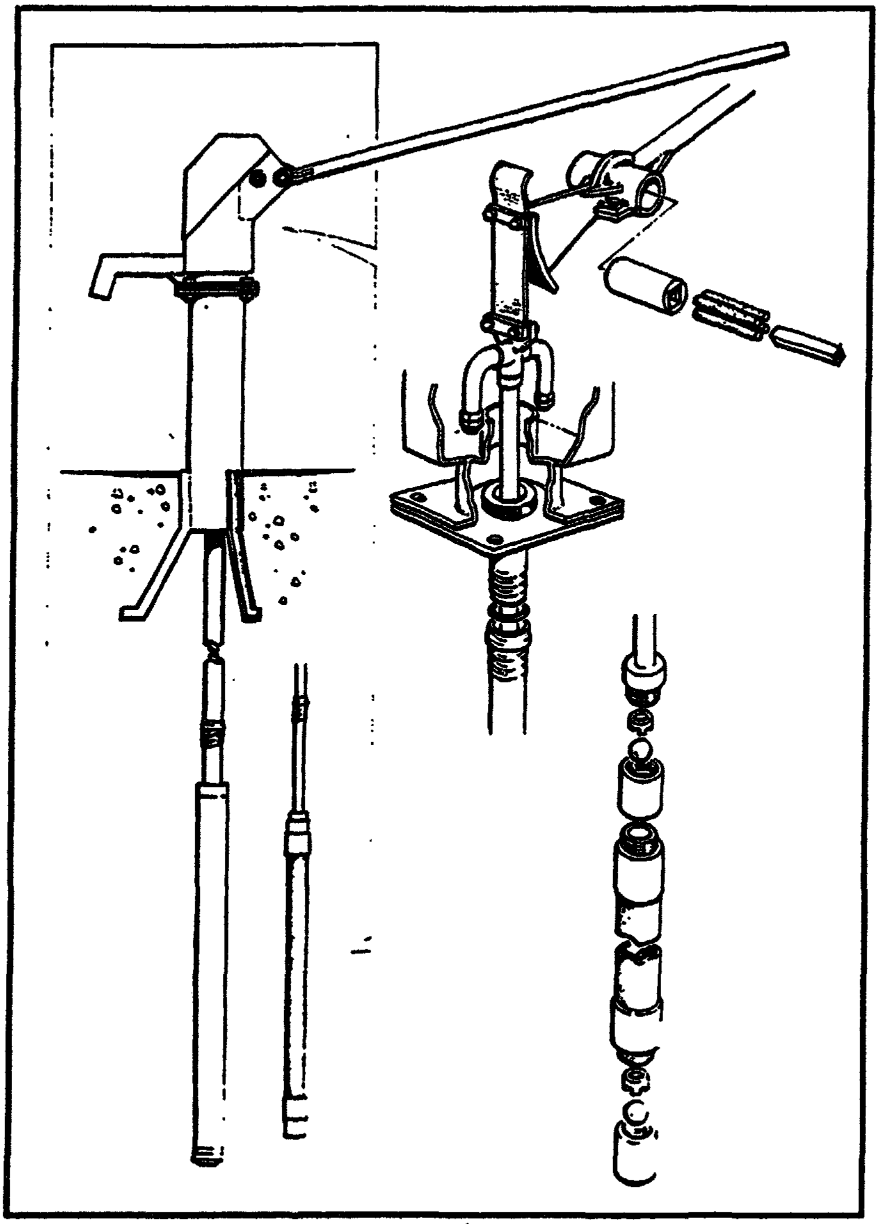
Other improvements introduced by the manufacturer following the CRL tests:
Improved quality control procedures so that pump heads should never be supplied with incorrect nuts, washers, bearing spindles, etc.
Welding to be checked for acceptability and any roughness or sharp edges in the galvanising should be corrected before the product leaves the factory. Rising main flange adapter to be retapped after galvanizing to avoid the threads being clogged with zinc.

Rubber gasket to be increased in thickness to take up any distortions in the base the pump. Packaging of the pumps will normally be to the customers' requirements so if no fork lift was available the pumps would be sent in small light crates to make them easy to handle.

Pump rods to be packed on a timber base with timber noggins for fork lift access. The maximum weight of one bundle is 80 kg unless the customer acknowledges receipt of heavier loads.

Pumpstand height to be increased by mounting it on a concrete plinth above the user area. Handle to be strengthened.

D8. Atlas Copco Model 111 Handpump



Construction
The pumpstand was fabricated from galvanized steel and was designed to be built into a concrete plinth. The handle was designed to apply the necessary amount of pre-tensioning on the rubber hose; it was formed from galvanized solid steel bar and was exceptionally long and heavy. Two handle lengths were available, 1,300 mm or 1,600 mm, to suit different depths. The handle bearings were bonded rubber with no sliding contact.

The rising main was formed from stainless steel. Connections between the three meter lengths were made using rope threads sealed with a rubber *o*-ring. These sections could be assembled and tightened by hand to produce a seal at up to 45 meters static water head. The pump rod was also formed from stainless steel with connections similar to those of the rising main. Plastic guides were supplied for use with the pump rod. The perforated the pump rod. The perforated pumping element surround was fabricated from stainless steel and provided a small amount of pre-tension to the rubber hose.

Atlas Copco offer two unconventional deep-well handpumps, models 111 and 122. The 122 uses a conventional cylinder, whereas the 111 has the unique rubber hose pumping element first seen on the Petro handpump. This exploits the reduction in volume of a stretched rubber hose to provide the pumping action. The Atlas Copco pumps were tested in 1988; the CRL reference is A9136.

Manufacturer	Atlas Copco Energy AB S-105 23, Stockholm, Sweden
Price (October 1990)	Complete for installation at 30 m depth, in lots of 50: $2,110 per pump, including stainless steel riser pipes.

Weights

Pumpstand assembly:	49.5 kg	Rising main, per meter:	1.3 kg
Cylinder assembly:	11.0 kg		

Dimensions (with 1.6-meter handle)

Maximum handle height:	1,460 mm	Spout height:	565 mm
Minimum handle height:	210 mm	Maximum diameter of below-ground assembly:	77 mm
Overall handle length:	1,835 mm		
Angular movement:	45°		
Handle ratio:	8.2:1		

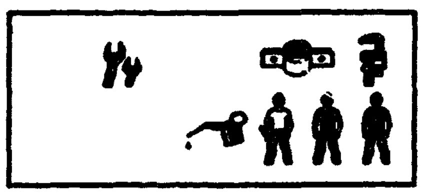
Manufacturing

Above-ground assembly:	Steel fabrication, general machining, galvanizing, rubber molding, aluminum casting
Below-ground assembly:	Specialist rubber fabrication, stainless steel fabrication, plastic molding, aluminum forming

The pump has limited scope for manufacture in a developing country. Both the pumping element and stainless steel pipes require specialist skills and facilities.

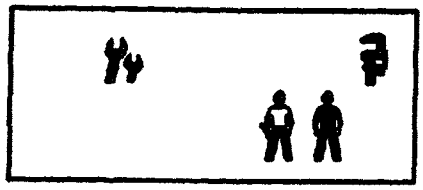
Installation and major repairs

Installation and removal of the below-ground assembly is quick and easy with the pipe clamp and lifting tool supplied with the pump. Dismantling the cylinder is likely to be time-consuming, however.



Routine maintenance

The handle fulcrum unit must be replaced as a complete unit, and two people will be needed to cope with the very heavy handle. A good tool kit was supplied, but the pump is not well-suited to village-level maintenance.



Installation and maintenance information

A comprehensive manual was supplied with the pump, including directions for building a suitable platform, full installation instructions, a spare parts list, and a schedule for weekly and monthly inspections. The instructions were well illustrated, though some reference to the text would also be necessary to assemble the pump correctly.

Resistance to contamination

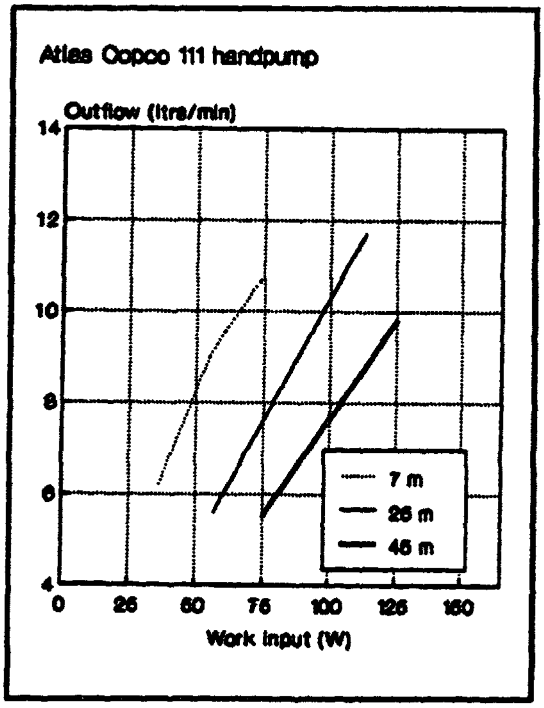
Acceptable. It would be difficult to push sticks or stones into the spout, but it could be blocked off to build up water inside the pump, with a consequent risk of contamination.

Resistance to abuse

Good. The pump is sturdy, and the fastenings are protected from pilferage.

Pump performance

The pump demanded relatively high levels of force to achieve a reasonable outflow. It was tested with both the handles supplied: the best results were achieved with the longer handle (see illustration, right). For a depth of 45 meters, an input of 100 watts produced an outflow of approximately 7.5 liters per minute. The efficiency varied from 20 percent at 7 meters to approximately 56 percent at 45 meters, contrasting with 17 percent to around 44 percent using the shorter handle.



After the endurance test, the available stroke had increased, suggesting greater freedom of movement in the handle bearings. An input of 100 watts produced an outflow of 9.5 liters per minute from 45 meters depth.

Leakage

Insignificant at all depths tested.

Endurance

Test record

Hours:	2,006	4,000
Start	Inspection and volume flow check; guide bushes badly worn	Final inspection and full performance test

There were no failures in the endurance test, but the acetal guide bushes in the pump stand were found to be badly worn at the 2,000- hour inspection and were replaced by polypropylene bushes.

In the final inspection, the rubber in the handle bearings was found to be extruding from the bearing housing, though the bearings were still functional. The polypropylene guide bushes fitted after 2,000 hours were in good condition. The ends of the cylinder were badly corroded.

Abuse tests
The pumpstand body was undamaged by side impacts; the handle was slightly distorted but was still functional. No damage resulted from repeatedly banging the handle on its stops.

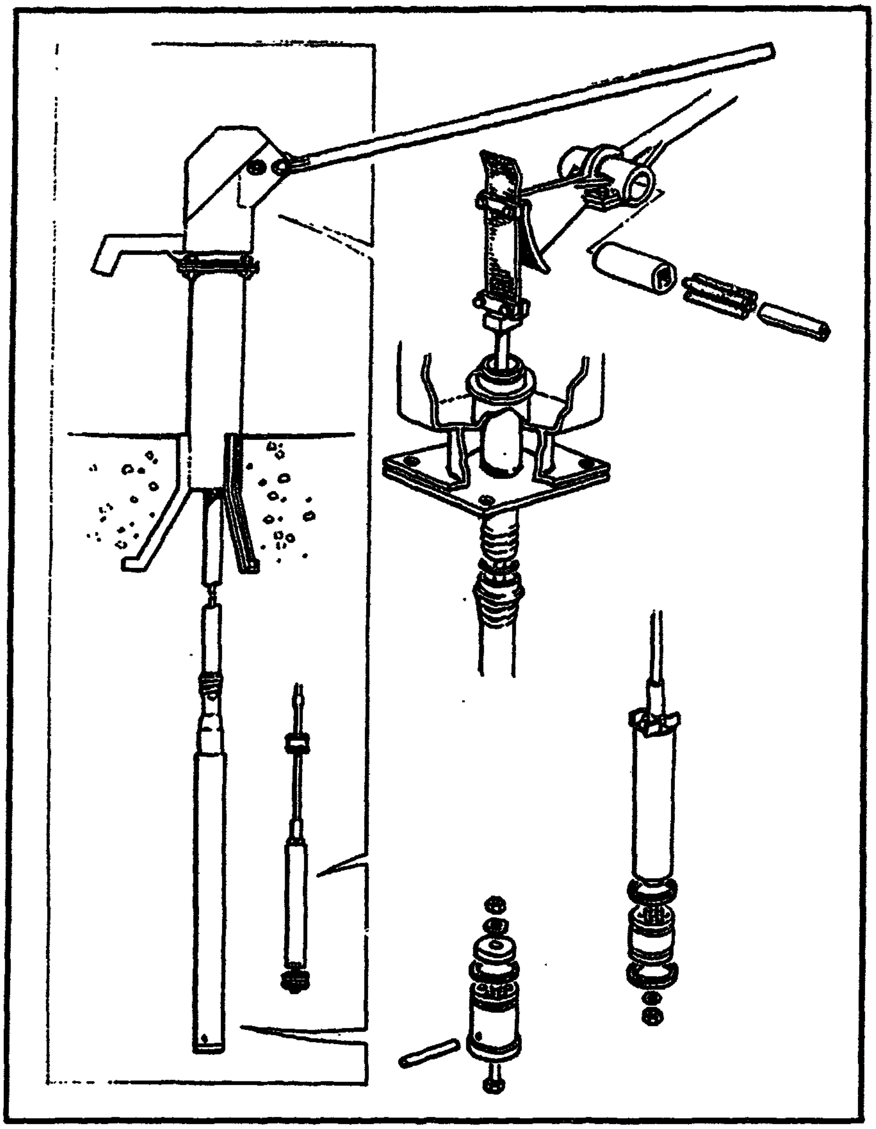
Verdict
The Atlas Copco 111 handpump was a heavily built pump of generous proportions and resistant to abuse. The pump was easy to install using the clamps and wrenches supplied, but it was difficult to dismantle the below-ground components. It should be possible for the pumpstand and other above-ground components to be manufactured in many developing countries, although the below-ground components are unlikely to be suitable for manufacture in developing countries at the present time.

The pump proved to be reliable during the endurance phase and provided all pumps of this type are supplied with the polypropylene split guide bushes the pump should give good service in the field.

Further information
The manufacturer has introduced a number of modifications following the testing by CRL:
Pump stand The split guide bushes are now manufactured from polypropylene.

Handle A strengthening web has been incorporated in all handles since the beginning of 1987. The clearance between the web and the top cap has been adjusted correctly.
Webbing strap A synthetic fiber strap is now standard.
Pump rod and rising main To ensure that the *o*-rings will not be displaced during assembly, they can be lubricated with a little petroleum jelly. A note about to that effect will be added to the installation manual, and petroleum jelly will be supplied with the pump.

D9. Atlas Copco Model 122 Handpump



Construction

The pumpstand was fabricated from galvanized steel and was designed to be built into a concrete plinth. The handle was formed from galvanized steel bar. It was exceptionally long and heavy, acting as a counterweight to the below-ground components. Two handle lengths were supplied, 1.3 meters and 1.6 meters, to suit different depths. The handle was mounted on rubber torsion bushes, eliminating sliding contact. The connection to the pump rod was a webbing strap.

The rising main was 42.4 mm outside diameter stainless steel, with connections made by rope threads formed in the pipe and sealed by rubber *o*-rings. The joints could be tightened by hand to produce satisfactory joints at up to 45 meters static head. The pump rod was 10.8-mm diameter stainless steel. The cylinder was stainless steel, and incorporated a third valve for emptying the rising main when withdrawing the pump from the well. The piston and footvalve were plastic and the piston seals rubber.

Atlas Copco offers two deep-well handpumps, models 111 and 122. The 122 is a conventional force pump with a piston and cylinder and is intended for use at depths to 60 meters. The pump was tested in 1988; the CRL reference is A9136.

Manufacturer	Atlas Copco Energy AB S-105-23, Stockholm, Sweden
Price (October 1990)	Complete for installation at 30 m depth, in lots of 50: $2,220 per pump, including stainless steel riser pipes and pump rods.

Weights

Pumpstand assembly:	49.5 kg	Rising main, per meter:	1.3 kg
Cylinder assembly:	7.6 kg		

Dimensions (using long handle)

Maximum handle height:	1,640 mm	Nominal cylinder bore:	65 mm
Minimum handle height:	120 mm	Maximum stroke:	185 mm
Handle overall length:	1,835 mm	Nominal maximum volume/cycle:	614 ml
Angular movement:	58 °	Maximum diameter of below-ground assembly:	75 mm
Handle ratio:	8.2 : 1		
Spout height:	565 mm		

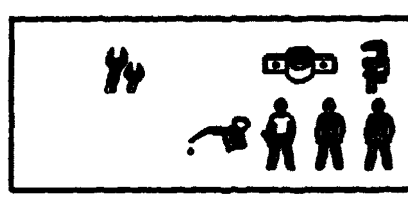
Manufacturing

Above-ground assembly:	Steel fabrication, general machining, galvanizing, rubber molding, aluminium casting
Below-ground assembly:	Stainless steel fabrication, general machining, plastic molding

The manufacture of the stainless steel cylinder and rising main pipes require specialist skills and facilities. However, the pumpstand has some potential for manufacture in developing countries.

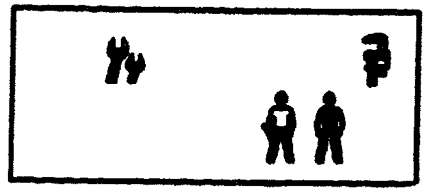
Installation and major repairs

Installation and removal of the below-ground assembly was quick and easy using the pipe clamp and lifting tool supplied with the pump, although working on the pump-rod joints was rather awkward.



Routine maintenance

The handle fulcrum unit must be replaced as a complete unit, and two people would be needed to cope with the very heavy handle. A good tool kit was supplied, but the pump was not well-suited to village level maintenance.



Installation and maintenance information

A comprehensive manual was supplied with the pump, including directions for building a suitable platform, full installation instructions, a spare-parts list, and a schedule for weekly and monthly inspections. The instructions were well illustrated, but needed some clarification in a few areas.

Resistance to contamination

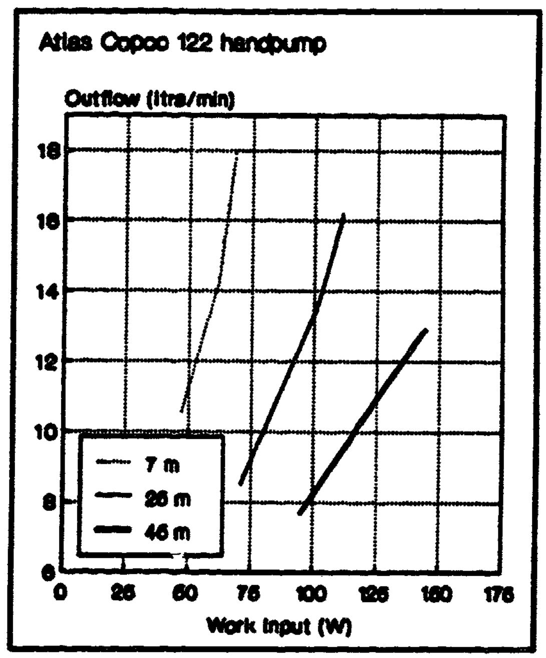
Acceptable. It would be difficult to push sticks or stones into the spout, but it could be blocked off easily to build up water in the pumpstand, with a consequent risk of contamination.

Resistance to abuse

Good. The pump was sturdy, and the fastenings were protected from pilferage.

Pump performance

The pump was tested with both the handles supplied. The results were similar, though slightly better for the 1.6m handle (see illustration, right) than for the 1.3-meter handle. The pump produced an output of just over 8 liters per minute from a depth of 45 meters for an input of 100 watts. Efficiency varied from about 25 percent at 7 meters to over 60 percent at 45 meters depth.



After the endurance test, a slight improvement in efficiency was measured, suggesting a reduction in friction. However, because the handle bearing had lost some of its resilience, more effort was needed than before on the return stroke.

Leakage

Significant leakage, varying from 6 liters per minute at 45 meters head to 36 liters per minute at 7 meters head, was observed from the footvalve.

Endurance

Test record (failures set in Italic type)

Hours:	*1,560*	2,006	*2,103*	*2,377*	*3,771* *3,801*	4,009
Start	*Webbing strap pulled out of bottom connection*	Inspection and volume flow check	*Piston & footvalves seized due to sand, kielesguhr*	*Handle broken around bearing housing*	*Piston valve seized shut due to*	Final inspection and performance test

At the 2,000-hour stage the webbing strap was replaced at the manufacturer's request with a strap of synthetic fiber. After the addition of sand and kieselguhr, the piston valve was prone to seizure. After the handle assembly broke, the manufacturer provided a modified version with a web over the top of the bearing housing and a modified top cap which did not locate properly.

In the final inspection, the handle bearings and the webbing strap were found to be worn but still functioning. The footvalve was still leaking but functional, and the sand trap was half full of sand and keiselguhr. The piston seals were satisfactory. The pump rod centralizer in the rising main was badly worn.

Abuse tests
The pumpstand body was undamaged by side impacts; the handle was slightly distorted but still functional. No damage resulted from repeatedly banging the handle on its stops.

Verdict
The Atlas Copco 122 was a heavily built pump of generous proportions that gave it good resistance to abuse. The unusual pipe connections made it easier to install, maintain, and repair than many pumps with conventional threaded pipe joints, but it was still not well suited to village-level maintenance. The pumpstand could be produced in many developing countries, although the cylinder and rising main would have to be imported.

The pump was unreliable in the endurance test, and modifications carried out by the manufacturer during testing would need to be implemented to prevent failure in the field. The usable life of the bearing when working at 45 meters water head was short. For sandy applications the clearance on the valve stems would need to be increased to prevent premature failure.

Additional Information

Modifications have subsequently been introduced by Atlas Copco:

Handle. A strengthening web has been incorporated in the handle and the clearance between the web and the top cap has been adjusted correctly.

Webbing strap. A synthetic fiber strap is now standard.

Fulcrum bearing. The rubber type has proved to be inadequate in certain climates and has therefore been replaced by sealed ball races.

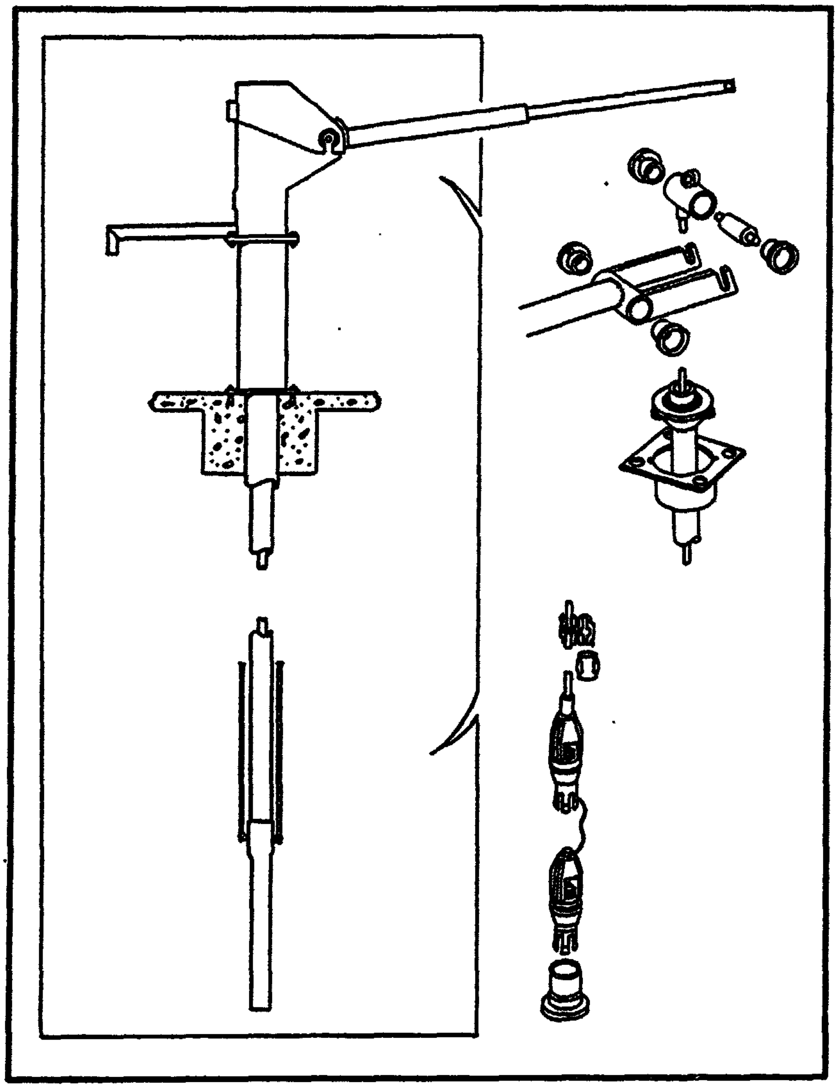
Rising main joints. A little petroleum jelly is recommended to ensure that the *o*-rings will not be displaced during assembly. A note to this effect will be added to the instructions and petroleum jelly will be supplied with the rising main pipes.

Cylinder. The clearances in the footvalve and the piston valve have been increased to eliminate sticking problems in sandy waters. The sand trap has been left out. The lower piston seal has been reversed so it will sweep the cylinder walls clean on the return stroke in sandy water. This lower seal can also be used as a spare part and replacement for the upper seal.

Footvalve leakage. The design of the sealing surfaces in the footvalve has been improved.

Centralizers. When necessary, centralizers can be delivered in other materials or with bushings to decrease wear. If any centralizer is worn through, the plastic bushing on the connecting nut gives protection until the centralizer is replaced.

D10. Aquadev Handpump



Construction
The pumpstand and adjustable *t*-bar handle were steel, protected by passivated zinc electroplating. Both the handle fulcrum and pump rod hanger used identical two part nylon and polyacetal plain bearings, with stainless steel pins. The rising main was uPVC with solvent-cemented joints, and was suspended from the pumpstand by a compressed rubber cone, with a polypropylene rope to retrieve the rising main in the event of a breakage. The 10-mm pump rods, available in carbon or stainless steel, had upset ends and plastic couplings which also acted as rod centralizers.

The 50-mm internal diameter cylinder was a section of rising main lined with a stainless steel tube. The piston and footvalve bodies used identical components, injection molded in polyacetal and welded. The valve bobbins were molded rubber. The piston and footvalve were connected together by a nylon line to enable the footvalve to be extracted with the piston through the rising main.

The Aquadev, made by Mono Pumps of the UK, was the first handpump from an established manufacturer to be based on the Afridev concept since it was placed in the public domain. It is a deep-well force pump, designed to suitable for manufacture, installation, maintenance and repair within the existing resources of many developing countries. The pump was tested in 1989; the CRL reference is A9218.

Manufacturer	Mono Pumps Limited, MENCA Division Cromwell Trading Estate, Cromwell Road, Bredbury, Stockport, Cheshire SK6 3RF, United Kingdom
Price (October 1990)	Complete for use at 30 m depth, in lots of 50, with stainless steel pump rods: $880 per pump.

Weights

Pumpstand assembly:	54.7 kg	Rising main, per meter:	1.2 kg
Cylinder assembly:	3.4 kg	Pump rod, per meter:	0.7 kg

Dimensions (with handle adjusted to mid-point)

Maximum handle height:	1,416 mm	Nominal cylinder bore:	50 mm
Minimum handle height:	497 mm	Maximum pump stroke:	225 mm
Handle length:	921 mm	Nominal volume per cycle:	442 ml
Angular movement:	60°	Maximum diameter of below-ground assembly:	82.5 mm
Handle ratio:	4.1 : 1		
Spout height:	760 mm		

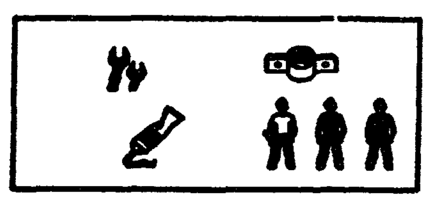
Manufacturing

Above-ground assembly:	Steel fabrication, general machining, plastic molding, rubber molding, electroplating
Below-ground assembly:	Plastic molding, rubber molding, stainless steel fabrication

Developing countries with skills and facilities in general engineering and plastics processing would be able to manufacture the pump. Strict quality control will be needed to ensure locally produced uPVC pipe meets international standards.

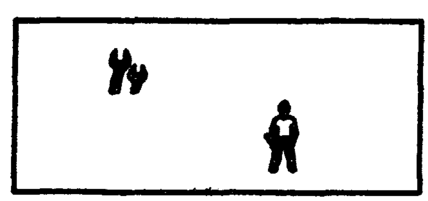
Installation and major repairs

Lifting tackle is not required, but tying off the ropes supporting the rising main requires many hands. The short rods supplied with the pumps avoid the need to cut a thread on the top of the pump rod.



Routine maintenance

A single spanner is supplied which fits all the fastenings on the pumpstand, though a 19-mm spanner would also be required to release the lock-nut on the pump rod. The handle bearings can be replaced in minutes.



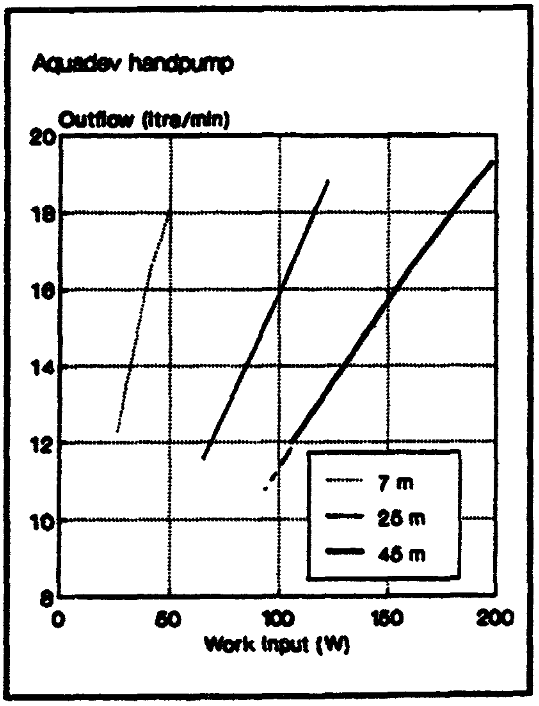
Installation and maintenance information
A manual was supplied, in English. The installation instructions relied rather heavily on an understanding of the text, but the maintenance information was presented on a single encapsulated sheet and little reference was needed to the text accompanying each of the 23 line drawings.

Resistance to contamination
Fair -- the base of the pumpstand was not flat and could allow surface water to penetrate, although the design allows the borehole casing to extend above the plinth level inside the pumpstand. The spout could be blocked off to build up water in the water tank, with a risk of contamination.

Resistance to abuse
Good -- the pump was sturdy, and all the fastenings on the pumpstand except the flange bolts were protected from pilferage.

Pump performance
With a cylinder of 50 mm diameter and a relatively long stroke, the Aquadev could lift large quantities of water, even from deep settings. This demanded correspondingly high levels of work input, however. For an input of 100 watts, the test results indicated (right) that the pump would be capable of providing water at over 11 liters per minute from a depth of 45 meters. The efficiency varied from around 50 percent at 7 meters to about 80 percent at 45 meters depth.

After the endurance test, the pump delivered more water per stroke than when new, but at the expense of an increase in work input. Overall efficiency did not change significantly.



Leakage
Insignificant at all depths tested.

Endurance
Test record (failures set in Italic type)

Hours:	2,013	4,006
Start	Volume flow check	Final inspection and performance test

The pump completed the endurance test without incident. In the final inspection, the retaining lug had broken off one of the handle fulcrum bearings and caused a circumferential crack. The hanger bearings were satisfactory. Both the handle fulcrum pin and the hanger pin were badly corroded on the threads and captive nuts. The pumpstand was badly corroded inside the water tank, and the handle showed signs of rust where the surface had been damaged. The pump-rod connectors were worn and allowed free play in the rod string.

Inside the cylinder, the piston and footvalve were in good condition, but the nylon line attaching the footvalve to the piston was frayed and broke when it was used to attempt to withdraw the footvalve.

Abuse tests
The pump was undamaged by side impacts on the body of the pumpstand and lateral impacts on the handle. In the test where the handle was repeatedly struck on its stops, a weld on the handle securing the handle top yoke to the forks broke. The handle was replaced with a handle welded on the inside angle of the yoke as well as on the outside. The second handle also failed, this time at the base of the handle tube 3 mm in front of the welded area. A third handle completed the test without further incident.

Verdict
The Aquadev performed well in the tests, gave good efficiency and completed the endurance test without incident. However, the pump's low resistance to corrosion will need to be improved to ensure the longevity of the pump. The handle also requires strengthening to improve resistance to abuse.

The pump is suitable for manufacture in a number of developing countries, and its ease of maintenance should ensure its inclusion in VLOM-based projects.

Further information

Pump rods. All pumps are now supplied with stainless steel pump rods.

Finish. The external finish of the pumpstand is now phosphate and chromate treatment to British Standard 3189, followed by two coats of hammer-finish paint. The inside of the pumpstand is protected by a bituminous coating to British Standard 3416.

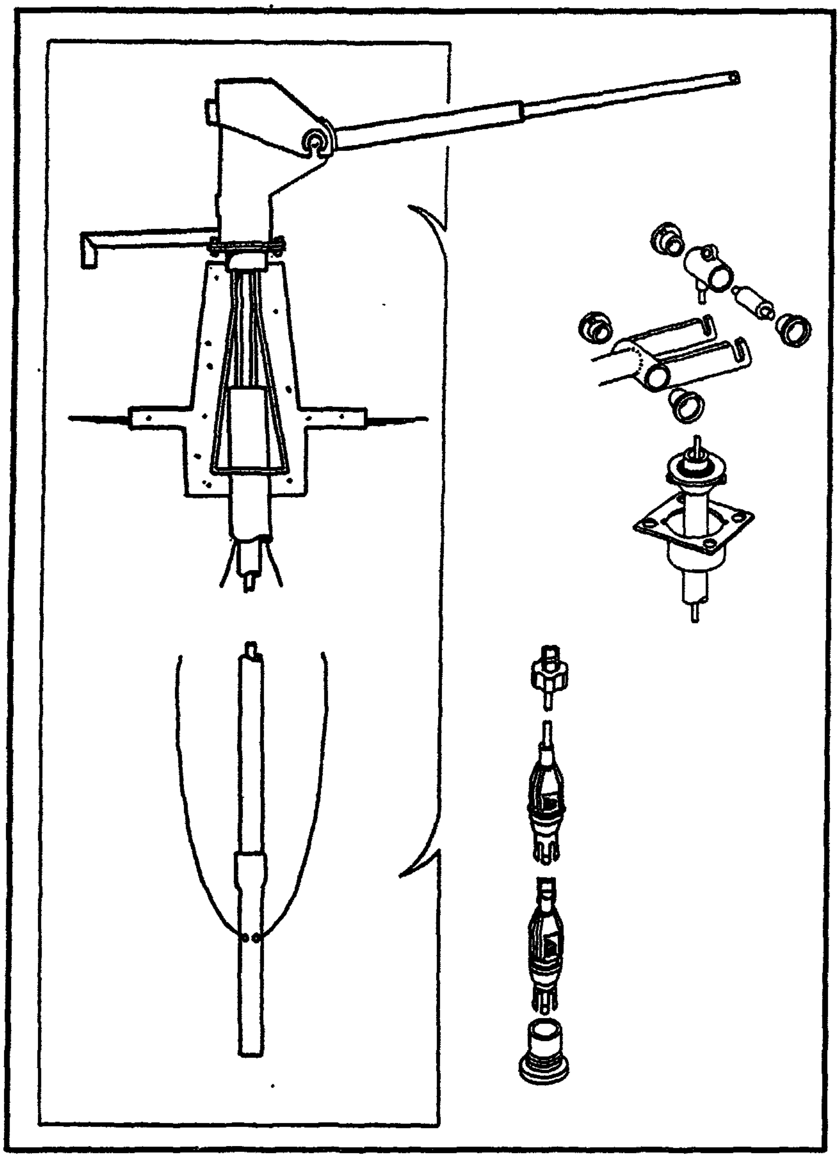
Footvalve retrieval. The nylon connecting cord is no longer fitted. Instead, each pump is supplied with a separate fishing tool for retrieving the footvalve.

Rising main. Pipes are supplied in 2.8 meter lengths to maintain straightness in transit.

Instructions. A pictorial leaflet encapsulated in plastic is now supplied with each pump. The main language is English, but provision has been made for local language subtitles.

Local manufacture. Discussions are under way to set up joint manufacturing ventures in Nigeria, Malawi, Kenya, Tanzania, and Ethiopia.

D11. Afridev Handpump



Construction
The pumpstand was galvanized steel, with a *t*-bar handle adjustable for length to suit different water depths. Identical two-part nylon and acetal plain bearings, running in stainless steel housings, were used for both the handle fulcrum and the pump rod hanger. All routine maintenance on the pumpstand could be carried out using a single spanner, which was supplied.

The rising main was uPVC pipe with solvent cemented couplings, and was suspended from the pumpstand by a compressed rubber cone. The pump rods had special joints which eliminated the need for tools for assembly or dismantling. The joints incorporated rod centralizers. The cylinder was a length of the rising main pipe, fitted with a brass liner: this gave it an internal diameter of 50 mm, and meant that the piston could be extracted without disturbing the rising main. The piston and footvalve were molded from acetal, spun-welded, and were fitted with rubber valves and seals. The safety rope would enable a broken rising main to be recovered.

The Afridev is a deep-well handpump for water depths down to 45 meters, developed from the Maldev handpump. The design is in the public domain, and aims to demonstrate the VLOM concepts of easy, low-cost maintenance and suitability for manufacture in developing countries. The pump was tested in 1989, with samples supplied from Kenya; the CRL reference is A9218.

Manufacturer East African Foundry Works (K) Ltd
PO Box 48624, Nairobi, Kenya

Price (October 1990) Complete for installation at 30 m depth, in lots of 50: $643 with galvanized rods, $978 with stainless steel rods, per pump, ex-works Kenya. Export prices may be somewhat lower due to government subsidies.

Weights

Pumpstand assembly:	47.2 kg	Rising main, per meter:	1.4 kg
Cylinder assembly:	6.1 kg	Pump rod, per meter:	0.6 kg

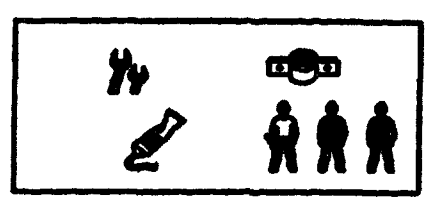
Dimensions (with handle adjusted to midpoint)

Maximum handle height:	1,285 mm	Nominal cylinder bore:	50 mm
Minimum handle height:	350 mm	Maximum stroke:	234 mm
Handle length:	1,120 mm	Nominal volume per cycle:	459 ml
Angular movement:	63°	Maximum diameter of below-ground assembly:	95 mm
Handle ratio:	4.1 : 1		
Spout height:	465 mm		

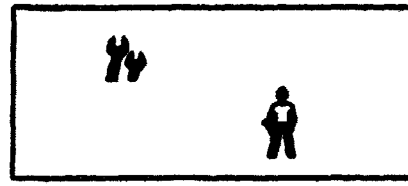
Manufacturing
Above-ground assembly: Steel fabrication (including stainless), general machining, plastics and rubber molding, galvanizing
Below-ground assembly: Plastics extrusion and molding, rubber molding, steel fabrication

Developing countries with skills and facilities in general engineering and plastics processing will be able to manufacture the pump. Strict quality control will be needed to ensure that locally produced uPVC pipe meets international standards.

Installation and major repairs
Lifting tackle is not required, but tying off the ropes supporting the rising main requires many hands. In the latest design, the need to cut a thread in top of the pump rod has been eliminated (see Further Information, p. 138).



Routine maintenance
A single spanner is supplied which fits all the fastenings on the pumpstand. The handle bearings can be replaced in minutes.

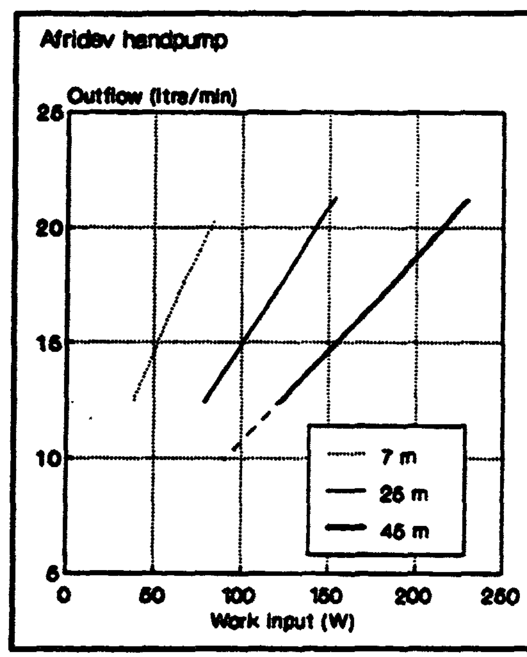


Installation and maintenance information
The instructions supplied with the test samples were poor, with a number of errors and ambiguities and a lack of clear diagrams. It would have been difficult for a person with little literacy or with little knowledge of the English language to install the pump.

Resistance to contamination
Good, although the spout could readily be blocked off to build up water inside the pump, with a consequent risk of contamination.

Resistance to abuse
Good. The pumpstand was robust and all the fastenings on the pumpstand except the flange bolts are protected from pilferage.

Pump performance
With a cylinder of 50-mm diameter and a relatively long stroke, the Afridev can lift large quantities of water, even from deep settings. This demanded correspondingly high levels of work input, however. For an input of 100 watts, the test results indicated that the pump would provide about 11 liters of water per minute from 45 meters depth. The efficiency varied from 35 per cent at 7 meters to approximately 70 per cent at 45 meters.



After the endurance test friction in the pump was reduced, with a consequent improvement in efficiency to around 75 per cent at 45 meters depth.

Leakage
There was no significant leakage at 25 meters or 45 meters depth. At 7 meters depth, leakage from the footvalve was measured at 57 ml/minute.

Endurance
Test record

Hours:	2,003	4,009
Start	Inspection and volume check	Final inspection and full performance test

There were no failures during the endurance test. However, the endurance test certainly contributed to the subsequent pump rod failure during the handle shock test (see Abuse tests, below).

In the final inspection, the handle bushes were worn and some were very difficult to separate. There was some evidence of corrosion at the stainless steel liner/sleeve interfaces. Superficial rusting was also found in areas of the pumpstand and handle where the galvanized coating had been worn away. The pump rods were severely corroded. The rising main was badly worn where the rod centralizers had been in contact with it. The piston and footvalve were in good working order.

Abuse tests
The pump was undamaged by side impacts on the body of the pumpstand and on the handle. In the test where the handle was repeatedly struck on its stops, the pump rod broke about half way through the test at one of the hook-and-eye connectors. The joint was replaced and the test was completed without further incident.

Verdict
Overall, the Afridev pump performed well in the laboratory tests. It completed the endurance test without failure, though there was evidence of potential problems related to rising main wear and corrosion.

The pump was suitable for manufacture in many developing countries and the inherent ease of maintenance should ensure its inclusion in VLOM-based projects. Changes in the pump rod jointing method, corrosion protection and centralizers will need to be considered to ensure long term reliability. The instruction manual must be clarified and changed to include simple line drawings and to minimize the accompanying text.

Further information
A number of changes have been introduced to the Afridev pump since the CRL test was carried out, principally:
Rod hanger: A clamp-type hanger is now used, which accepts a plain 10 mm pump rod and secures it with a 16 mm bolt. This has eliminated the need to thread the end of the pump rod during installation.
Rod centralizers: molded rubber centralizers are now used instead of polyethylene, and have performed successfully in the field: wear takes place on the centralizers rather than the rising main.
Footvalve: the footvalve fitting has been modified to eliminate any risk of the footvalve's jamming on the piston.
Instructions: the instructions have been completely revised, although it is acknowledged that there is still scope for further improvement. A training video on installation is also planned.
Pump rods: stainless steel pump rods are now recommended for applications where groundwater is less than pH 6.0.

Other comments from UNDP-World Bank project staff :
Manufacture of Afridev pumps is under way in Kenya, India, Pakistan, and England, and is planned for Malawi, Ethiopia, and Madagascar. Corrosion of the bearing housing liners noted in the laboratory test has not been apparent on pumps in the field, even in severe conditions. The pump incorporates overflow holes just above the spout to prevent a build-up of water if the spout is blocked. The two parts of the bearing assemblies are intended to be difficult to separate, to ensure that bearings are always fitted and replaced as pairs. The minimum recommended operating depth is 10 meters.

APPENDIX. CRL's Handpump Test Program

The Consumer Research Laboratory has been involved with handpump testing and development since 1977, for the Overseas Development Administration, the World Bank, donor agencies, and manufacturers. CRL's approach reflects over 30 years of experience in the field of comparative testing of a very wide range of products. The remainder of this Appendix describes the handpump test program in detail, including the laboratory's conditions of acceptance of handpumps for testing.

CRL's facilities for testing and development of handpumps include:

- a handpump testing tower
- 4 blind boreholes, the deepest of which is 100 m, with variable water levels
- cylinder testing rig with 8 test stations
- bearing test rigs in temperature-controlled chambers
- large workshop facilities

For further information, you may contact:

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CRL handpump test procedures

1. Description

The test samples (a minimum of two complete samples) should be representative of the manufacturer's normal output. Wherever possible, sample pumps should be obtained through independent procurement agencies.

1.1 Manufacturer or agency: name and address of pump manufacturer and/or supplying agency

1.2 Pump model and type: manufacturer's model reference, deep or shallow well type, free discharge or delivery lift

1.3 Cost

2. Inspection

2.1 Packaging: Assessment of how well the packaging has stood up to transportation to the laboratory, and of the suitability of the packaging for transport in developing countries.

2.2 Condition of pumps: Whether received in working order, summary of defects on delivery. The pumps will be dismantled and inspected for visible defects.

2.3 Literature: whether supplied with pump or obtained from other source. Assessment of clarity, accuracy and usefulness.

3. Weights and measures

3.1 Weights of principal components: pumpstand including handle, cylinder, rising main per meter length, pump rods per meter length (including couplings)

3.2 Principal cylinder dimensions: nominal bore and stroke, nominal volume per stroke, usable cylinder length

3.3 Cylinder bore diameter: measured at ten points along two perpendicular axes parallel with the cylinder axis, to check for ovality and taper. The surface roughness of the bore is measured at three points along axes parallel to the cylinder axis.

3.4 Ergonomic measurements: handle and spout heights, angular movement and velocity ratio of handle, description of exit water pattern. Pumps designed to be installed on plinths will be mounted at the manufacturer's recommended height. Where this information is not available, pumps will be installed so that the midpoint of handle operation is as close as possible to 0.9 meters from floor level, subject to a maximum spout height of 0.6 meters.

4. Pump performance

4.1 Volume flow, work input and efficiency: measurements of volume flow, work input and the efficiency of the pump can be combined in a single test procedure. Strain gauges will be attached to the pump handle to measure the applied forces, and a rotary potentiometer or optical transducer fixed to the body of the pump will measure angular movement. A microcomputer is programmed to record the data from the transducers and calculate the work done by the operator on the pump. The computer compares this work done on the pump with the work done by the pump in raising water (the product of the weight of water raised and the head) to calculate the efficiency of the pump. The transducers are calibrated at the start of each test; the calibration procedure is built into the computer program. Shallow-well pumps are tested at 7 meters head. Deep-well pumps are normally tested at 3 heads - 15 meters, 25 meters, and 45 meters, but other depths can be accommodated.

For each head, the pump is tested at three operating speeds, normally 30, 40, and 50 strokes or revolutions per minute. The stroke rate will be altered if necessary, and actual rates agreed with the manufacturer before testing. For each test, the computer will plot applied force on the handle against handle displacement.

4.2 Leakage: the volume of water leaking past the footvalve is measured for the same heads as the tests of volume flow, work input, and efficiency.

5. User trial

A small number of users will be recruited. They will be women and children, of various heights and ages. All users are given an opportunity to become familiar with the pump and to find their preferred method of operation. They are asked to fill a 10-liter container in their own time. The number of strokes or revolutions and the time taken are noted. Deep-well pumps are normally set at 20 meters depth.

5.1 User comments: each user will be asked to fill out a short questionnaire to record their opinions of the ease of operation of the pump.

5.2 Observation of users: methodical observations of the relationships between pumps and people are made, reinforced by selective video recordings.

5.3 Water exit pattern: comments are made if the water pattern leaving the spout would not be suitable for narrow-necked vessels.

6. Endurance test

Two stages of 2,000 hours with a check test of volume flow after the first stage. The pumps are mechanically driven, normally at 40 strokes or revolutions per minute, or at the speed most appropriate to pump design. The handles of the reciprocating pumps are driven in simple harmonic motion imposing no shock loads. The simulated depth is 45 meters for deep-well hand pumps unless otherwise agreed with the manufacturer.

6.1 Stage 1: Clean hard water, approximate pH 7.2, followed by volume flow check.

6.2 Stage 2: Hard water with one gram per liter of Kieselguhr, maximum particle size 7.5 μm, and one gram per liter of fine sharp quartz sand, particle size between 75 μm and 500 μm. This is followed by a performance test at three speeds at the endurance test head to compare with the results obtained initially and obtain data on changes caused by wear. For stage two the water is agitated, and frequent checks made to ensure the correct concentration of contaminants is maintained.

6.3 Failure Report: any failure is examined and an assessment made of the probable cause – use of materials, design, inadequate quality control, or poor manufacture, for example. Suggestions for design improvements or manufacturing changes are made.

7. Abuse tests

7.1 Handle shock loading test where applicable: controlled shocks are applied to the handle stops using impacts determined by using a human operator where the handle is allowed to travel with the normal level of effort on to the stops. Both deep-well and shallow-well pumps are tested at a head of 7 meters, since for deep-well pumps the user is more likely to hit the handle on its stops when the pump is used at relatively shallow depths. The test will be carried out using the normal endurance stroke speed at a rate appropriate for the type of pump. The test consists of 96,000 shocks for force pumps and 72,000 shocks for suction pumps, or until pump failure.

7.2 Impacts on pumpstand: using a pendulum, impacts in steps of 100 Joules to a maximum of 500 Joules, on the center of the pumpstand.

7.3 Impacts on handle: using a pendulum, impacts in steps of 50 Joules to a maximum of 200 Joules, on the center of the pump handle.

8. Engineering assessment

The pumps are dismantled. Each component is examined to evaluate the material, the method of manufacture, the degree of skill required, and the standard of workmanship, to form the basis of the overall assessment of suitability for manufacture in developing countries.

8.1 Materials, manufacturing methods, etc: identification of materials and manufacturing processes used for each component of the pump. Assessment of fitness for purpose of chosen materials and processes.

8.2 Suitability for manufacture in developing countries: summary of manufacturing processes required, and assessments of the degree of skill demanded for each process.

8.3 Ease of installation, maintenance and repair: assessment of techniques, skills, and equipment required. In assessing ease of installation, maintenance, and repair, CRL considers the degree of technical competence required by the design and construction of the pump, and whether the pump could be repaired using indigenous materials.

8.4 Resistance to contamination and abuse: assessment of sanitary sealing of both pumpstand and wellhead. Assessment of resistance to deliberate abuse, pilferage, impacts by domestic animals etc. In assessing sanitary sealing, CRL considers the resistance of the pumpstand to accidental or deliberate contamination, and the likelihood of contamination of the well by surface water. Resistance to abuse includes both the probable susceptibility of the pumpstand to impacts (from domestic animals, for example), pilferage, or vandalism.

8.5 Potential safety hazards: assessment of potential dangers -- of finger traps, insecure fastenings, and projections, for example -- to both pump users and bystanders.

8.6 Suggested design improvements: suggestions for improvements in either pump design or manufacture, at minimal cost. CRL hopes these suggestions will stimulate a response from pump manufacturers.

9. Verdict

A short summary of the main good and bad features of the pump and its performance. Comment on suitability for manufacture in developing countries.

10. Reporting

10.1 The first interim report contains all information prior to the start of the endurance test. It details performance test results for the particular pump. This preliminary report gives manufacturers an opportunity to comment on the testing to date, and to question any of the results. CRL hopes this approach will encourage a dialogue with manufacturers.

10.2 Contacts will be made with the client as required when significant problems are encountered in endurance testing.

10.3 The final Technical Report includes full details of the pumps, test procedures, results, relevant drawings, and photographs.

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