Village Handpump Technology: Research and Evaluation in Asia, Publication IDRC-204e

edited by Donald Sharp and Michael Graham

Published by:

IDRC
Box 8500
Ottawa
CANADA K1G 3H9

Available from:

same as above

The International Development Research Centre is a public corporation created by the Parliament of Canada in 1970 to support research designed to adapt science and technology to the needs of developing countries. The Centre's activity is concentrated in five sectors; agriculture, food and nutrition sciences; health sciences; information sciences; social sciences; and communications. IDRC is financed solely by the Parliament of Canada; its policies, however, are set by an international Board of Governors. The Centre's headquarters are in Ottawa, Canada. Regional offices are located in Africa, Asia, Latin America, and the Middle East.

Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa, Canada

Sharp, D.
Graham, M.

IDRC-204e

Village handpump technology : research and evaluation in Asia. Ottawa, Ont., IDRC, 1982. 72 p. : ill.

/Pumps/, /hand tools/, /appropriate technology/, /rural/, /water supply/, /developing countries/ — /project evaluation/, /testing/, /technical aspects/, /market/, /economic aspects/, /case studies/, statistical data.

UDC: 621.651(1-22) ISBN: 0-88936-360-9

Microfiche edition available

Il existe également une édition française de cette publication.

La edición española de esta publicación también se encuentra disponible.

IDRC-204e

Village Handpump Technology

Research and Evaluation in Asia

Editors: Donald Sharp and Michael Graham

Résumé

Depuis six ans le CRDI appuie financièrement des recherches sur la mise au point de pompes plus efficaces pour l'approvisionnement en eau potable des régions rurales. Les avantages de nouveaux matériaux et modèles de pompe ont été étudiés, plus particulièrement l'emploi de matières plastiques. L'Université de Waterloo a collaboré à la production d'un assemblage de cylindre et clapet de pied simple qui constituerait le premier élément d'une pompe à main pour puits de surface susceptible d'être fabriquée dans les pays en développement avec les ressources disponibles sur place. Soumise à des essais en laboratoire, la pompe a ensuite été testée dans diverses conditions environnementales dans quatre pays asiatiques et deux pays africains pour déterminer son coût de fabrication, sa fiabilité et sa durabilité, sa facilité d'entretien par les villageois et son efficacité technique. Cette publication passe en revue les résultats de recherche présentés à l'atelier tenu à l'Université de Malaya, Kuala Lumpur (Malaisie) du 16 au 19 août 1982, au terme des projets réalisés en Asie. Elle contient également une évaluation technique et économique globale des quatre projets et une évaluation des recherches à faire et des priorités à leur donner. Les futurs travaux porteront probablement sur la possibilité de lancer une production à grande échelle de pompes à main et sur les difficultés que présenterait la réalisation d'une telle entreprise.

Resumen

En los últimos seis años el CIID ha apoyado investigaciones tendientes a desarrollar sistemas más efectivos de bombeo de agua para el área rural. Se han estudiado las implicaciones de los nuevos materiales y diseños de bombas, en especial el uso de materiales plásticos. En colaboración con la Universidad de Waterloo, se desarrolló un conjunto económico de pistón y válvula-pedal como base para una bomba manual de pozos pandos que pudiera ser fabricada en los países en desarrollo con recursos locales. Después de ser ensayada en laboratorio, la bomba fue sometida a prueba bajo diferentes condiciones ambientales en cuatro países de Asia y dos de Africa con el objeto de determinar costos de fabricación, confiabilidad y durabilidad, capacidad de mantenimiento a nivel rural y desempeño técnico. Este libro ofrece una reseña de los resultados de las investigaciones presentados durante un seminario realizado en la Universidad de Malaya, Kuala Lumpur, Malasia, del 16 al 19 de agosto de 1982 a la culminación de los proyectos asiáticos. Se incluyen además las evaluaciones técnicas y económicas generales de los cuatro proyectos, así como una estimación de las futuras necesidades y prioridades de la investigación, entre las cuales se contarán probablemente el potencial de producción a gran escala y los problemas involucrados en la implantación del sistema.

Contents

Not all the health assistants in the world can get rid of dysentery and cholera if water supplies are contaminated.

Barbara Ward. 1976. The Home of Man. W.W. Norton & Company Inc., New York, NY, USA. Page 229.

Preface

Many factors are involved in efforts to provide safe drinking water for all during this the International Water Supply and Sanitation Decade. One of the keys, however, is the development and use of a reliable handpump that can be locally produced, installed, and maintained at a reasonable cost.

The International Development Research Centre (IDRC) has invested about CA$730000 in a network of water-supply projects in Asia and Africa over the last 6 years to help develop more effective pump systems for rural water supplies. This publication reviews the results of the Asian segment of the network and identifies future research priorities, specifically the need to investigate large-scale manufacturing of the polyvinyl chloride (PVC) pump that has been developed and the essential social and public-health factors that must be part of any implementation program.

It should be pointed out that the technology developed and tested by these IDRC-supported research projects is applicable to rural situations all over the world, not just to those few countries in Asia where field testing was carried out. The development of a handpump utilizing inexpensive PVC components, which can be manufactured locally and simply enough to be maintained at the village level, is a giant step forward in the struggle to provide adequate, clean, water supplies to rural populations.

The technology has been tried, tested, and proven. But the question remains: how can the desire to utilize it and maintain it be best transferred to those who need it most? It is our hope that this volume will stimulate efforts to implement this technology and foster new research initiatives in all countries where provision of potable water is still a major problem.

The papers presented in this publication are summaries of the full reports of each country project. More specific details may be obtained by writing to the Health Sciences Division of IDRC to obtain microfiche copies of the complete reports.

Elizabeth Charlebois, *Director*
Health Sciences Division
International Development Research Centre

Acknowledgments

Over the past 6 years, many researchers, engineers, technicians, consultants, support staff, and others have contributed to the development of IDRC's concept of the village level operated and maintained (VLOM) handpump. The list is too numerous to acknowledge each person by name. It goes without saying, however, that it is the dedicated efforts of these people that made this publication possible.

Thanks are also due to the University of Malaya, where the end-of-project seminar-workshop was held, and to Dr Goh Sing Yau, local coordinator, and his colleagues, Dr Tee Tiam Ting, Dr Tan Bock Thiam, Mr Chong Kah Lin, and Mr Teo Beng Hoe, for their hard work in ensuring the success of the meeting. Mr Lee Kam Wing acted as IDRC coordinator and a special word of thanks is due to Ai Ling Goh, Health Sciences Division, IDRC, Singapore.

Also credit should be given to Tim Journey, who carried out the early design work for handpumps utilizing plastic components under the sponsorship of the World Bank and was later hired by IDRC to continue the effort.

It must be pointed out that, although the pump described in this publication is often referred to as the IDRC-Waterloo design, it is really nothing more than an updated version of a wooden pump used in Europe about six centuries ago. Elements of the design are clearly illustrated in a 16th century plate appearing in a book on mining translated by Herbert Clark Hoover and Lou Henry Hoover in 1950.

It is interesting that scientists continually reinvent the wheel or, in this case, the pump.

Introduction

The precise links between improved water supply and health benefits are difficult to document. However, all people appreciate the significance of a clean, adequate water supply. Nevertheless, an increased supply of safe water must be accompanied by certain behavioural changes that affect personal hygiene and sanitation practices before enteric diseases can be significantly reduced. These changes are complex and are not likely to occur spontaneously. The target population must be supplied with readily understood information about the benefits of change and convinced to adopt new behavioural patterns and accept new technologies. Furthermore, consumer acceptance of water and sanitation technology depends on devices that can hold up to abuse, function for long periods, and can be purchased and maintained by the villagers themselves.

The selection, development, and use of reliable handpumps that can be locally produced and installed and maintained at a reasonable price is a major step toward providing reliable, safe drinking-water supplies to rural communities. Due to many technical and economic factors, such as the complexity of engine-driven pumps and the high cost of fuel, manual pumps will continue to be used in most parts of the world, not only for potable water but also for domestic use, livestock, and irrigation.

For the past decade, senior officials of national water authorities in developing countries, along with personnel from international and bilateral agencies, have observed that one of the most important problems in rural water-supply programs is the high failure rate of conventional manual pumps. Failures occur mainly because pumps were not designed for the level of stress and abuse encountered from large user groups within rural communities. Furthermore, the materials from which they are made, mainly cast iron and steel, are not only expensive, but also not readily available locally. Consequently, many developing countries have been relying on imported pumps and parts supplied by international and bilateral donors. This has implications in terms of costs, maintenance requirements, and problems of procurement of spare parts.

For the past 6 years, the International Development Research Centre (IDRC) has been supporting research in the development of more effective pumping systems for rural water supplies. The approach taken has been to examine systematically the implications of new materials and improved pump designs. In view of the wide-spread introduction of plastics technology that has taken place in developing countries in the last decade, particular attention was focused on the polymer resins, specifically polyvinyl chloride (PVC) piping, which is widely available throughout Africa and Asia. In many respects, plastics technology is to developing countries what cast iron was to industrialized countries years ago and the vast potential of plastics has yet to be tapped.

The IDRC-sponsored design work centred on developing a simple, low-cost piston and foot-valve assembly for a manual, shallow-well pump. This stage of the research, in collaboration with the University of Waterloo, was completed in May 1977. The piston and foot-valve assembly developed at the University of Waterloo was tested at the Consumer's Association Testing Facility in England. This testing program was initiated by the Overseas Development Ministry in the United Kingdom to analyze the characteristics of 10 commercially produced manual pumps that were manufactured in industrialized countries. The project established the reliability and efficiency of the Waterloo design compared with the existing technology. The Waterloo pump differs from others in that it has been designed specifically for fabrication in developing countries, utilizing existing locally available resources.

In 1978, after the laboratory testing, research projects were set up in two countries in Africa and four in Asia to field test the pump under various environmental conditions and levels of technical sophistication with different user groups. The countries involved in this phase were Malaysia, the Philippines, Sri Lanka, and Thailand in Asia, and Ethiopia and Malawi in Africa.

The Waterloo handpump has brought clean water to rural families in Malaysia.

The primary objectives of these studies were to assess the Waterloo pump design in various field conditions for characteristics such as capacity for local manufacture, cost of manufacture, reliability and durability, maintenance capability at the village level, and technical performance. The basic piston and foot-valve design produced by the University of Waterloo was used by all the projects with some local modifications. The above-ground components were locally designed and produced in each country.

In the Philippines, the Institute for Small-Scale Industries at the University of the Philippines carried out the research in collaboration with the National Institute of Science and Technology, the Department of Local Government and Community Development, Department of Health, and the Local Utilities and Water Works Agency. In Thailand, the Asian Institute of Technology conducted the research in cooperation with the Department of Health, the Department of Public Works, the Office of Accelerated Development, and the National Economic and Social Development Board. In Malaysia, the Faculty of Engineering at the University of Malaya conducted the research in collaboration with the Environmental Engineering Division of the Ministry of Health. In Sri Lanka, the Lanka Jathika Sarvodaya Shramadana Sangamaya (the Sarvodaya Movement), which is involved in grass-roots community-development work, carried out the research.

The research included an economic analysis of cost effectiveness compared with other handpumps being used in the region. It also involved assessing the potential for rural water-supply development, making projections on the percentage of rural households that could be served by piped water, and attempting to determine the future market demand for handpumps in the region.

In August 1980, the mid-project meeting for the four Asian projects was held at the University of Malaya in Kuala Lumpur to review the projects' progress and establish common monitoring and measurement techniques. A unique method for accurately determining pump usage with a mechanical counting device, developed at the University of Malaya, was also incorporated into the field-testing program. This device made it possible to correlate measurements of wear with the distance the piston traveled or the amount the pump was used.

The activities of the four projects in Asia have now been completed and the results are encouraging. Two workshops were therefore sponsored by IDRC in collaboration with the Faculty of Engineering of the University of Malaya from 16 to 19 August 1982 in Kuala Lumpur.

For the first 2 days, the project leaders from the four Asian countries reviewed and discussed their results and assessed the overall technical and economic implications of their findings. During the last 2 days, a dissemination seminar was held to present the results to interested governmental and nongovernmental agencies from the region and to observers from various international agencies and private concerns. The status of handpump technology in the region was reviewed and new research priorities were identified.

The PVC pump demonstrated during the field trials that it holds considerable potential for use at the village level. It can be made locally at reasonable cost and is easily repaired with locally fabricated parts. However, it must be realized that, as with any technology, there are limitations. If one is looking for a "magic," maintenance-free pump, then this technology is not the answer. The results of field trials indicate that, although the pump is durable, there are limitations that must be understood and respected or malfunctions will occur. Also, failure will occur if the well is improperly developed. More importantly, the outcome of this research has clearly demonstrated that inexpensive plastics can be used in handpump manufacture, making it possible to produce pumps and spare parts locally and to incorporate designs that are simple to understand and easy to maintain at an affordable cost.

This volume deal primarily with handpump technology, but it must be remembered that the pump is more than just a convenient means of drawing water from the well. It is an essential element in public-health efforts because the only safe way to provide adequate sanitary protection from surface contamination is to seal the well and install a pump. Unless this and other public-health measures are taken to protect the well, water-related diseases will continue to take their toll.

In the coming years, limited resources will have serious consequences upon the provision of safe, adequate, water supplies for rural populations. If this problem is to be addressed, governments and water authorities must focus their resources on developing low-cost technologies that are easily understood, operated, and maintained at the village level. By publishing this volume, we hope that the results of this research will stimulate the implementation of such appropriate technology and at the same time foster new research initiatives.

Sri Lanka

Pathirana Dharmadasa, Upali Wickramasinghe, and Douglas Chandrasiri

The majority of the rural people in Sri Lanka obtain water for daily use from rivers, canals, lakes, irrigation tanks, and uncovered wells. The water from such sources is often unsuitable for drinking and most other domestic purposes. Because few people boil the water before drinking it, this results in many diseases: a fact that village people do not understand.

The Sarvodaya Movement is playing a major role in setting up health-education programs and in providing facilities for improving the health of the rural masses in Sri Lanka. One component of this program is the covered-wells program (Fig. 1). The main emphasis of this program is the introduction of low-cost handpumps made from locally available materials as a means of providing clean drinking water for household use. During this project, three new designs were developed for the above-ground components of the Waterloo pump developed with funding from the International Development Research Centre (IDRC). As well, several modifications were made to the piston and check valve, which was used in place of a foot valve, to make the pump easier to manufacture with local resources. The goal of this design work was to develop a pump that incorporated the following features: the use of low-cost materials available in Sri Lanka; easy maintenance and repair without the need for highly skilled labour; and the use of polyvinyl chloride (PVC) plastic to eliminate corrosion problems.

Organization of the Project

A preliminary survey was undertaken in January 1979 in several villages in the districts of Galle, Matara, and Hambantota to investigate: the economic situation in the villages; the existing social conditions; the irrigation facilities; and the attitudes of the villagers toward handpumps. Based on the findings of this survey, it was initially decided to install 60 pumps in six villages, but later, due to

Fig. 1. *View of well showing drainage channel to remove spilled water and stone layer to assist drainage.*

geographical and political reasons, the number was reduced to four pumps in each of five villages: Akurala Village, Talawa Village, Hingurudugoda Village, and Ginimellagaha Village in the Galle District and Yatiyana Village in the Matara District. In addition, one pump was installed at the Sarvodaya Centre office for demonstration purposes.

The project was divided into three phases: construction of the wells, installation of the pumps, and inspection and field testing. During the study, the importance of covering the wells and the health problems caused by using water from uncovered wells was emphasized to the villagers. All construction work was carried out by the Sarvodaya Rural Technical Service. The pumps were assembled and installed by the Engineering Section of the Sarvodaya Movement, and the survey work was handed over to a team selected for the purpose.

The preliminary surveying was completed by July 1979 and the construction work completed by February 1980. During February-August 1980, the pumps were installed and the monitoring work was started. Pump pistons, piston rings, fulcrum shafts, journals, check valves, check-valve bolts, and pump heads were produced at the Sarvodaya Main Centre. Parts that were easier to make were produced at the Village Centres.

Location and Construction of Wells

Careful consideration was given to the placement of wells. The wells were located at least 30 m from the nearest latrine or other source of contamination and in well drained areas devoid of surface water even during heavy rains (1 m = 3.28 ft). The wells were constructed by digging a pit and positioning a precast concrete ring in the hole. A second ring was then added and digging continued until the water table was reached. These concrete rings, therefore, formed the walls of the well. This technique was so successful that the Sarvodaya Rural Technical Service committee decided to construct all the wells in the same way. Moulds for the rings were

Table 1. Summary of material used, fabrication equipment required, cost, and quality of the components used in different pump designs.

Pump element and design	Material used[a]	Tools and equipment required	Cost (Rs)[b] Material	Cost (Rs)[b] Labour	Quality
Frame					
L1	Angle iron	Welder, hacksaw	145	90	Satisfactory
L2[c]	Concrete	Mason's tools, mould	80	60	Poor
L3	Angle iron, GI sheet metal	Drill, hacksaw, welder, sheet-metal tools	210	150	Very good
V1	GI pipe, MS plate	Hacksaw, welder, drill	30	50	Good
Handle					
L1	GI pipe, MS, brass bushings	Drill, hacksaw, lathe, welder	80	100	Good
L2	Wood	Carpenter's tools	120	80	Poor
L3	GI pipe	Hacksaw, welder, blacksmith's tools	100	100	Very good
V1	Wood, bolts, washers	Carpenter's tools, hacksaw, drill, files	12	60	Satisfactory
Piston and check valve					
1st	Wood, leather	Lathe, drill, leather cutter	10	50	Not durable, low volumetric efficiency
2nd	PVC	Lathe, drill, solvent cement, blowtorch	175	90	Leaked, broke easily
3rd	PVC, wood	Lathe, drill, solvent cement	100	50	Good

[a] Abbreviations: GI, galvanized iron; MS, mild steel; PVC, polyvinyl chloride.
[b] Rs20 = US$1
[c] Because of problems with this design, it was eliminated from the field testing. Wells originally having these pumps were fitted with L3 pumps instead.

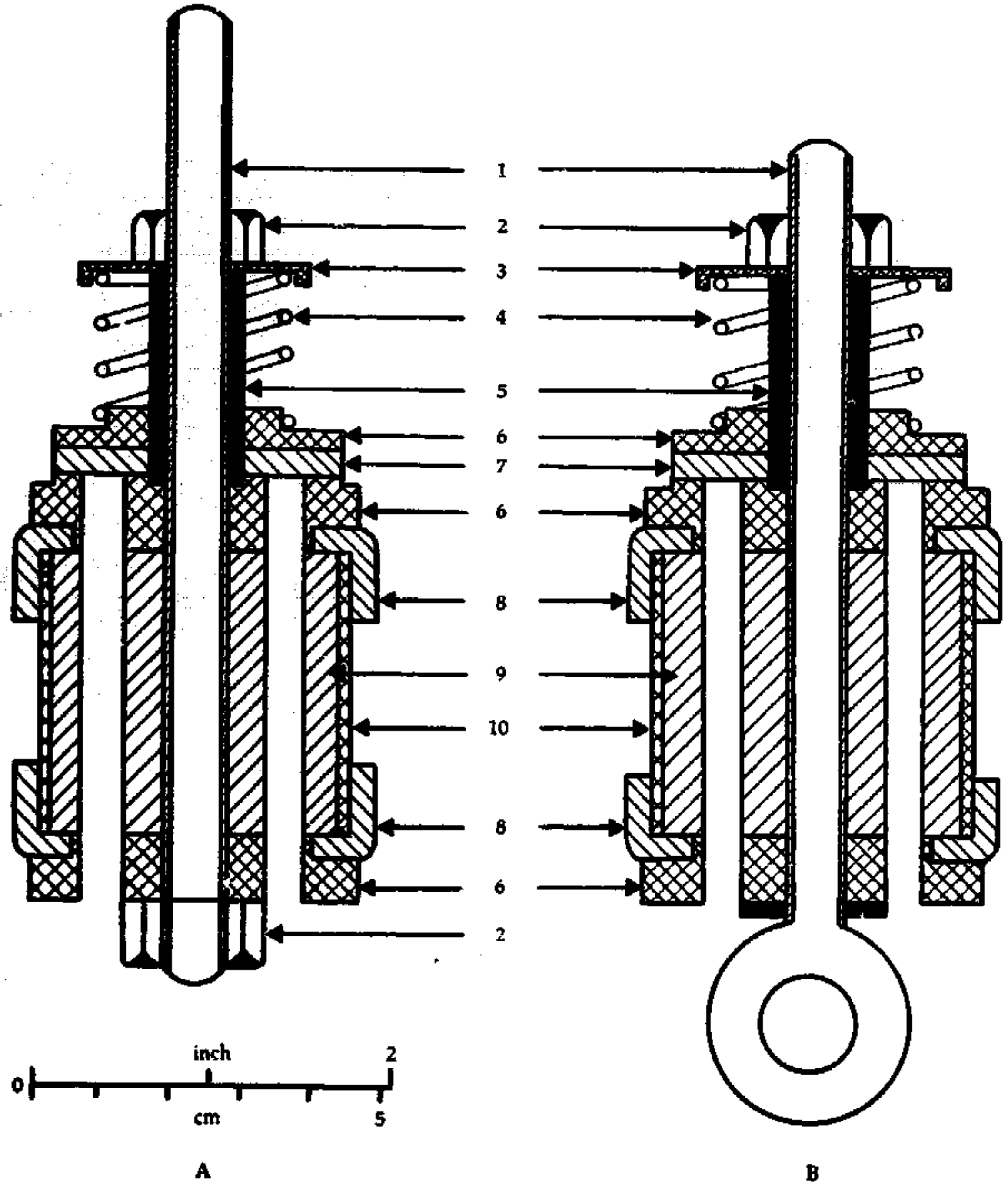


Fig. 2. *Details of (A) piston and (B) check valve used in L1 and L3 pumps: (1) "J" bolt; (2) brass nut; (3) PVC cap; (4) brass spring; (5) brass bushing; (6) PVC washer; (7) leather plate valve; (8) leather cup; (9) wood; and (10) PVC pipe.*

made out of 1/8-inch (3-mm) mild-steel plates and angle iron. These moulds were sent to the villages where the concrete cylinders were then made. In each village, the Rural Technical Section trained six persons to make the rings with the aid of the village masons.

In all cases, the well was sealed, a drainage channel was provided to remove spilled water, and a stone layer was laid to assist drainage (see Fig. 1). Access to the well was provided by a manhole in the cover. A week after construction was completed, the walls were washed and water was drawn from the well using a gasoline-engine pump.

Description of Pumps

The three pumps that were designed during this project shared essentially the same below-ground components but differed significantly in their above-ground configuration. The modifications made to both the below-ground and above-ground parts are described in detail below and summarized in Table 1.

Below-ground components

A PVC check valve based on the original Waterloo design was used in the V1-type pump; in the other pumps, however, the piston and check valve were changed to those shown in Fig. 2. In the modified pistons and check valves, a piece of wood with eight holes drilled in it is inserted in a section of PVC pipe 5 cm long with an outside diameter of 4.5 cm (1 cm = 0.39 in.). In this new design, the piston seal is obtained by using locally made leather cups. These were used instead of rings made of polyethylene, a material that is not manufactured in Sri Lanka, is difficult to obtain, and is expensive. Leather, however, is available all over the island. The PVC washers were made locally by flattening heated PVC pipe and then forming the washers on a lathe. The plate valve is made from flattened PVC pipe on which a piece of leather is glued to create a seal and prevent leaking. This change was required because severe leakage was observed when PVC and brass were used together. The use of a leather valve completely solved this problem.

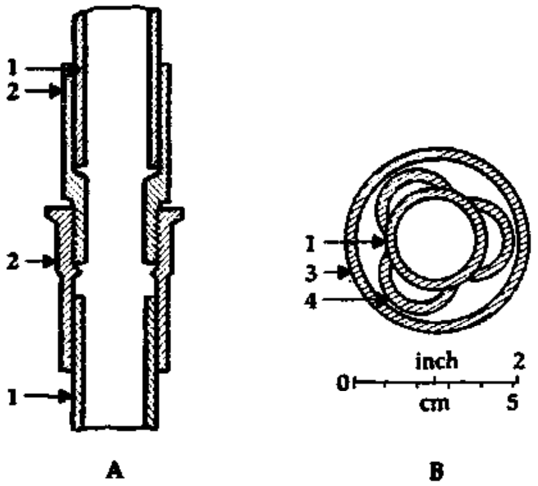


Fig. 3. *(A) Threaded PVC piston rod couplings and (B) PVC piston rod guides glued to piston rod to reduce vibration during operation of pump: (1) connecting rod; (2) threaded coupling; (3) riser pipe; and (4) rod guides.*

A piece of galvanized steel wire, used to make the spring, was held in place by a brass nut and washer. A threaded brass "I" bolt 12.5 cm long holds the parts of the piston together. A 3.5-cm long brass bushing is placed over the "I" bolt to facilitate movement of the plate valve. This bushing also ensures the proper spacing of the components of the piston and check valve and correct tension of the spring when the parts are assembled.

The connecting-rod guides in the pump cylinder are made of PVC pipe cut into sections and solvent-welded to the PVC rod.

Threaded couplings are used to join the sections of the piston rod together (see Fig. 3). Initially, the rods were joined using a bolt, but the bolts broke because of stress at the joint. The use of PVC couplings has been very successful.

Above-ground components

The L3 pump

For field-testing, a total of six of these pumps were installed. Four at Talawa and one each at Ginimallagaha and at the Sarvodaya Main Centre. These pumps were used to replace the L2 pumps that had been installed originally in these wells. The frame of the L2 was made out of concrete and used a wooden handle. The original L3 pumps also used a handle that pivoted on a bearing fixed in a concrete pedestal. Although this arrangement proved more successful than the L2 pump, it also had to be changed because of excessive, and rapid, wear of the wood at the pivot point. This meant that the handle could be lowered to the point where it would make contact with the outlet spout, resulting in a constant banging by the handle during the operation of the pump that resulted in the joint between the pump head and the spout cracking. This problem was remedied by designing a new handle that prevented overlowering and at the same time made the pump easier to operate (Fig. 4).

Frame Angle iron is used to make the square frame for this pump. Four 9-mm bolts are welded to the upper section of the frame to hold the pump head and four 12.5-mm holes are drilled in the lower section for attachment to the well (1 mm = 0.039 in.). Two brackets made of flat iron are used to

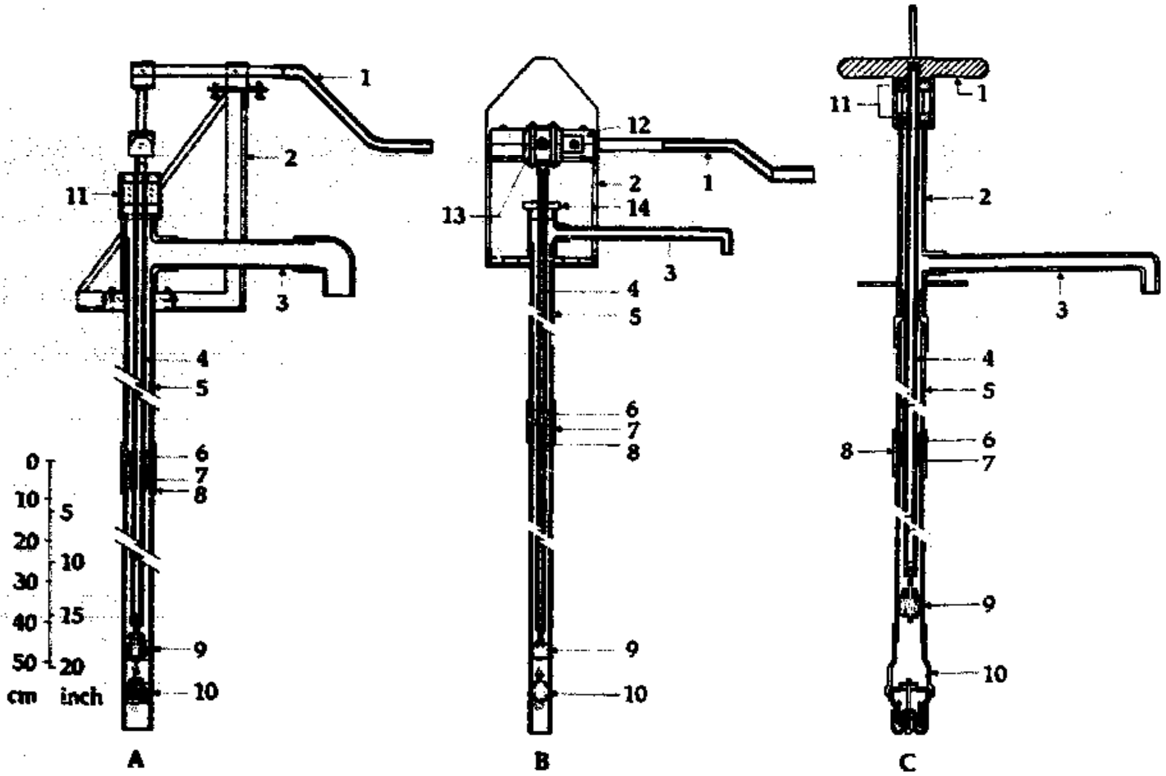


Fig. 4. (A) L1 pump, (B) L3 pump, and (C) V1 pump: (1) handle; (2) frame; (3) spout; (4) piston rod; (5) riser pipe; (6) piston rod guide; (7) piston rod joint; (8) riser pipe joint; (9) piston; (10) check valve; (11) wooden bearing and counter box (L1 and V1); (12) main bearing (L3); (13) big-end bearing (L3); and (14) counter base (L3).

hold the riser pipe. One is welded to the lower section of the frame, the other is fixed to the stationary bracket with 6-mm bolts (see Fig. 5).

Bearings Wood (satin or palu) is used for both sets of bearings. One set is fitted to the piston rod. The other set is used for the pivot point in the handle and is designed so that the bearing can be reversed once wear is excessive, thus prolonging the life of the bearing (Fig. 5).

Spout The spout is made of 25-mm galvanized pipe. The pipe is filled with sand to prevent crimping and bent using heat on a specially designed jig made by the project staff. The other end is threaded to fix it to the pump head.

Connecting rod A 19-mm PVC pipe is used for the piston rod. The sections of the rod are joined using threaded PVC couplings and the rod is connected to the piston using a threaded brass coupling.

Frame cover A galvanized sheet-metal (22 gauge) cover is attached to the frame with nuts and bolts. The upper section, which can be removed, is tapered to protect the pumping mechanism from rain, which is important for prolonging the life of the wooden bearings. The removable cover also allows easy access for inspection and maintenance.

Handle Originally, the handle was mounted on one side of the pump frame. However, this design caused excessive wear on the wooden bearing and thus the design was changed. The handle is now made of 12.5-mm galvanized pipe and two pieces of flat iron (see Fig. 5). This handle was designed to increase the life of the wooden bearing, make the pump easier to use, and at the same time limit the length of the stroke. When the handle is lowered too far, the user's hand bangs on the iron spout. This simple design feature not only protects the internal parts of the pump from damage but also allows the pump to be locked with a chain and padlock if desired.

The L1 pump

Six of the L1 pumps were installed in Baddegama, three at Ginimallagaha, and three at Hingurudugoda. The above-ground

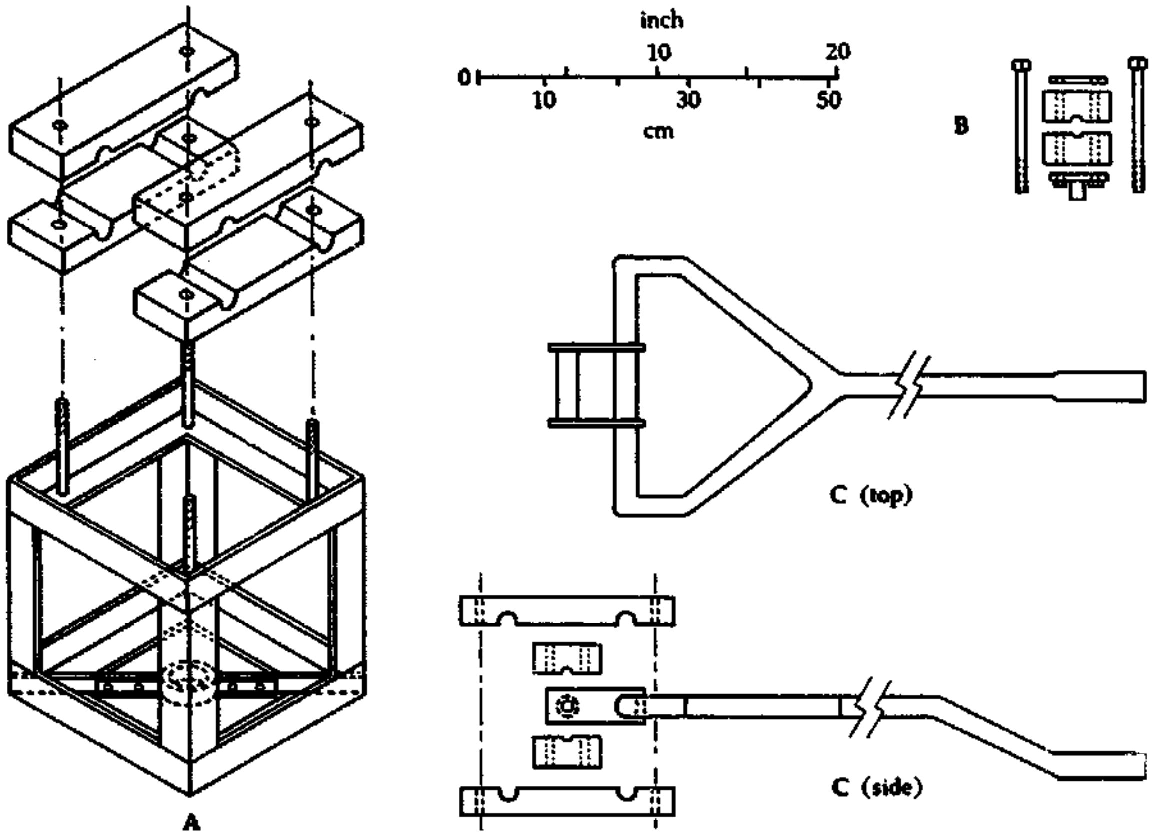


Fig. 5. Details of L3 pump: (A) frame and wooden bearings, (B) big-end bearing, and (C) final handle design showing position of wooden bearings.

components of these pumps (see Table 1 and Fig. 4) worked well and did not require modification. Originally, a 7.5-cm cylinder was used for the riser pipe and a 5-cm pipe was used for the above-ground portion of the pipe. However, this meant that the 7.5-cm piston could not be removed for repairs without cutting the cylinder. To make repairs easier and to save time and labour, a 5-cm piston is now used along with a 5-cm pipe for the entire length of the riser pipe and cylinder.

The V1 pump

Nine of the V1 pumps (Fig. 4) have been installed: four at Akurala; four at Yatiyana; and one at Hingurudugoda. The wells at these sites are 3–4 m deep. The above-ground components of this pump were modified based on our experience, the results of the field testing, and the suggestions of the users. We found that the original metal handle made this pump difficult to operate, therefore we switched to a wooden handle. We also discovered that the piston could be pulled out of the cylinder during use so we installed a simple metal bracket to prevent over-raising (see Fig. 6). The cost of this pump is low; about US$75 for the complete pump to draw water from 3 m. However, because there is no lever mechanism in the design, the user must lift the full weight of the water in the column, thus making extensive use tiring.

Frame The pump frame is made of 5.1-cm galvanized pipe. A galvanized plate is used to fix the frame to the well and a 2.5-cm socket is welded onto the frame for attachment of the spout.

Spout The spout, made of 2.5-cm pipe, is screwed to the pump frame. The other end of the spout is bent, using heat, to an angle of 90°.

Handle Hard wood such as satin and jak is used to make the handle, which is held in place by a bolt. The pump is very easy to operate, but usage for a long period can be tiring. In a few instances, the wooden handle broke when the pump was in operation; however, it is interesting to note that the people in the village can easily make a new handle themselves.

Main pipe PVC pipe, 5 cm in diameter, is used for the riser pipe. Although the outside of the pipe is smooth, the inside is rough and not completely round because of local manufacturing problems. Because of these problems, it was impossible to obtain an adequate seal in the piston and check valve using PVC rings. Instead, leather cups that could be made in the villages were designed to solve this problem. These cups were made using a simple press and a locally fabricated die. The leather was treated with tallow and held in the press for about 30 minutes to acquire the required shape. These cups have been used for more than 1 year and continue to give good results. Problems were also encountered when the locally available couplings were used to join the 5-cm riser pipe. These couplings produced poor quality joints and, because of their configuration, left a ridge in the joined pipes. This ridge created a problem because the leather piston cups stuck at the joints making it impossible to remove the piston except by cutting the riser pipe. To overcome this problem, the pipes were joined by making bell joints. The end of the PVC pipe was dipped in hot coconut oil to soften the plastic and then it was forced over a locally made metal form to increase its diameter enough to fit tightly over the normal end of the adjoining pipe. The pipes could then be joined with solvent cement. This system has worked well and allows the piston to be removed easily for maintenance and repair.

Technical Assessment

During the course of the field testing, a number of design modifications using locally available materials and expertise were introduced to solve problems. Extensive measurements were also made of the wear of the piston rings, piston plate valve, check valve, journals, fulcrum shaft, and connecting rod to assess the durability of these pumps under field conditions. The technical performance of the pumps was also measured with the aid of a specially mounted counter (see Fig. 6). This counter measured the length of each stroke of the piston and thus gave a reading on the amount of use of the pump. The volumetric efficiency of the pump was calculated from: volumetric efficiency = (actual discharge × 100)/

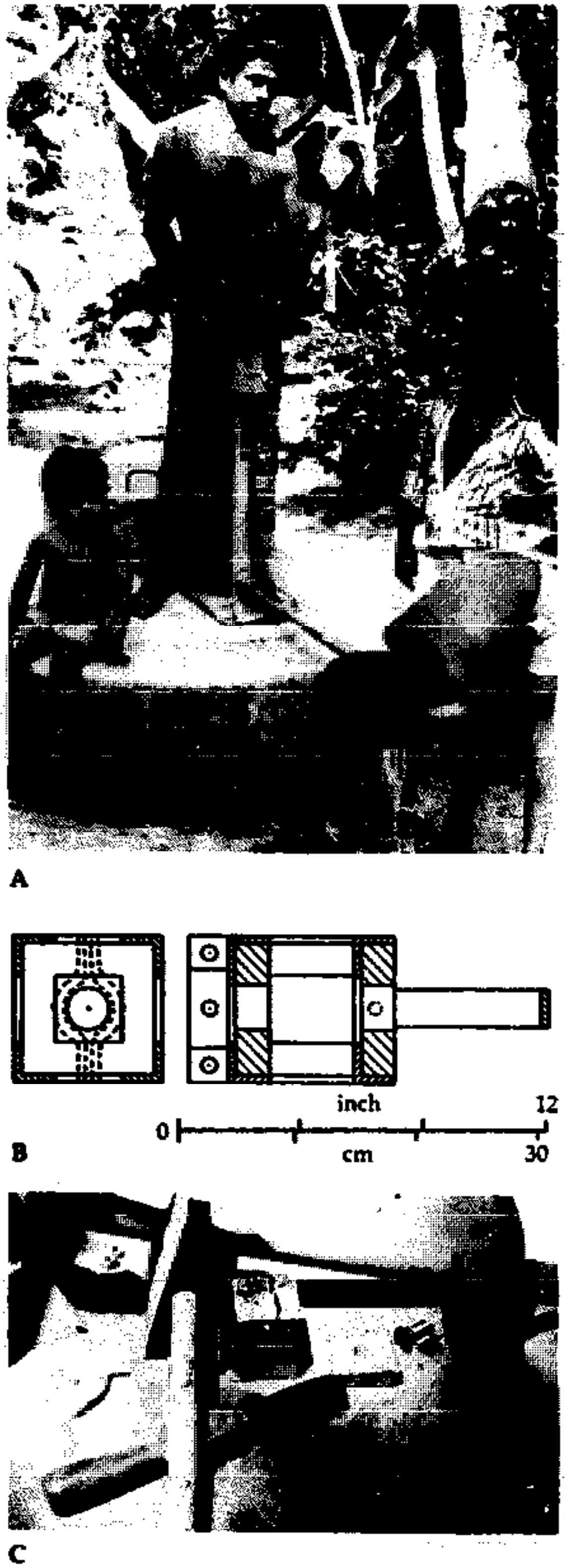


Fig. 6. *(A) Stop and counter box attached to V1 pumps, (B) details of counter installation, and (C) counter assembly from V1 pump.*

(cylinder area × length of standard stroke). The mechanical efficiency of the pumps was also calculated.

During the initial stages of the testing, many pumps malfunctioned because the joints in the piston rod broke. The galvanized bolts used to join the sections broke after about 3 months of use due to vibration of the piston rod during operation of the pump. In addition, the holes drilled in the piston rod at the joints caused weakness and, occasionally, breakage of the rod. The rods are now joined with threaded PVC couplings that are readily available locally. The couplings are glued to the ends of the rods and the rods are screwed together. This method has been very satisfactory. As well, guides made of sections of PVC pipe were attached to the piston rod (see Fig. 3). These guides reduced the amount of vibration of the piston rod and thus reduced some of the fatigue problems.

In the L1 pump, a 7.5-cm diameter pipe was used as the pumping cylinder to increase the output of the pump; however, this caused problems because the piston could not be raised above the cylinder section as the riser pipe was of smaller diameter. To remove the piston for repair or maintenance, the cylinder had to be cut. Therefore, in all pumps, we now use 5-cm pipe throughout the entire length of the riser pipe and cylinder. One problem still remains with the riser pipe: the joints in the pipe occasionally separate during pumping because of the vibration of the pipe. However, this problem was only observed when the riser pipe is more than 5 m long. For shallower wells, this has not been a problem.

Because the riser pipe was open at the end, the original check valve with polyethylene rings frequently dropped into the well: again because of vibration during operation of the pump. The use of leather cups in the valve seems to have solved this problem. For additional security, the end of riser pipe is heated and crimped to prevent the check valve from falling into the well. A screen placed over the end of the riser pipe was also used to correct this problem but crimping the end of the pipe was found to be more practical.

Local fabrication of the Waterloo piston and check valve cause considerable difficulty because solid PVC stock is not available in Sri Lanka. Several attempts were made to improvise with locally available materials. Initially, we tried making a "solid" rod or cylinder by gluing progressively smaller PVC pipes inside one another. Problems were encountered with this design because, when grooves were cut for the piston rings, the ends of the rod tended to break off. It was also very difficult to drill holes along the length of this "built-up" pipe. Next, we tried to fabricate the piston and check valve from wood and still use polyethylene rings as a seal. Although the construction of the valves was easier, they were not successful because the piston rings stuck in the grooves and did not seal properly against the wall of the riser pipe. Also, a poor seal resulted because of the rough inside surface of the PVC pipes available in Sri Lanka. This rough surface also quickly wore the polyethylene rings, resulting in burrs on the edge of the rings, which contributed to their sticking in the grooves.

The problems related to these valves were eventually solved by using a design that combined a hollow PVC pipe with a wooden core and employed leather cup seals. This design (see Fig. 2) completely solved the leakage problem. Not only was the problem of leakage remedied but the wear of the riser pipe was also lessened. When polyethylene rings were used during field testing, the riser pipe wore by 0.35 mm after 90 days of use. This is believed to be due to silt particles becoming embedded in the rings and acting like sandpaper against the cylinder wall. Similar tests with leather cups produced much less wear. This design makes local fabrication and repair possible and it has proven its reliability under field conditions for over 1 year.

During the field testing of these pumps, two types of check valves were tried. In the V1 pumps, a check valve using a rubber plate valve was screwed into the bottom of the riser pipe. However, a retrievable check valve of the same design as the PVC-wood piston was used for the L1 and L3 pumps. A rubber plate valve was used in the V1 pump and it worked very well (Fig. 7). But, because it is screwed to the riser pipe, its use is only practical in shallow wells where it is easy to remove the entire length of riser pipe to service the valve. The PVC-wood valve (Fig. 2) used in the L1 and L3 pumps can be extracted without removing the riser pipe. Because it incorporates leather cups and a PVC-leather plate valve, the villagers can easily repair worn parts themselves. Rubber suitable for the plate valve used in the V1 pump, on the other hand, is not so easily

Table 2. Overview of performance data,[a] measurements of wear, and maintenance and repair required.

Pump type and number	Number of users	Volumetric efficiency (%)	Water head (m)	Avg water output (L/day)	Percentage wear			Down time (days)	Maintenance and repairs	
					Piston rings	Cylinder	Journals		Parts (US$)	Time (hours)
V1 pumps										
BA 01	73	80	3.4	900	12	7.5	11	7	17.70	3.25
BA 02	50	65	1.5	403	22	9	12	6	11.75	3.50
BA 03	48	91	1.4	115	15	10	22	4	11.25	2.00
BA 04	56	74	1.4	285	12.5	5	21	5	11.10	2.00
BH 15	44	62	2.9	821	13	8	21	3	3.50	2.00
MY 17	17	85	2.4	292	3.8	2.5	20	3	5.00	2.00
MY 18	21	69	2.9	726	11	5	23	-	-	-
MY 19	43	73	1.8	389	13	5	22	4	4.75	1.50
MY 20	34	55	1.2	49	16	2.8	11	3	1.25	0.25
L3 pumps										
BT 05	21	77	3.0	513	14.1	7	8	6	14.00	4.50
BT 06	27	84	2.3	400	15	5.2	7	6	18.75	6.00
BT 07	62	75	5.4	536	14.6	8	8.8	6	10.00	4.75
BT 08	29	69	6.0	476	12	5.8	12	6	8.50	5.75
BG 12	32	86	7.9	340	11.5	7.9	9	7	12.00	6.25
MC 21	50	80	5.9	100	-	-	-	1	-	1.00
L1 pumps										
BG 09	46	99	3.5	490	7	9.2	1.3	11	19.00	6.50
BG 10	52	87	5.3	875	5.5	3	1	10	20.00	7.00
BG 11	58	89	6.6	832	13	5	2	11	15.00	4.50
BG 13	42	88	2.8	930	12	5.7	1.6	6	14.50	3.50
BG 14	33	92	2.5	705	6	5.5	1.4	8	15.85	5.25
BH 16	76	93	3.3	972	4.8	10.5	2	7	2.50	3.50

[a] 1 m = 3.28 feet; 1 L = 0.22 gallon.

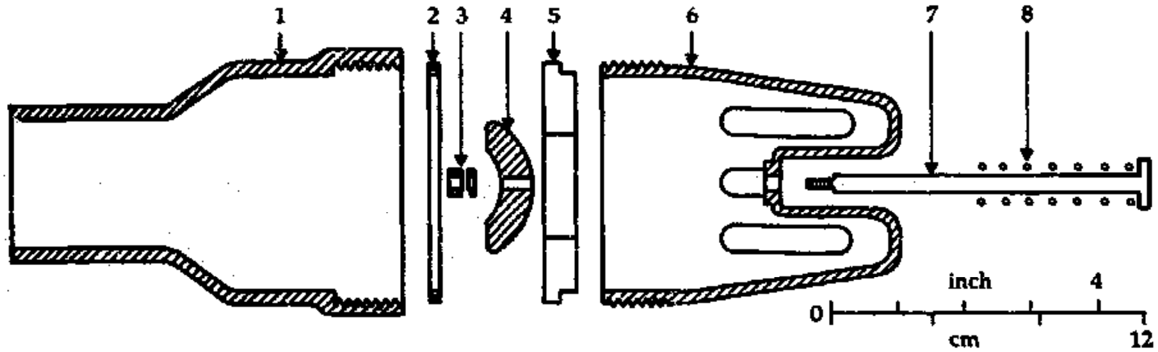


Fig. 7. *Details of check valve used in V1 pumps: (1) PVC cover; (2) rubber ring; (3) brass nut and washer; (4) rubber check valve; (5) PVC plate; (6) PVC screen; (7) brass bolt; and (8) brass spring.*

obtained and is more expensive.

Using the mechanical counting device, it was possible to determine the amount of usage of each pump. Estimates were then made on the average water output in litres per day, the distance the piston had traveled, and the amount of wear each component had undergone in relationship to usage. Table 2 provides a summary of performance data collected from March 1981 to April 1982. The results of this monitoring indicated that the L1 pump experienced the least amount of wear and maintained the highest volumetric efficiency. This was probably due to the leather cup seals. Because it was not possible to purchase high quality PVC piping, i.e., most pipes were out-of-round and were rough on the interior surfaces, the initial wear on the polyethylene rings was substantial until abrasion shaped the rings to the interior configurations of the cylinder. Wear on the journals (bearings) varied greatly according to the material used. For example, the brass bearings used in the L1 pump wore a maximum of 2%, whereas wear on the wooden bearings used in the L3 pump was as much as 23%. It was found that, although wooden bearings are more subject to wear, this wear does not hinder the operation of the pump; in contrast, as little as 1 mm of wear on brass bearings makes the pump difficult to operate.

It was interesting to note that, of the three pumps tested, type L1 was subjected to the largest user groups, the average being 51 persons. Type L3 experienced the least amount of usage with an average of only 37 persons per group. An average of 42 persons per group used pump V1. Even with the larger numbers of people using the L1 pump, the breakdown rate was not any higher than the L3 model. The V1 model, or direct action pump, had the lowest breakdown rate.

To conclude, although the original concept of the Waterloo design was to utilize polyethylene rings to create a seal between the piston and cylinder and the foot valve and cylinder, this was not successful due to the poor quality of the PVC piping and the fact that polyethylene is not easy to obtain.

Because leather is easily accessible and inexpensive, this was the logical alternative. Using a metal die, it was fairly easy to shape the leather into the desired form. This technique is simple enough to be mastered by a village worker. Although the L1 angle-iron pumps were durable, wear on the brass bearings made their operation difficult. It was, therefore, more practical and less expensive to use the wooden bearings, as in the L3 model, even though they required more frequent maintenance.

We feel that the pump that has been developed as a result of this IDRC-supported project is durable, can be produced at a reasonable cost, and can be maintained at the village level with very little special training.

Acknowledgments The Waterloo pump research program was carried out by the Lanka Jathika Sarvodaya Shramadana Movement (Inc.) Sri Lanka and sponsored by IDRC. We wish to express our sincere thanks to: the Sarvodaya Coordinators in the Galle District, Mr Danny Dissanayaka, and the Matara District, Mr P. Hewavitharana; Mr Karl Wherle, Mr Thomas Zimmerman, and Mr Gunapala Ganegama of the Rural Technical Section Unit, Sarvodaya, Moratuwa; and to all the workers in the Sarvodaya Gramodaya Centres and the people who helped us to make this task a success.

Thailand

Pichai Nimityongskul and Pisidhi Karasudhi

The National Economic and Social Development Board of Thailand reports that more than 80% of the people in Thailand live in rural villages and that only 40% of these people have access to a safe water supply. Although people in the urban areas have a relatively good quality water supply, the supply in rural communities is far from adequate. In rural areas, potable water and water for other domestic purposes is obtained from various sources: rainwater catchment, deep or shallow wells, reservoirs, ponds, and streams. Of these sources, water from deep or shallow wells is the safest in terms of protection from waterborne diseases.

Approximately 90% of the existing wells in Thailand use handpumps and over 5 million people depend on these handpumps to obtain their water for consumption and other domestic uses. As a result, handpumps are an integrated part of the life of the rural people and the operation and maintenance of these pumps poses a challenging task. It is estimated that the cost of repair and maintenance of the 7000 handpumps installed by the Department of Mineral Resources alone is over US$500 000 annually. Furthermore, NIDA (1978) reported that, based on a random sample, roughly 5000 of the 19 000 handpumps installed in Thailand by different government agencies were out of operation on any given day.

Purpose and Scope of the Project

The main objective of this study was to test, under various field conditions, the handpump developed at the University of Waterloo and subsequently to modify and optimize the handpump design to suit local conditions. Specifically, the aim of this study was to: (1) conduct a review of the handpumps currently used by the five main government agencies responsible for rural water supply in Thailand; (2) carry out laboratory tests on various handpump types, including the Waterloo pump, to compare their performance and endurance under various conditions; (3) install and conduct field tests of the Waterloo handpump configuration; and (4) based on the field and laboratory test results, adapt and improve the Waterloo design and field test the modified handpump under village conditions.

This project was sponsored by the International Development Research Centre (IDRC) and carried out with the cooperation of the following Thai government agencies: Department of Mineral Resources (DMR), Ministry of Industry; Department of Health, Ministry of Public Health; Department of Public Works, Ministry of Interior; Office of Accelerated Rural Development (ARD), Ministry of Interior; and Agricultural Technology Office, Ministry of Agriculture and Cooperatives. In addition, the National Economic and Social Development Board of the Office of the Prime Minister served as the coordinator for these agencies.

Review of Existing Handpumps in Thailand

Historically, the existing handpumps in Thailand originated from Europe and North America and were designed for use by a single family in the developed countries. In developing countries, the pump was shared by many people living in the rural community and, because of the increased usage, it broke quite often and, in most cases, could not be repaired by the villagers. According to the ARD Office (1980), several different types of handpumps have been installed in Thailand by different government agencies. However, the different handpumps in Thailand can be broadly classified into two groups: the DMR handpumps and the ARD handpumps.

The prototypes of the handpumps from the DMR are the Demster, Red Jacket, and other handpumps donated by, or procured from, the United States of America. This type of handpump has a three-pin lever with a cross head and a cylinder that generally has a plunger with two leather cup seals and a poppet valve at the plunger. The lower valve consists of a spring-activated poppet and the pump has a 3-inch (7.5-cm) cylinder, 7/16-inch (11-mm) pumping rod, and 1.25-inch (3-cm) drop pipe (riser pipe). The inlet-valve lining, piston cup, top gasket, and cylinder gasket of these pumps are made of leather, whereas the spout gasket is made of rubber. There are 42 different components and most of them are made of brass. Cold-drawn steel is used for the cylinder reducing coupling, bottom fulcrum pin, and piston rod.

The handpumps provided by the Public Work Department are also included in this group because they are similar to DMR handpumps except that the drop pipe is slightly larger (1.5-inch, 3.8-cm diameter).

The ARD handpump, which is usually called the Korat handpump, has been adopted by the Department of Health, the ARD Office, and the Local Administration Department. The pump mechanism consists of a rack and pinion (gear type). Leather is used for the piston seal, gasket, and bushing seal. All of the packing nut caps, valves, locks, and handle gear bushing are made of brass. The pump has a 3-inch (7.5-cm) cylinder and 1.25-inch (3-cm) drop pipe and is composed of 32 components.

There is a slight difference in the handpump supplied by ARD. It is essentially the same as the Korat handpump except that it has a 3-inch (7.5-cm) cylinder made of polyvinyl chloride (PVC) and 1.25-inch (3-cm) drop pipe. The pumps supplied by the Local Administration Department are normally used for shallow wells.

The advantages and disadvantages of the DMR and ARD handpumps are summarized in Table 1.

In the Waterloo handpump, basically, all the components are made of rigid PVC and polyethylene, which are low cost commodity polymers. These plastics have been selected for ease of manufacture and low cost as well as for their efficiency. The below-ground components consist of a PVC well casing that also functions as the pump cylinder for the plastic piston. The plastic foot valve is constructed of components that are common to the piston (Fig. 1). The flow of water in the piston and foot valve is regulated by simple rubber plate valves. Polyethylene piston rings provide adequate hydraulic seals on the piston with much less frictional resistance than leather cups or rings. It has been found that wear is concentrated on the rings, which can be replaced easily, rather than on the well casing. The foot valve can be removed easily for inspection or repair and serves as a reserve piston whenever necessary. Both 2-inch (5-cm) and 3-inch (7.5-cm) diameter pistons were used in this study.

The pistons and foot valves for the Waterloo pumps were made at the Asian Institute of Technology (AIT) using locally available PVC rods. The piston rings and foot-valve adapters were made from polyethylene supplied by IDRC. Based on the results of the laboratory and field tests, the piston and foot valve were later modified.

Table 1. Advantages and disadvantages of existing handpumps in Thailand.

DMR	ARD
Advantages	*Advantages*
The air chamber of the above-ground component helps maintain a continuous flow of water The handle is made of a single piece of cast iron having appropriate shape and size, hence it is easy to operate and is durable	Vertical movement of the pumping rod is by using a rack and pinion There are fewer moving parts subject to wear and tear The shock-absorbing spring prevents the plunger from slamming against the upper and lower parts of the cylinder
Disadvantages	*Disadvantages*
Direct contact between the axle and the bushing causes rapid wear If the axle breaks, the handle can move horizontally and may damage other parts The contact area between the axle and stuffing box is relatively loose. This can result in eccentric movement of the pumping rod and reduced pump efficiency The plunger could slam against the upper and lower parts of the cylinder if not properly installed The cast-iron fulcrum link is not strong enough and, under repeated use, tends to break	The flow of water is not continuous due to the absence of an air chamber The handle and pinion are separate parts and failure often occurs at this joint

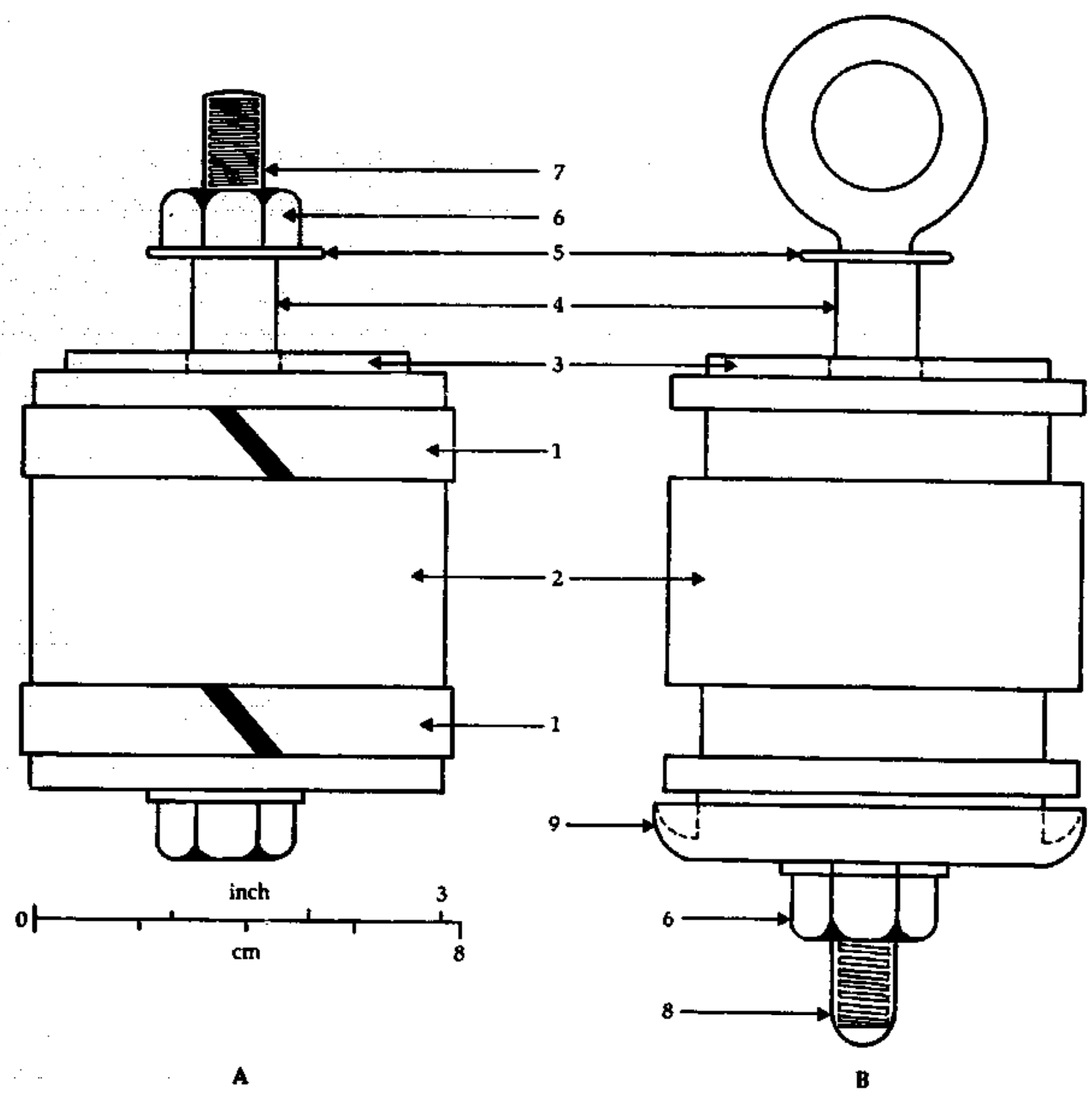


Fig. 1. *(A) Piston and (B) foot-valve assembly of Waterloo handpump: (1) polyethylene ring; (2) piston; (3) PVC plate valve; (4) brass valve guide; (5) flat washer; (6) nut; (7) bolt; (8) bolt with eye; and (9) polyethylene foot-valve adapter.*

Laboratory Testing

Laboratory tests were carried out in the Structural Engineering Laboratory, AIT, for all three handpumps. The DMR and ARD handpumps were supplied by various government agencies and the Waterloo handpumps were made at AIT. The parameters that were varied were: stroke length of the piston, orifice/piston area ratio, and rate of pumping.

A steel platform, 4 m high, was erected and a mechanized rocker arm was installed on this platform to drive 12 sets of handpumps

Table 2. Testing program for Waterloo handpump.

Orifice/piston area ratio (%)	Speed of piston (strokes/min)	Piston stroke length (inch)[a]					
		3	4	5	6	8	10
12.5	20	X	X	X	X	X	X
17.0	30	X	X	X	X	X	X
22.2	40	X	X	X	X	X	X
	50	X	X	X	X	X	X
	60	X	X	X	X	X	X

Note: For all three orifice/piston area ratios, tests were made for each piston speed and stroke combination. Each X represents a single test that was carried out twice.

[a] 1 inch = 2.54 cm.

simultaneously. A head simulation system was also fabricated to test the performance of the handpumps under different water heads.

A detailed testing program for the Waterloo handpump was undertaken (Table 2). In this table, the orifice/piston area ratios of 12.5, 17.0, and 22.2% represent an opening in the piston area of eight holes each having a diameter of 3/8 inch (9.5 mm), 7/16 inch (11 mm), and 1/2 inch (12.5 mm), respectively. For each series of tests, the discharge for 10 strokes of the piston was measured using a bucket and a graduated cylinder. The test was performed twice and the average value was recorded. The volumetric efficiency was defined as actual divided by theoretical discharge times 100 where the theoretical discharge is equal to the stroke length multiplied by the cross-section of the cylinder.

In addition to the tests on the performance of handpumps, several other tests were also conducted.

The mechanical properties — tensile, compressive, and fatigue strengths — of the PVC material were determined. A 300-kN universal testing machine was used for the tension and compression tests. For the fatigue test, a servo-pulsator having a capacity of 15 t was used.

Leakage was tested to check the performance of the foot valve, which was the modified foot valve that was installed in the field.

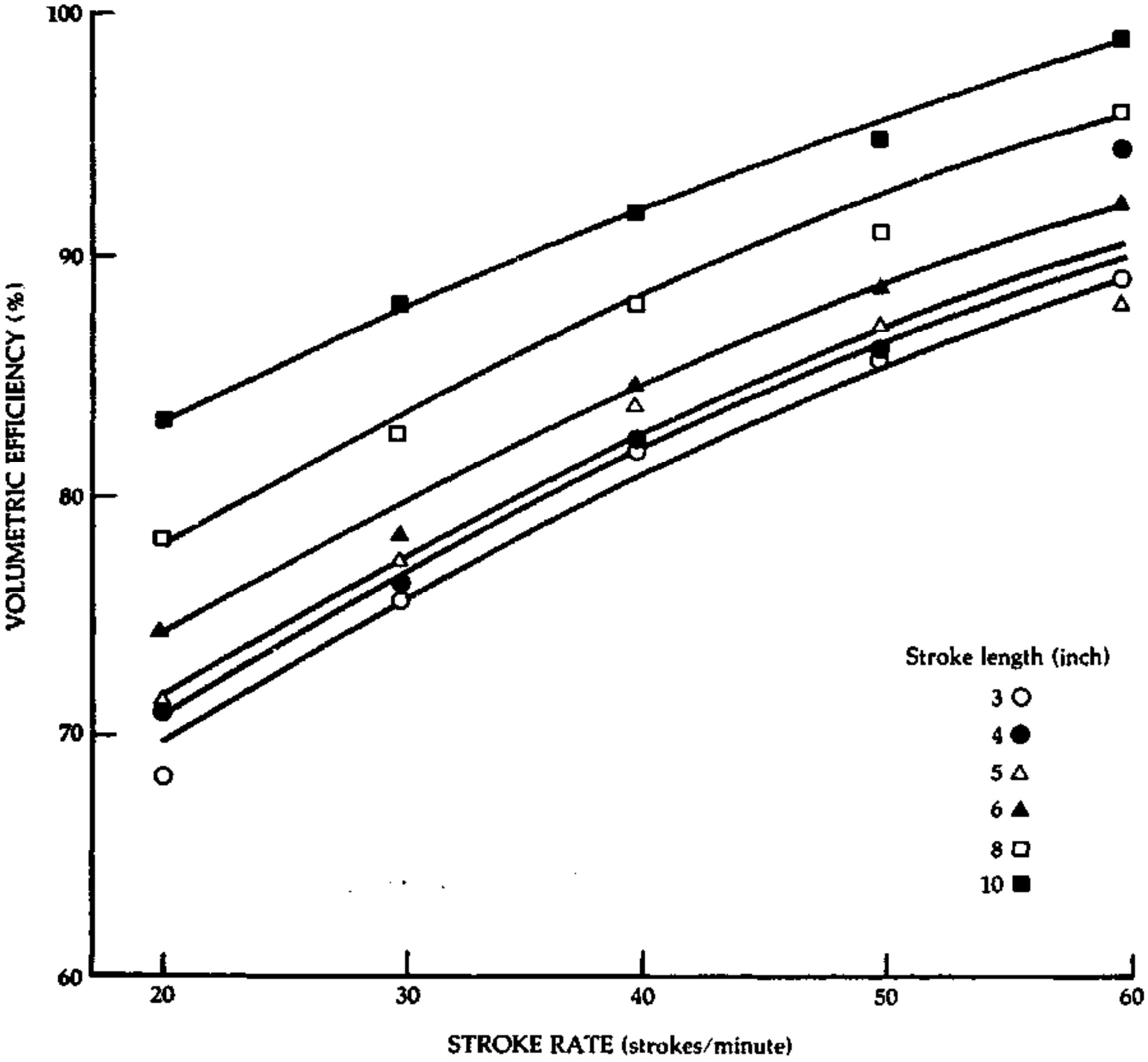


Fig. 2. *Influence of stroke lengths on volumetric efficiency of Waterloo pumps having 12.5% orifice/piston area ratio. (Water head, 15 feet (4.57 m); piston diameter, 3 inches (7.5 cm); valve gap, 0.25 inch (0.6 cm); piston foot-valve clearance, 12 inches (30 cm).)*

The tensile strength of the PVC pipe joint used in final design of the PVC system was determined for 3/4-inch (2-cm) and 3-inch (7.5-cm) diameter pipes. The joint was made using a PVC coupling.

Results of laboratory testing

Performance of handpumps

The influence of piston stroke length on the volumetric efficiency of Waterloo pumps having orifice/piston area ratios of 12.5, 17.0, and 22.2% was plotted against the speed of the piston for all pumps. An example of the result is given in Fig. 2. The piston diameter, the gap of the foot valve, the piston foot valve, and the water head clearance were kept constant throughout these tests. The volumetric efficiency of the pump increased as the piston stroke length as well as the speed of the piston increased. The influence of orifice/piston area ratios on the volumetric efficiency of Waterloo pumps having piston strokes of 4, 6, and 8 inches (10, 15, and 20 cm) were also determined. The results for a 6-inch (15-cm) stroke are given in Fig. 3. The results indicated that, for a piston stroke of 4 inches (10 cm), the orifice/piston area ratio had little effect on the volumetric efficiency of the pump. However, for longer piston strokes, the volumetric efficiency of the Waterloo pump increased as the orifice/piston area ratio increased.

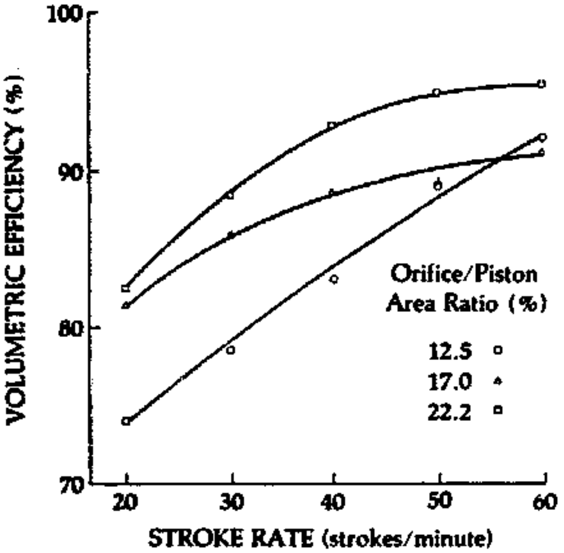


Fig. 3. *Influence of orifice/piston area ratio on volumetric efficiency of Waterloo pumps having 6-inch (15-cm) stroke length. (Water head, 15 feet (4.57 m); piston diameter, 3 inches (7.5 cm); valve gap, 0.25 inch (0.6 cm).)*

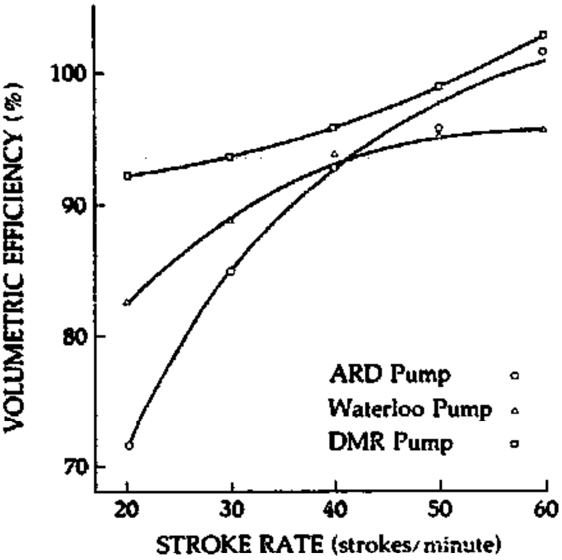


Fig. 4. *Comparison of volumetric efficiencies for different pumps having 6-inch (15-cm) stroke length.*

The performance of DMR and ARD handpumps under laboratory conditions was also plotted. At low speeds of piston movement, the volumetric efficiency of ARD handpumps was lower than that of DMR handpumps. At higher speeds of piston movement, however, the volumetric efficiency of ARD handpumps improved significantly. At very high piston speeds, the volumetric efficiency of the DMR handpumps exceeded 100%. This can be explained by the fact that, when the pump is operated at very high speed, extra water from the riser pipe is pumped up.

The volumetric efficiencies of the existing handpumps and the Waterloo handpumps having piston strokes of 4, 6, and 10 inches (10, 15, and 25 cm) were compared. Figure 4 depicts the comparison for a stroke of 6 inches (15 cm). At low piston speeds, the volumetric efficiency of the Waterloo handpump was between that of the DMR and ARD handpumps. At higher piston speeds, however, the volumetric efficiency of the Waterloo handpump was the lowest of the three. For a piston stroke of 10 inches (25 cm), the performance of all three handpumps was similar.

Other tests

The tensile and compressive strengths of PVC material were determined to be 5370 and 10130 lb/inch^2 (37025 and 69844 kPascal), respectively. In the fatigue test, the mechanical properties of PVC were considerably influenced by the temperature rise that was induced by repeated loadings. During field operation, however, the PVC piston is not subjected to continuous repeated loading as simulated by the servo-pulsator.

The leakage test was carried out by completely filling the riser pipe with water and allowing it to leak through the foot valve for 1 day. Test results indicated that there was nc water leakage by the modified foot valve for a water head of 5.00 m (16.4 feet). Both rubber and plastic seals were tested and the same results were obtained.

The variation of strength with curing time for joints in 3-inch (7.5-cm) and 3/4-inch (2-cm) PVC pipes was also tested. The tensile strength of 3-inch (7.5-cm) joints reached over 120 kg/cm^2 after curing for 15 minutes, which can be regarded as the initial setting time of the solvent cement.

During laboratory tests, it is impossible to simulate the actual field conditions to which the handpumps will be exposed, especially using the head simulation system. Other relevant factors such as the quality of the water in the wells, the rate of pumping or speed of the piston, the direction of the force exerted on the pump rod, and the condition of the above-ground components must also be taken into account. Therefore, the Waterloo piston and foot valves were monitored under field conditions.

Field Testing

The wells that were selected for field testing of the Waterloo pump were used daily by the villagers in the community. Normally, the selected well was equipped with either a DMR or ARD handpump and only the below-ground components (cylinder, piston, and foot valve) were replaced by the Waterloo components. If the replaced components did not perform as well as the old ones, or the pump did not function normally due to the replacement, the villagers had to find a new source of water and complained. It was, therefore, important for the working team to ensure that the components that were installed in the well functioned properly. Hence, the following modifications were made to the PVC components, based on the laboratory tests, before the pumps were installed in the field.

Modifications

PVC cylinder

The cylinder suggested by the University of Waterloo was ordinary PVC pipe that could be obtained in the local market. When the PVC cylinder was installed for testing in the laboratory, failure occurred at the joint between the steel cap and the PVC cylinder. One solution was to increase the thickness of the PVC cylinder, but it was found that the new cylinder was too costly. The solution that was adopted incorporated a steel casing with a PVC lining. Figure 5 shows the details of the modified 3-inch (7.5-cm) diameter cylinder together with its steel cap. The steel casing strengthens the upper and lower joints and the PVC lining is required to reduce the wear of the polyethylene piston rings.

PVC piston

The details of the original piston are shown in Fig. 1. However, problems were encountered with breakage of the top and bottom ribs of the piston, which are the weakest parts of the piston. Failure was due mainly to the ribs hitting the wall of the cylinder repeatedly when the pump rod moved eccentrically. To prevent this, the thickness of the top and bottom ribs was doubled from 1/4 inch (6 mm) to 1/2 inch (12 mm). The details of the modified piston are shown in Fig. 6.

Foot valve

The foot-valve assembly of the Waterloo handpump is shown in Fig. 1. This foot valve was originally attached to the cylinder wall with a polyethylene adapter that sealed tightly against the cylinder wall. However, because the inner surface of the PVC cylinder was not perfectly round and smooth, water leakage occurred at the foot valve. Another problem was that sand particles often became trapped between the PVC plate valve and the upper face of the piston, resulting in additional water leakage. The first attempt to solve this problem was to replace the polyethylene adapter with drilled stainless-steel plates, place a compression spring on top of the plate valve, and glue a thin piece of rubber to the PVC plate.

One problem that remained after the first modification was that sand particles trapped inside the grooved portion of the piston caused wear. To solve this, the idea of using

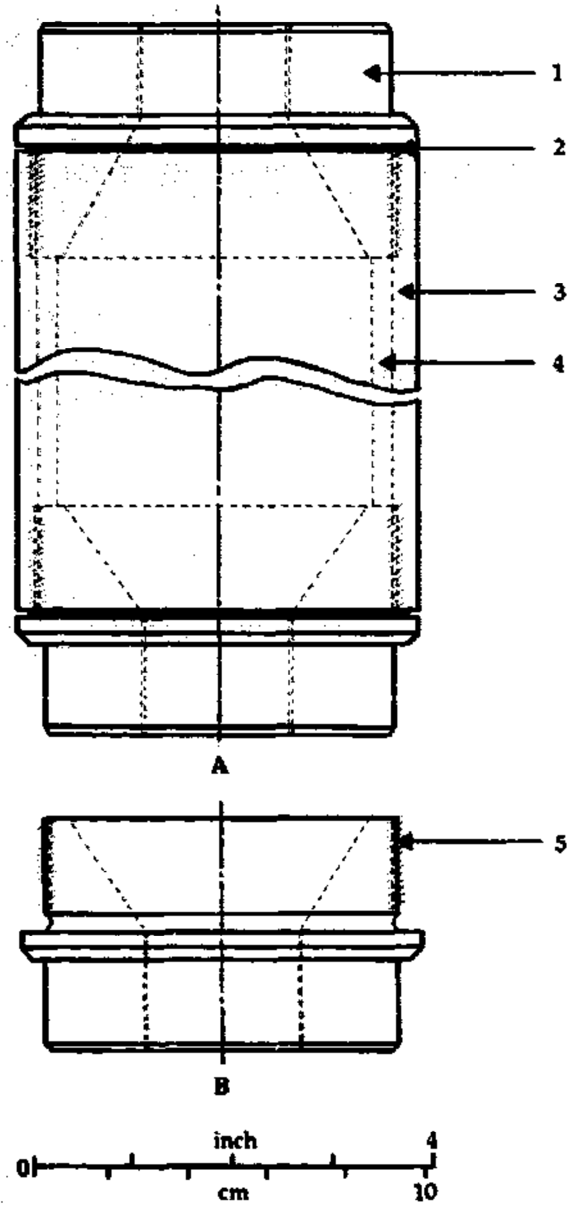


Fig. 5. Modified 3-inch (7.5-cm) diameter cylinder (A) and steel cap (B): (1) steel cap; (2) rubber O-ring; (3) steel casing; (4) PVC lining; and (5) threaded section. (Total height of cylinder is 27 inches (68.6 cm).)

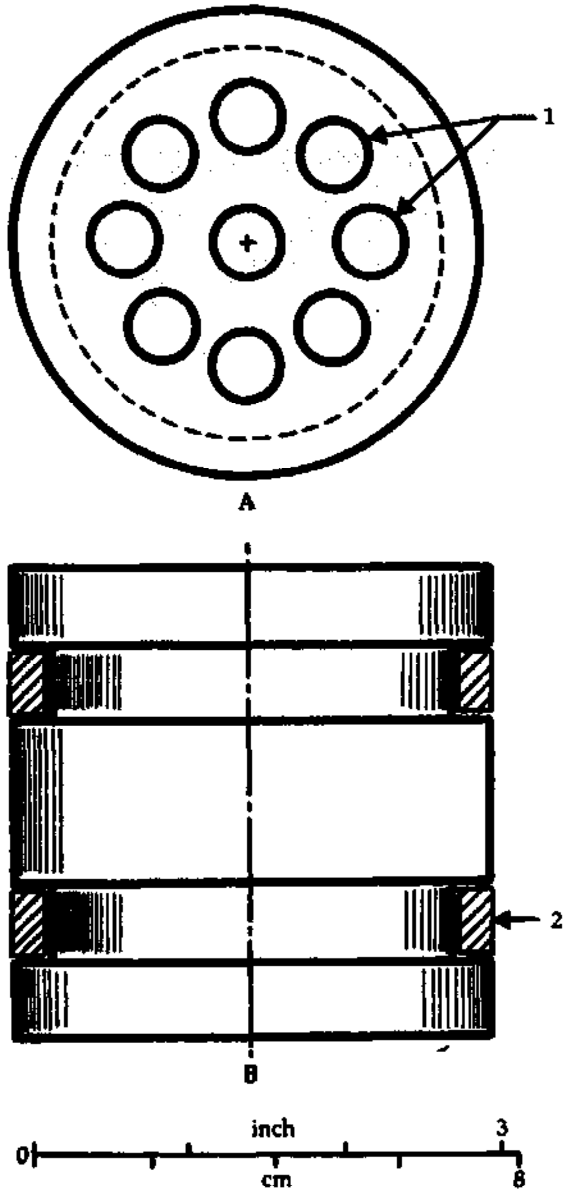


Fig. 6. (A) Top and (B) side views of modified piston of Waterloo handpump; (1) 7/16-inch (1.11-cm) holes; and (2) PVC piston ring.

the foot valve as a spare piston was eliminated. In the second modification, the contact area between the PVC plate valve and the stainless steel plate was kept to a minimum by means of two small ridges. This foot valve performed satisfactorily in the field. To reduce the production cost, however, a third modification was made by eliminating the compression spring and changing the PVC plate valve to a 1/4-inch (6-mm) solid rubber plate. The moving distance of the rubber plate valve was kept at 1/4 inch (6 mm). The third modification of the foot valve is shown in Fig. 7. In total, 54 wells in three regions used this type of foot valve.

Site selection and installation of PVC pumps

The sites of the field tests were in central, northeastern, and northern Thailand. The

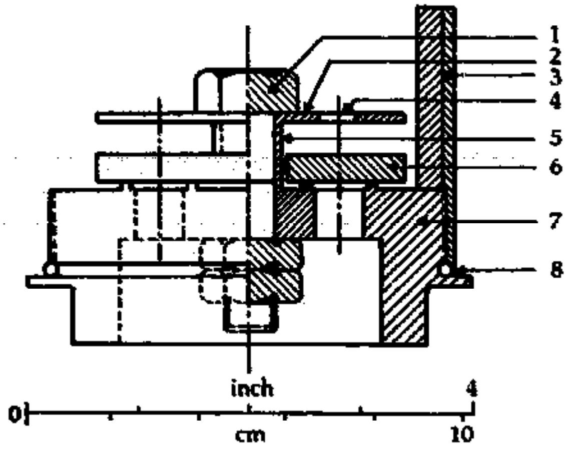


Fig. 7. *Third modification of PVC foot valve: (1) threaded bolt; (2) stainless-steel plate; (3) PVC lining and steel casing; (4) 7/16-inch (1.11-cm) holes on 1.5-inch (3.8-cm) pitch diameter; (5) brass guide; (6) rubber plate valve; (7) steel cap; and (8) O-ring.*

three regions that were selected were located in the following areas: (1) Saraburi and Lopburi provinces, central Thailand; (2) Khon Kaen province, northeastern Thailand; (3) Lamphun and Chiang Mai province, northern Thailand.

In each region, 18 wells having different characteristics were equipped with the modified PVC cylinders, pistons, and foot valves. One important factor that was considered in well selection was to choose a well with a high frequency of usage, because many wells are rarely used in some areas. Another factor that was considered was the existence of an access road to the well. If the well was too far and difficult to reach, the monitoring would have become very difficult, and sometimes impossible, during the rainy season.

Monitoring

Before the PVC components were installed, initial measurements were made on three aspects — above- and below-ground components and the static water table.

The configuration of the above-ground component of the handpump was noted and all the relevant dimensions of the components were recorded.

For the below-ground components, the thickness of the upper and lower polyethylene rings on the piston was measured using a micrometer. For each ring, the measurements were taken at three different positions spaced 120° apart. The diameter of the piston was noted and the inner diameter of the PVC cylinder was measured with an internal vernier caliper. The cylinder and piston assembly were inspected at roughly 3-month intervals.

The static water level is the distance from the surface of water (water table) in the well to the outlet spout of the pump. This static water level was measured using an electronic sound probe. A wire lead from this device is lowered slowly into the well through a hole drilled in the pump casing. When the wire touches the surface of the water, a sound is produced electronically. The static water level equals the length of the wire plus the distance from the hole to the spout of the pump. The static water level was observed monthly.

After installation of the PVC components, the performance of the pump was tested by measuring the actual volume of water discharged per 10 strokes of piston movement. These data were also collected on a monthly basis.

In addition to these tests, samples of the water from the wells in the three regions were tested in the laboratory for water quality. The analyses were conducted by the Environmental Engineering Division using standard methods for 10 parameters: *p*H, turbidity, colour, hardness, calcium, chloride, nitrate, manganese, iron, and fecal coliform. The water quality index was calculated based on two different approaches: the Delphi Approach using option 1 and the WHO Alternative Approach. The test results indicated that, for some wells, the water quality index was poor and the water in these locations was recommended for general domestic uses only and not for consumption. Normally, the villagers possessing these wells obtain their drinking water from open ponds that collect rain water during the rainy season.

Results of field testing

The fluctuations of static water levels for wells located in Saraburi and Lopburi, Khon Kaen and Chiang Mai, and Lamphun with respect to calendar time were plotted (see, for example, Fig. 8). The static water level was rather high during October to December and low during February to March, which correspond to the rainy and dry seasons respectively.

The volumetric efficiencies, volume of

water per 10-cm stroke, changes in thickness of upper and lower piston rings, and changes in the inner diameter of cylinders of all 54 wells located in the three regions were plotted against calendar time (see, for example, Fig. 9).

Records of the damaged parts of both the above- and below-ground components of PVC pumps from installation until the end of the field test were carefully tabulated. Table 3 presents a summary of the frequency of the different causes of pump failure.

AIT-PVC Handpump

Design

Based on the field monitoring and laboratory test results, a final design, called the AIT–PVC handpump, was developed. It incorporated the following features.

A new type of fulcrum link, hinged at both ends by means of ball bearings, was intro-

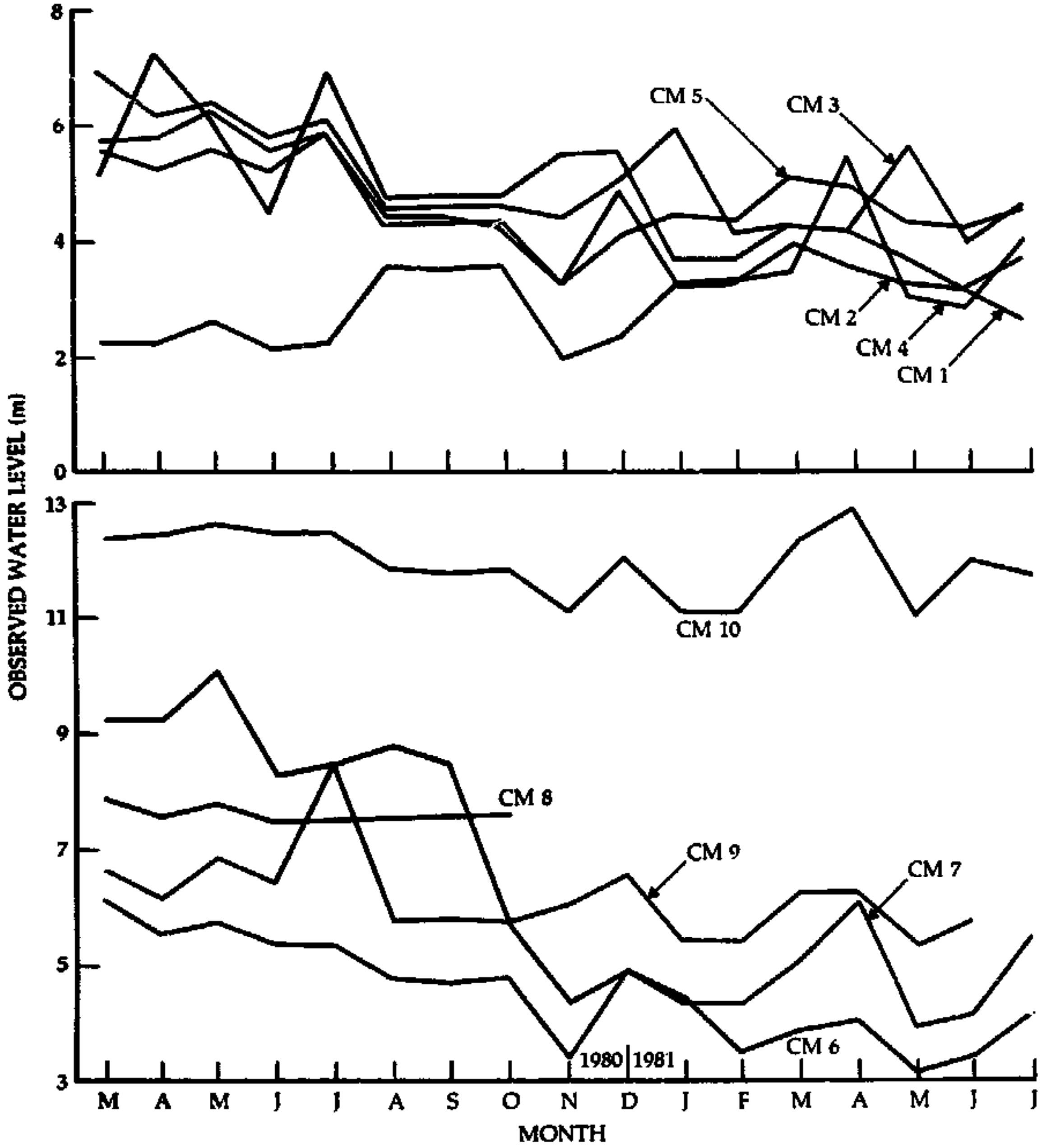


Fig. 8. *Observed static water levels of wells located in Chiang Mai (CM3–9) and Lamphun (CM1, 2, and 10).*

duced in this design. This fulcrum link replaces the type used in the DMR handpump, which failed frequently either at the joints or at the link itself. Details of the above-ground components are shown in Fig. 10.

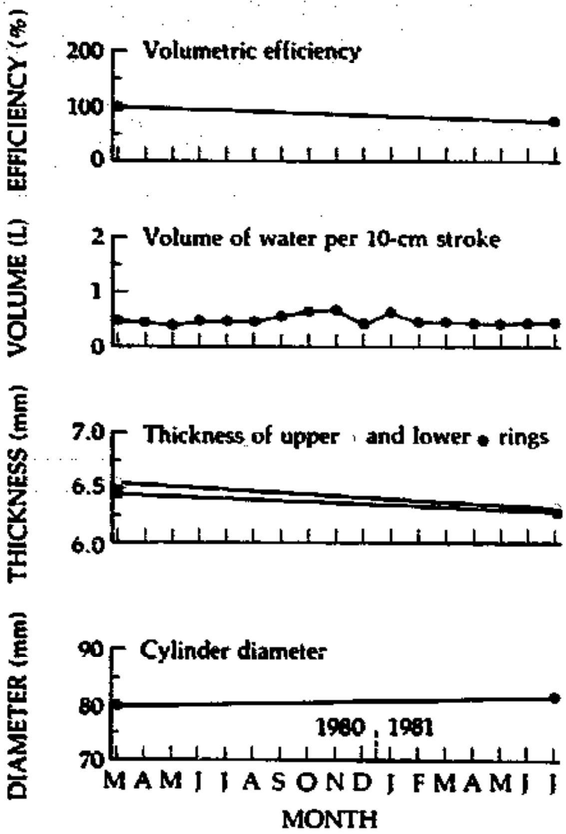


Fig. 9. *Performance of 3-inch (7.5-cm) cylinder handpump in Saraburi and Lopburi regions.*

Table 3. Statistical records of pump failures, March 1980–July 1981.

Types of failure	Number of failures
Above-ground components	
DMR pumps	
Breakage of fulcrum link	13
Breakage of handle	9
Loosening of stuffing box	3
Breakage of fulcrum pin	2
Wear on flat bar	2
Breakage of flat-bar bushing	2
ARD pumps	
Damage of sector gear	6
Loosening of handle	3
Breakage of spring	3
Breakage of spout	1
Below-ground components	
Leakage of foot valve	24
Failure at piston-rod joints	20
Failure at riser pipe	2

The riser pipe is made of standard 3-inch (7.5-cm) diameter PVC pipe 4 m (13.1 feet) long. This pipe is also used as the cylinder. The modified piston and foot valve (Figs. 6 and 7) discussed earlier were adopted in this new design. The only part not made of PVC is the 7/16-inch (11-cm) pump rod. Initially, a standard hollow 3/4-inch (2-cm) diameter PVC pipe was used for the pump rod but this was not strong or durable enough to withstand the pumping force. Even the steel pump rod was found to be insufficient and, as a result, a spacer is introduced at the

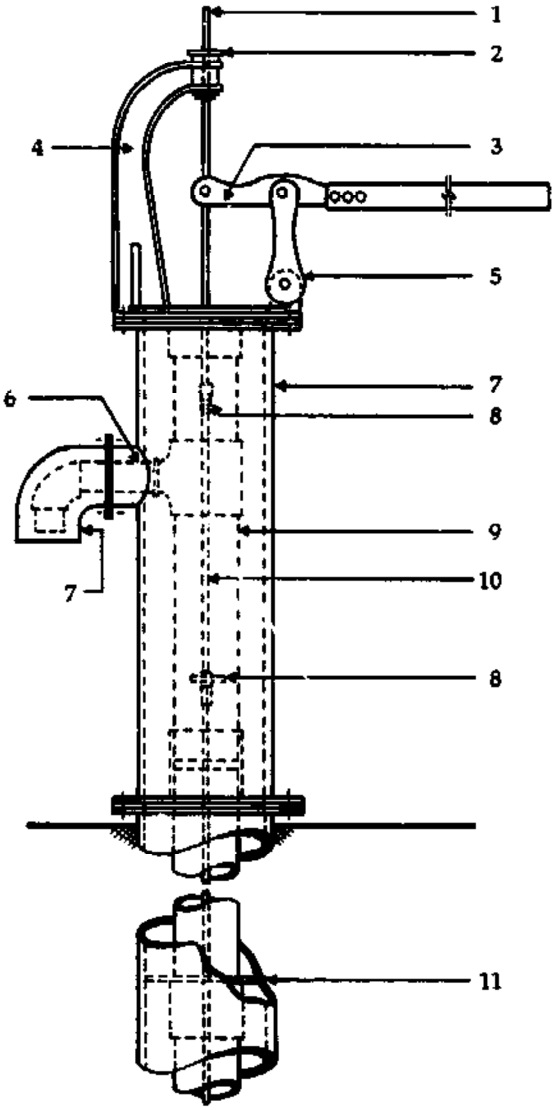


Fig. 10. *Above-ground components of AIT–PVC handpump: (1) round steel bar; (2) bar guide; (3) handle; (4) frame; (5) handle-support joint with ball bearings; (6) PVC faucet; (7) steel casing; (8) coupling; (9) PVC pipe; (10) steel rod; and (11) wooden spacer.*

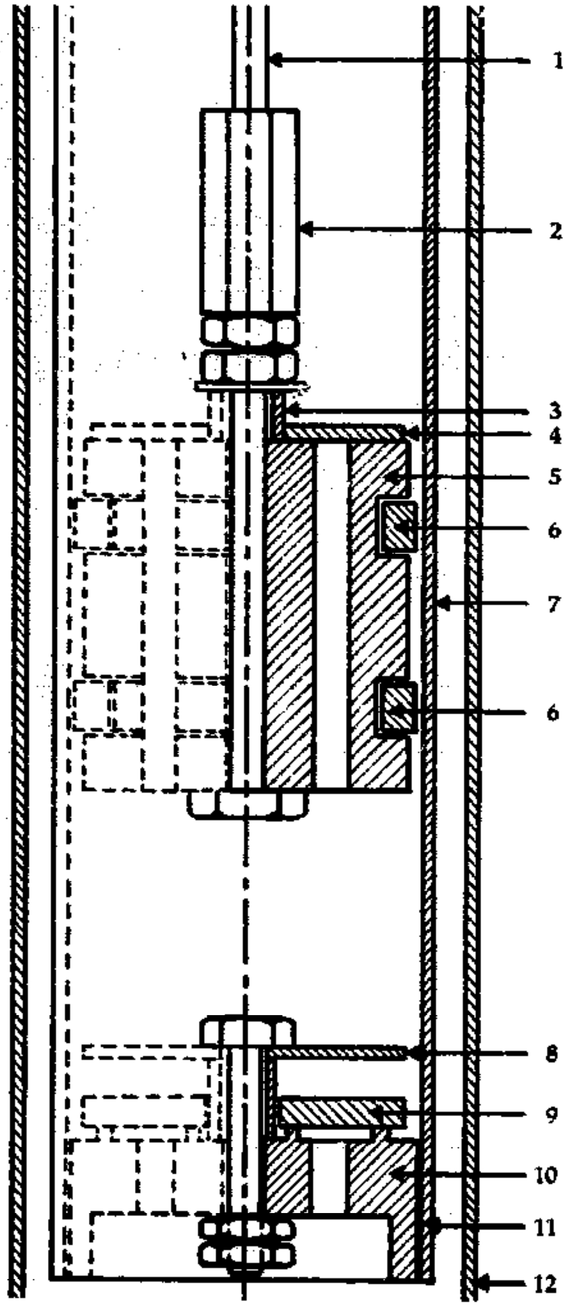


Fig. 11. *Below-ground components of AIT-PVC handpump: (1) steel rod; (2) coupling; (3) brass guide; (4) PVC piston valve; (5) PVC piston; (6) PVC piston ring; (7) PVC pipe; (8) stainless-steel plate; (9) rubber foot-valve plate; (10) PVC foot valve; (11) solvent cement glue; and (12) steel well casing.*

joint of the pump rod to minimize vibrations. Details of the below-ground components are shown in Fig. 11.

On a trial basis, three AIT-PVC handpumps were installed in wells located in three different regions and their performance was monitored. The identification and initial dimensions of the below-ground components and the performance of these all-PVC handpumps are summarized in Table 4.

Table 4. Specifications of the three AIT-PVC handpumps that were field tested.[a]

	No. 1	No. 2	No. 3
Installation date	22/8/80	15/11/80	19/11/80
Water level (m)	11.25	9.15	12.00
Volumetric efficiency (%)			
I[b]	76	78	73
E	98	91	86
Avg piston-ring thickness (mm)			
Upper			
I	6.59	6.71	9.43
E	6.28	6.55	7.21
% change	4.40	2.38	2.96
Lower			
I	6.53	6.49	7.42
E	6.31	6.40	7.23
% change	3.37	1.39	2.56
Avg inner diam of cylinder (mm)			
I	80.01	79.95	79.86
E	80.51	80.30	80.27
% change	0.64	0.43	0.42

[a] 10 mm = 0.39 inch; 1 m = 3.28 feet.

[b] I, at installation; and E, at end of field test.

Table 5. Cost comparison of above- and below-ground components of three types of handpumps used in Thailand (December 1980).

Type of handpump	Cost (Baht)[a]	Remarks
Above-ground		
DMR	2100	Mass production
ARD	2500	Mass production
AIT-PVC	2300	Single order
Below-ground[b]		
DMR	700	Mass production
ARD	700	Mass production
AIT-PVC	800	Single order

[a] 23 Baht = US$1.

[b] Excluding riser pipes. For AIT-PVC handpump, the cost of riser pipe is approximately 110 Baht/m (33 Baht/foot).

Cost analysis

The cost of an AIT-PVC handpump was estimated and compared with the DMR and ARD handpumps (Table 5). Two separate components are considered in the cost analysis, the above- and below-ground components. For the below-ground components, only the costs of the piston and cylinder are given because the length of the riser pipe depends on well depth.

The costs of DMR and ARD handpumps are based on mass-production, whereas the cost of the AIT-PVC system is based on a single order. Thus the cost of the AIT-PVC handpump could be reduced further if the pump were mass produced. The cost of the AIT-PVC handpump was 3100 Baht, whereas the DMR and ARD handpumps were 2800 and 3200 Baht, respectively.

Conclusion

The performance of the Waterloo handpump was studied in detail under both field and laboratory conditions. Existing handpumps in Thailand were also reviewed and their performance under simulated conditions was assessed. After careful observation in the laboratory, the below-ground components of the Waterloo pump were modified and installed in 54 wells and monitored for 15 months. Unlike the plastic handpumps that are available commercially and intended for use in shallow wells (2-5 m), the Waterloo handpump was found to be applicable up to a depth of 20 m. For deeper wells, a smaller diameter piston should be employed.

Based on the field monitoring and laboratory test results, a modified version, called the AIT-PVC handpump, was designed. On a trial basis, three of these handpumps were installed in the field and their performance was observed over 6 months. These handpumps performed satisfactorily and were appreciated by the villagers. One advantage of this proposed handpump is the use of PVC riser pipe that simultaneously acts as the cylinder of the pumping unit.

The field tests indicated that the Waterloo handpumps required some maintenance and repair. The weakest part of the pumping system was the foot valve, which often leaked in wells that contained sand particles in the water. However, the results cannot be fully evaluated because the frequency of pump usage was not included in the monitoring process.

Source Documents

ARD (Accelerated Rural Development Office). 1980. Improvement of handpump design in Thailand. Bangkok, Thailand: Ministry of the Interior, ARD. Report published under the sponsorship of United Nations Children's Fund, Equipment Control Division.

Kingham, J.A. 1979. Progress report on testing of IDRC prototype pumps. London, U.K.: Consumers' Association.

NIDA (National Institute of Development Administration). 1978. Evaluation on national rural water supply program. Bangkok, Thailand: NIDA. Research report under the joint sponsorship of the National Economic and Social Development Board and the United Nations Children's Fund. (In Thai.)

Rudin, A. and Plumtree, A. 1978. Design for plastic hand pump and well. Waterloo, Ont., Canada: University of Waterloo. Report No. 3 (Project 609-01-02).

Philippines

Antonio Bravo

This report outlines the field testing of the Waterloo handpump in the Philippines from January 1980 to May 1982.

The project sought to attain the following four objectives: (1) to field test the Waterloo handpump in the rural areas; (2) to evaluate the technical viability of the handpump by assessing its operational performance in terms of volumetric efficiency, mechanical efficiency, and ease of usage; (3) to determine problems related to the operation and use of the pump and provide solutions for the improvement in design and reliability of the pump; and (4) to assess prospects for eventual adoption of the Waterloo pump in the national program of handpump development.

In accordance with specifications provided by the International Development Research Centre (IDRC), prototypes of the Waterloo handpump were fabricated and installed in specific areas in the Philippines. Thirty handpumps were installed in Laguna, Cavite, Pangasinan, and Nueva Ecija. The sites chosen were typical rural communities where water supply is a problem and where a minimum of 10-20 users reside.

Periodic visits were made to the pump sites to monitor the performance of the pumps. Employing a monitoring format agreed upon by the representatives of the countries involved in the network project during a meeting held in Malaysia in the latter part of 1980, various parameters were observed and measured.

Pump Design and Construction

Below-ground components

The project team used a 3-inch (7.5-cm) diameter polyvinyl chloride (PVC) pipe for the well casing, which also functions as the pump cylinder. Pipes, 10 feet (3 m) long, were joined using PVC solvent cement and PVC couplings. The nominal pipe dimensions were 88.7 mm OD × 79.26 mm ID. The piston was machined from solid PVC stock. Two polyethylene rings each with a diameter of 3 inches (76.5 mm) and a thickness of 5/16 inch (7.93 mm) were used. The first (upper) piston ring was 5/9 inch (14.2 mm) wide whereas the lower one was 0.25 inch (6.35 mm). Eight 0.25-inch (6.35-mm) holes were drilled in the piston (Fig. 1A).

The project team decided to use an irrecoverable foot valve. Both piston and foot valve were basically similar except that the foot valve had larger holes than the piston (0.5 inch; 12.7 mm) (Fig. 1B). The foot valve was redesigned therefore, and, instead of two polyethylene rings, a rubber gasket (ID 2.34 inch and OD 3.5 inch; 59.5 and 88.9 mm) was used.

The foot valve was further modified by incorporating a brass spring. The valve seat was also chamfered to prevent sand particles from wedging between the flapper valve and the base (Fig. 2).

PVC pipes (OD 1.06 inch and ID 0.81 inch; 26.8 and 20.5 mm) were used as piston rods. These were 10 feet (3 m) long and were joined using PVC couplings and PVC solvent cement. A PVC screen filter (about 10 feet, 3 m, long) was incorporated in several pumps during installation. This PVC screen and sandtrap was improvised by cutting slots diagonally along a section of PVC pipe with a hacksaw. These slots were 0.25 inch (6 mm) apart and 1 inch (2.5 cm) long across the pipe. The end of the filter was cut and bent to give it a conical shape.

Above-ground components

The above-ground components consisted of a wooden handle assembly, metal yoke, a concrete pedestal, and a concrete platform reinforced by 0.5-inch (1.25-cm) steel reinforcement bars. The wooden handle was originally connected to the piston rod by a metal flange. This flange was connected by a bolt to a steel block into which a brass fitting connected to the piston rod was screwed. A problem in the design of this linkage caused the piston rod to buckle during operation. This was remedied by using a solid iron rod for the upper portion of the piston rod (Fig. 3). The pedestal for the pump was

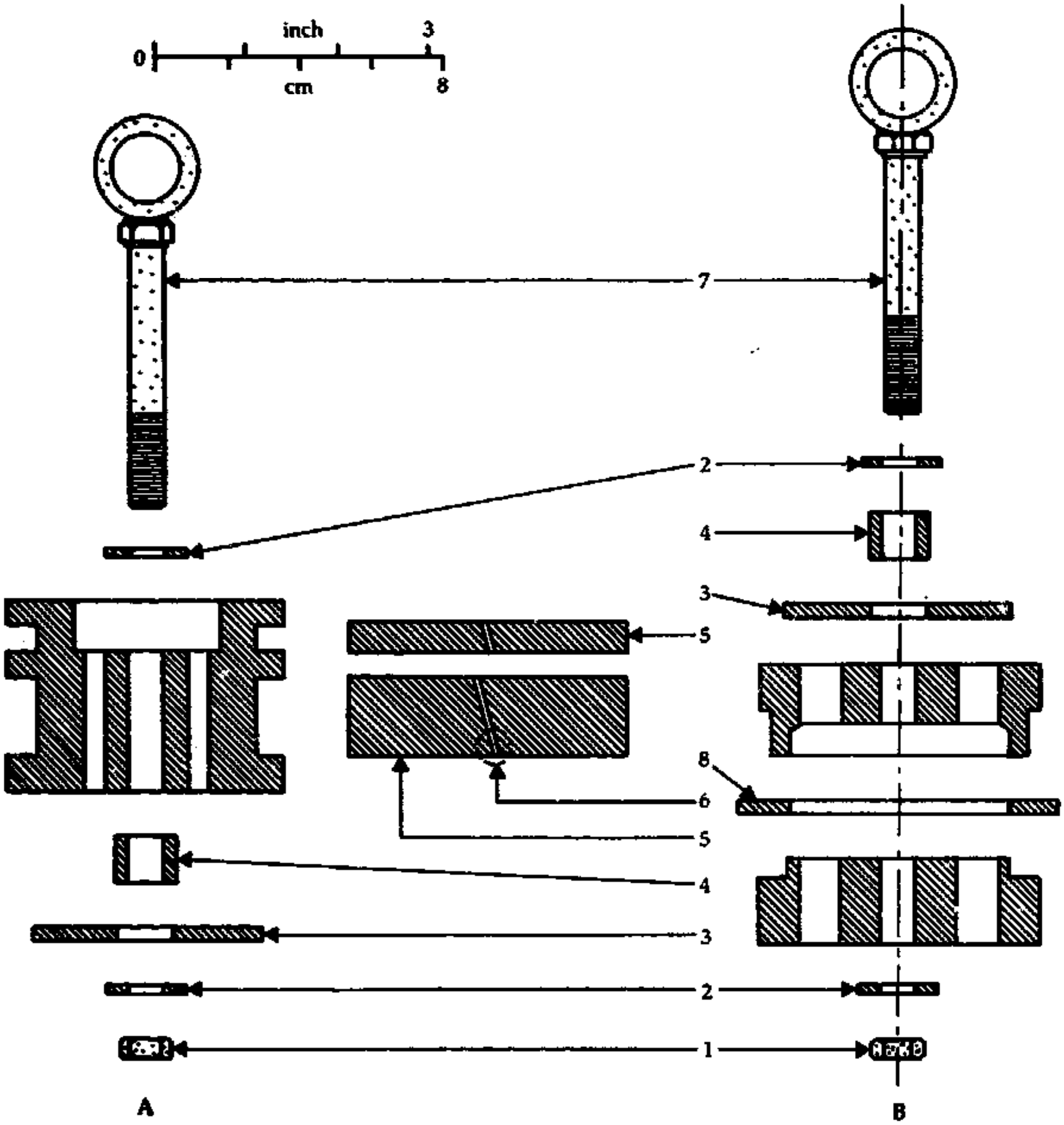


Fig. 1. *(A) Piston and (B) original foot valve: (1) hex nut; (2) plain washer; (3) plastic valve cap; (4) valve-cap slip guide; (5) plastic piston ring; (6) diagonal cut; (7) threaded bolt with O-ring welded in place; and (8) rubber seal.*

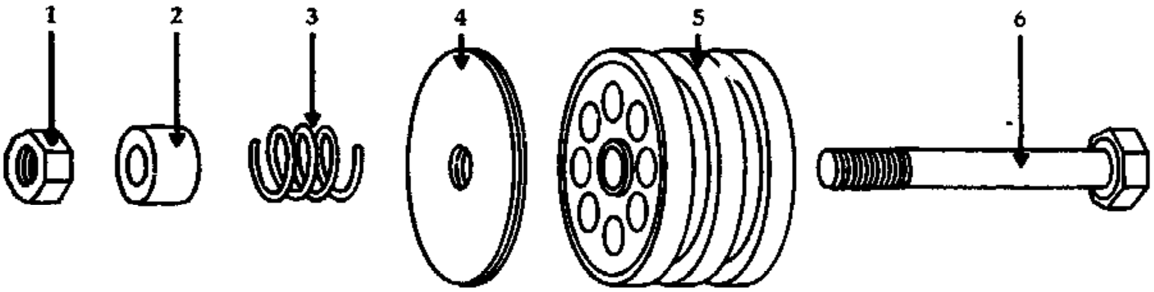


Fig. 2. *Modified foot valve: (1) nut; (2) brass valve cap and slip guide; (3) brass spring; (4) flapper valve; (5) PVC valve; and (6) threaded bolt.*

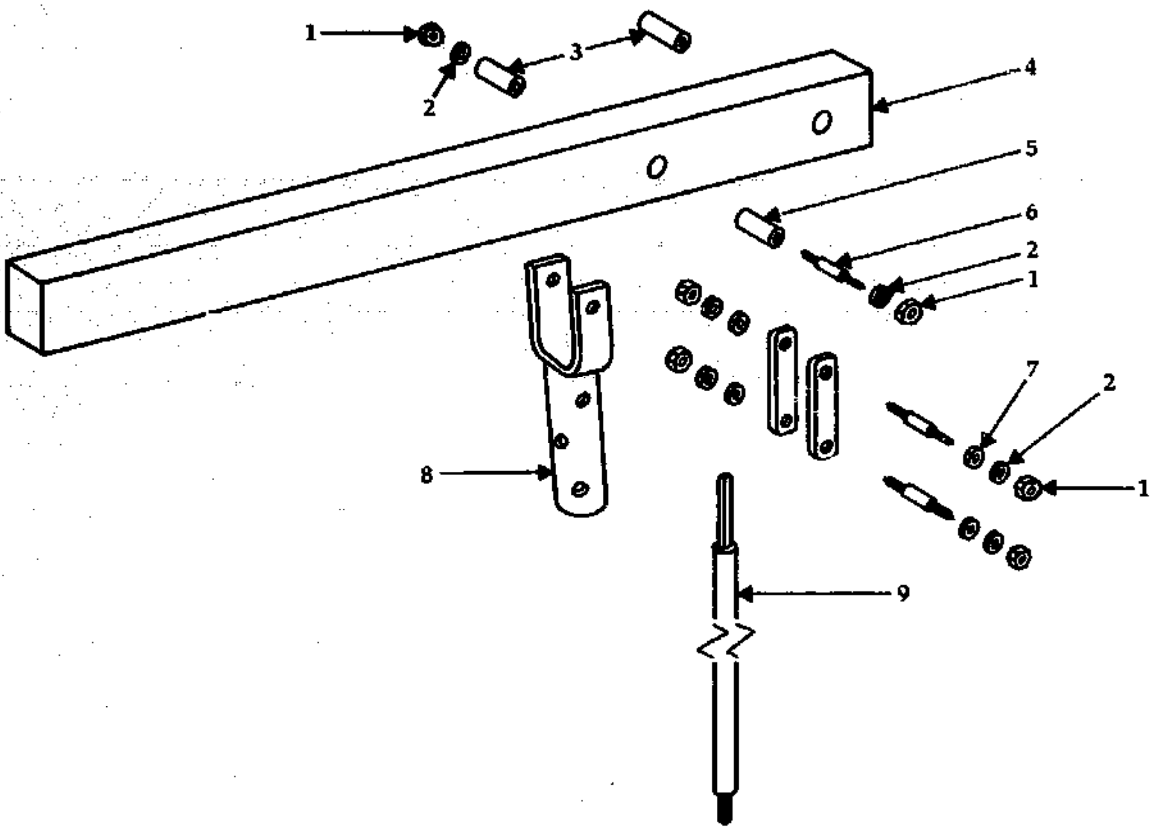


Fig. 3. *Modified version of above-ground components: (1) nut; (2) lock washer; (3) brass sleeve bearing; (4) wooden handle; (5) metal sleeve bearing; (6) bolt; (7) washer; (8) handle support pipe; and (9) solid iron rod.*

made of concrete (Fig. 4) and the platform on which the pump was mounted was a 5 × 10 foot (1.5 × 3 m) concrete slab about 6 inches (15 cm) thick.

The piston was attached to the pump rod by a brass connector, one end of which was screwed to the bolt on the piston while the other end was inserted into the PVC pump rod and locked with a pin.

Monitoring Techniques

The following parameters were measured at least once each month and the results are summarized in Table 1 and Fig. 5.

Volumetric efficiency was determined by the following method. The theoretical number (n_{th}) of strokes needed to fill a 20-L can was calculated from the formula:

$$n_{th} \text{ strokes} = v/[\pi(D^2 - d^2)/4][L/1000]$$

where: v = volume of container; D = inside diameter of well casing; d = outside diameter of piston rod; L = stroke length.

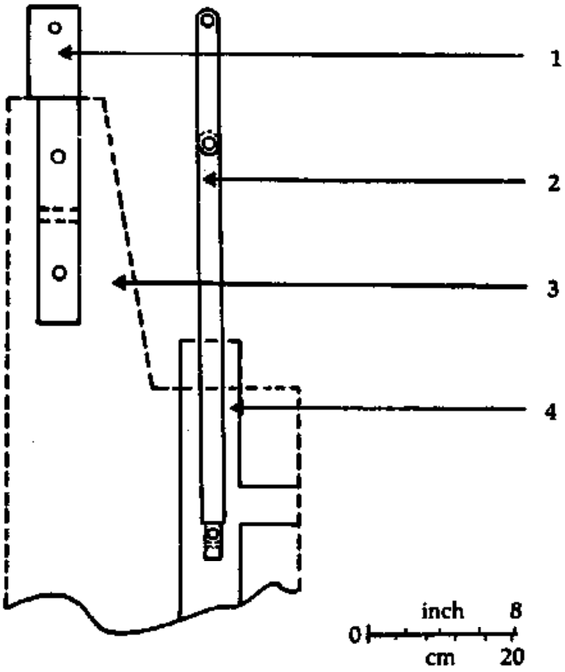


Fig. 4. *Details of concrete pump pedestal: (1) handle support pipe; (2) solid iron bar; (3) concrete; and (4) 3-inch (7.5-cm) galvanized pipe.*

Table 1. Summary of performance data.[a,b]

Pump number	Type	Date installed	Number of users	Volumetric efficiency (%)	Water head (m)	Avg water output (L/day)	Period monitored
PA_4	lift	5/2/81	12	60	1.93	715	1/3/81-15/5/82
PA_5	lift	1/3/81	15	64	2.63	800	1/4/81-15/5/82
NE_1	lift	30/9/81	8	56	1.41	1000	30/10/81-15/5/82
NE_2	lift	12/10/81	150	63	0.99	2100	15/11/81-15/5/82

[a] No observations made on down-time or on maintenance and repairs.
[b] 1 m = 3.28 feet; 1 L = 0.22 gallon.

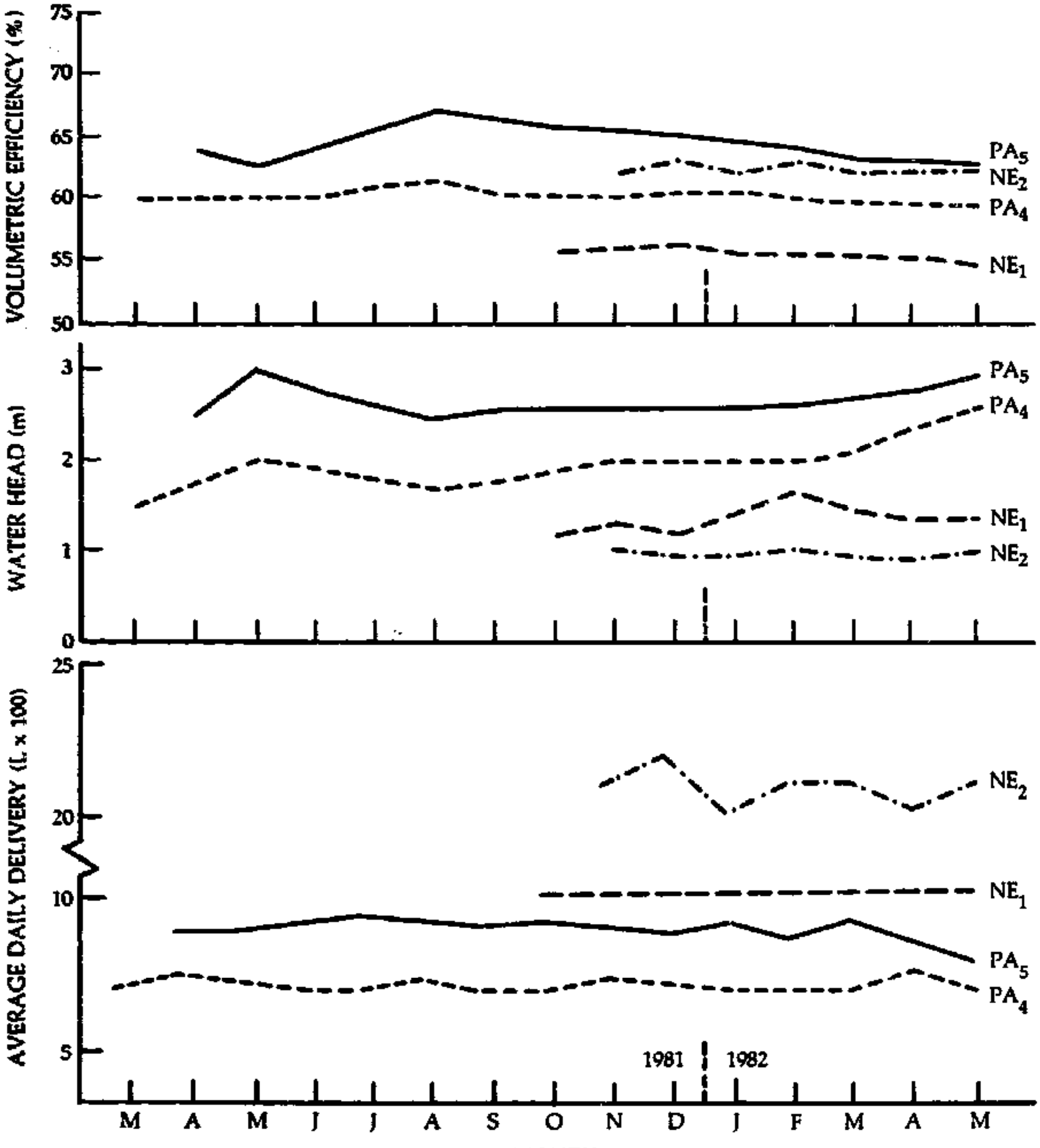


Fig. 5. *Volumetric efficiency, average water head, and monthly mean of the average daily delivery of the four pumps during field-testing.*

At a standard frequency of about 40 strokes per minute, the same 20-L can was filled to capacity while counting the actual number (n_{ac}) of strokes. The volumetric efficiency was then computed from the formula:

$$\text{Volumetric efficiency } (\%) = (n_{th}/n_{ac}) \times 100$$

The water head (distance between the water level in the well and the pump spout) was measured by using a calibrated string weighted at one end with a float.

Since no counter was installed to measure pump usage, the determination of total volume of water pumped was estimated. Monitors at the village recorded the number of 20-L cans (provided at the pump site for this purpose) that the village people pumped per day. This was used as the basis to estimate the amount of water pumped per month.

The thickness of the upper and lower piston rings at three points was measured monthly. The percentage rate of wear was then determined from the past and present measurements.

Highlights of Findings

The project was able to install 30 Waterloo pumps in several areas: Jala Jala Islands in Laguna (10), Cavite (9), Pangasinan (7), and Nueva Ecija (4). Of these 30 pumps, only 4 (13%) were considered functional/operational and appropriate for monitoring purposes. The other 26 pumps were eventually abandoned as they were beset with one or more of the following seven problems: (1) high leakage rate; (2) users found the pump to be very difficult, strenuous, and inconvenient to use because it took quite a long time to prime and draw water. (This situation is described with humour by one user with the following statement: "Our sweat comes out first before we pump out water."); (3) defective foot valve; (4) caving in of the well; (5) people eventually abandoning the use of the pumps because they started to draw up brackish or muddy water; (6) piston stuck and could not be extracted; and (7) foot valve slipped out of the casing and dropped down the well.

Given the alternative of being able to use other existing pumps (Jet-matic and pitcher pumps), the village users eventually switched to these other pumps. The original Waterloo-designed handpump that was fabricated according to specifications did not function as efficiently as expected when tested initially. The following specific observations were made.

The foot valve did not hold water satisfactorily because: (1) the original gasket or the seal (polyethylene ring) was not effective; (2) sand particles became trapped between the plastic flapper valve and the valve seat and caused poor seating of the valve; and (3) there was excessive clearance between the valve guide and the flapper valve. The piston's performance was similar to that of the foot valve.

Filter

The PVC filter did not function adequately. This may have been because the screen slots were too big and allowed fine sand and silt to pass. Another reason was that some wells were not adequately developed.

To try to overcome these problems, changes were made in the design of the foot valve. These changes included incorporating a brass spring, using a rubber gasket, and chamfering the valve seat to prevent sand particles from wedging between the flapper valve and the valve seat. These modifications improved the performance of the pumps slightly. However, it is not possible to state conclusively whether the improved performance was due solely to the modifications or was due to the fact that the wells had lower pumping heads: the four operational pumps had a water head of less than 10 feet (3 m).

Even when the Malaysian foot-valve design was tried, technical problems with the foot valves continued to be a major constraint. One interesting finding that has always puzzled the team is the seepage rate encountered in all the wells. Although a stronger spring was installed for the flapper valve, a high seepage rate persisted. This meant that 50-70 strokes of the pump handle were required to raise the water column so that water could be obtained; however, after a short period without pumping, the level of the water in the column fell back to the level of the ground water. Thus, priming had to be repeated. For areas with a high water table, like Aliaga, Nueva Ecija, and Pangasinan, the tedious process of raising the water column was not much of a problem. For deep wells, however, this is a very serious problem.

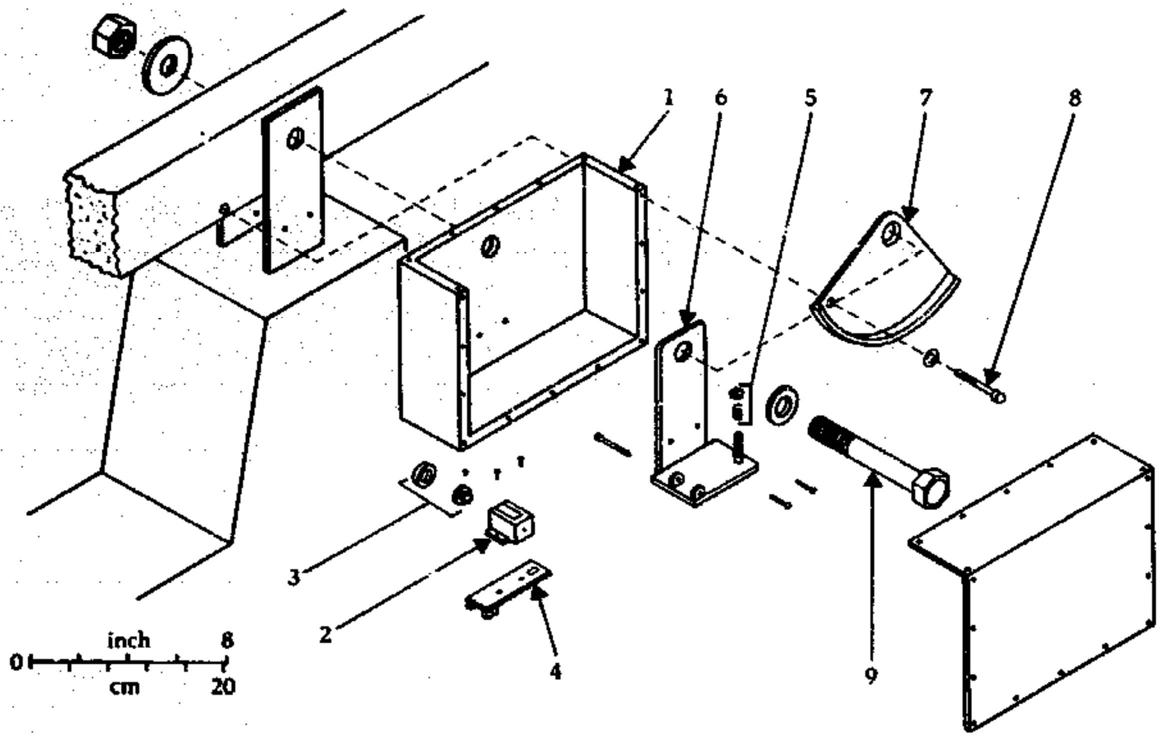


Fig. 6. *Design of mount for mechanical counter: (1) housing; (2) counter; (3) counter wheel and rubber ring; (4) counter support; (5) counter adjusting nut and spring; (6) guide assembly; (7) rocker; (8) rocker pin; and (9) pump handle pin.*

One possible explanation of the seepage problem could be sand intrusion interfering with the foot-valve assembly. Because of the strong suction power of the piston assembly, it is surmised that the water entering the foot valve causes turbulence in the water reservoir; this disturbs the sand particles in the wall of the well. These sand particles thus become suspended in the water and are drawn into the riser pipe. When pumping stops, the sand particles settle, causing the foot valve to malfunction. Sand was always found in the foot valve assembly when it was extracted for inspection. Another factor that was considered was the quality of workmanship on the foot valve. However, laboratory seepage tests did not indicate this as the problem. This high seepage rate problem has yet to be resolved.

Mechanical counter

Mounts were designed for a counter to measure piston travel. The initial design was based on a rubber-lined flywheel contacting the piston rod. However, this design impaired the free motion of the pump handle, thus limiting the travel of the piston rod and making it impossible to attain the desired stroke length. This problem was due to the peculiarity of design of the above-ground components. The design was abandoned and a new mount was tried. This mount was installed in parallel with the pump handle (Fig. 6). Although initial observations suggest that the design was feasible, the problems with high seepage rates prevented further experimentation with the mount.

Summary

Although major problems were encountered in this research project, the concept of using plastic materials as pump components has not been totally dismissed in the Philippines. The project team is optimistic that, given further opportunities to investigate designs suitable to local conditions, an appropriate handpump could be developed for use in the Philippines. Therefore, technically improved plastic handpump designs could yet prove beneficial in the development of rural water-supply systems.

Malaysia

Goh Sing Yau

The population of Malaysia is approximately 13 million and about 70% of the population live in rural areas. More than half of the rural households are not served with piped water supplies. In the late 1960s, the Environmental Engineering Unit (now renamed the Engineering Services Division) of the Ministry of Health initiated a program to improve the rural water supply. Part of the program involved the drilling of 2000 new tube wells every year and fitting them with handpumps each to serve four or five households.

At present, all handpumps installed by the Ministry of Health must be imported. Because of the relatively high water table in most lowland areas in Malaysia, most handpumps installed by the Ministry of Health are of the suction type, such as the Dragon, Fuji, and Gibson handpumps. A limited number of lift handpumps such as the Dempster and the India Mark II have been installed in deeper wells in hilly terrain. The Ministry of Health has found that the suction handpumps often do not last much longer than 1 year. The lift handpumps, which cost much more than suction handpumps, are more robust in their construction and last longer. However, spare parts for both the suction and lift handpumps, especially the cast metal components, are not readily available locally. This had led to the practice of cannibalizing parts to keep some of the handpumps in operation while others are abandoned for lack of spare parts.

This joint project between the Ministry of Health and the Department of Mechanical Engineering of the University of Malaya was initiated in an attempt to overcome some of these difficulties. The main objective of the project was to develop a relatively inexpensive handpump that could be produced locally from locally available materials. The handpump was to be a simple design that could be maintained by users at the village level.

Although handpumps have existed for a long time, many recent studies have been prompted by the recognition that they still have an important role to play in providing safe drinking water to the majority of the rural people in developing countries. In 1978, the International Development Research Centre (IDRC) encouraged the development of a PVC plastic handpump for use in developing countries. Initial studies were conducted at the University of Waterloo and further tests were carried out by the Consumers' Association in the United Kingdom. The major advantages of the polyvinyl chloride (PVC) plastic handpump over traditional cast-metal handpumps include: (1) simple fabrication procedures because PVC parts can be solvent-welded together; and (2) maintenance by users at the village level is feasible because PVC is relatively light and removal of the handpump assembly from the well for inspection and maintenance is easier.

Present Study

The results reported here cover the period January 1979–June 1982. The first phase of the project lasted approximately 1 year and involved an analytical study and parallel experimental investigation to determine the critical parameters for an optimum design for the plastic reciprocating handpump. During the second phase of the project, 17 handpumps were fabricated and field tested in two rural areas for 8.5 months.

For the purpose of this report, details of the laboratory investigation have been omitted (see Goh 1980).

The reciprocating piston handpump considered here consists essentially of a draw pipe with two identical valves. The bottom valve (foot valve) is in a fixed position at the bottom of the draw pipe and is immersed in water. The upper valve (piston valve) is attached to a piston rod that moves the piston valve in a reciprocating motion a short distance above the foot valve. The cycle of operation is illustrated in Fig. 1.

Theoretical Analysis

From an analysis of the forces acting on the piston rod for each stroke of the operating cycle, a corresponding force–displacement

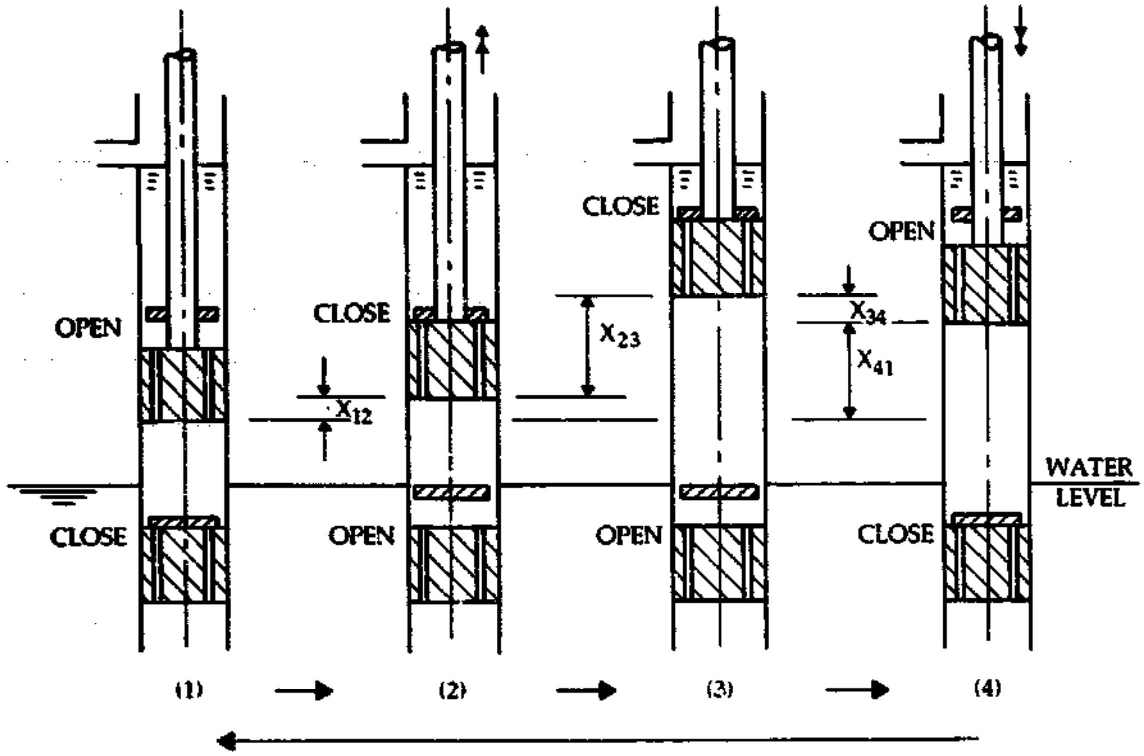


Fig. 1. *Cycle of operation of reciprocating piston handpump.*

diagram can be constructed (Fig. 2). The normal rectangular shape of the force-displacement diagram is distorted by the following: (1) the valve delays x_{12} and x_{34} corresponding to strokes 1 to 2 and 3 to 4 in Fig. 1; (2) the pressure resistance forces ΔpA_p during strokes 2 to 3 and 4 to 1; and (3) the frictional forces F_U and F_D.

The work input during the cycle of operation of the pump is given by the area enclosed by the force-displacement diagram. For a general case, the area of the force-displacement diagram is given by:

$$\oint FdL = A_p\rho gh_T L_o (1 - x/L_o) + F_T L_o + A_p\oint \Delta p dL \qquad [1]$$

where the terms on the right-hand side (RHS) represent the work input required: to lift the water (first term); to overcome frictional forces (second term); and to overcome pressure resistance forces (third term).

The volumetric efficiency (η_{vol}) may be defined as actual volume of water delivered per cycle divided by the volume displaced during the suction stroke:

$$\eta_{vol} = [(L_o - x_{12} - x_{34})A_p - V_L]/L_oA_p$$

therefore

$$\eta_{vol} = 1 - x/L_o - V_L/(L_oA_p) \qquad [2]$$

where the terms on the RHS represent the effect of: valve delay (second term); and leakage past the piston (third term).

The volumetric efficiency is therefore a measure of wastage of possible volumetric output capacity. Valve delays and leakage past the piston decrease the volumetric efficiency.

The mechanical efficiency (η_{mech}) may be defined as the work done by lifting water divided by the work input or:

$$\eta_{mech} = \eta_{vol}\rho gL_oA_ph_T/\oint FdL$$

Substituting equations [1] and [2] into this equation, we have equation [3]:

$$\eta_{mech} = \frac{1 - V_L/[L_oA_p(1 - x/L_o)]}{1 + [F_T/A_p + (\oint \Delta p dL)/L_o]/[\rho gh_T(1 - x/L_o)]}$$

For the limiting case when leakage, friction, and pressure resistance losses are negligible ($V_L = F_T = \Delta p = 0$), then $\eta_{mech} = 100\%$. Note that, for the limiting case, x/L_o need not be zero. In other words, if leakage, friction, and pressure resistance losses are negligible, the mechanical efficiency is independent of the valve delay. The mechanical efficiency is

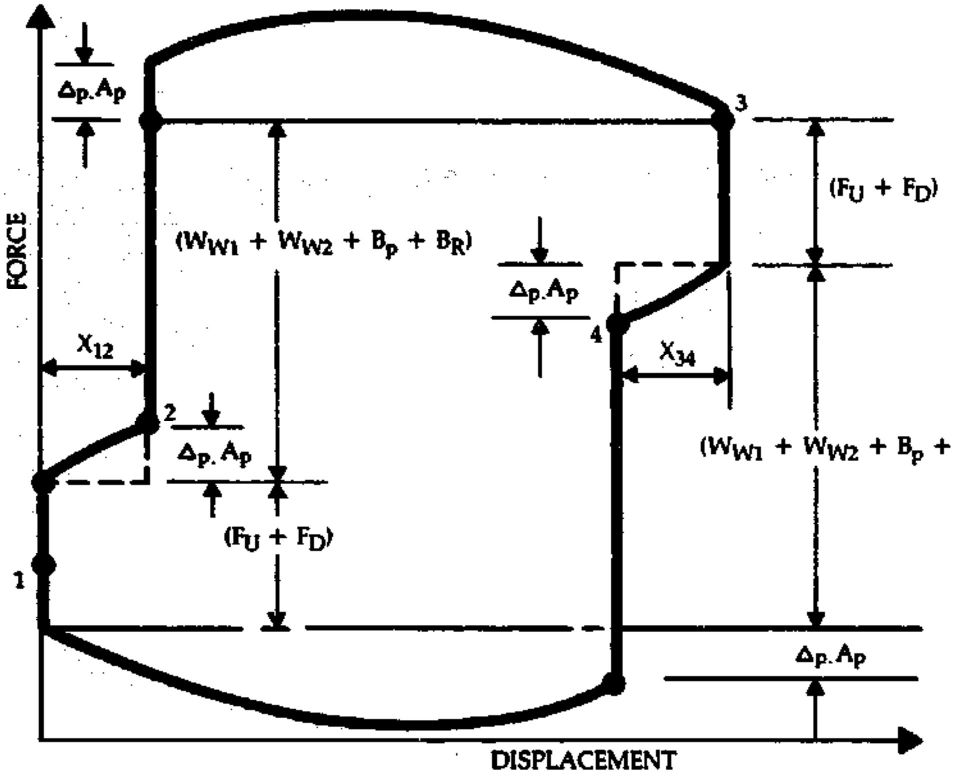


Fig. 2. *Force-displacement diagram.*

therefore a measure of the wastage of mechanical effort as a result of leakage, friction, and pressure resistance losses.

Equations [2] and [3] require a knowledge of the unknowns x (the total valve delay), V_L (the leakage past the piston), Δp (the pressure resistance losses), and F_T (the total frictional force acting on the piston). Other than F_T, which must be determined from experiments, the other unknowns may be derived.

Delay in closure of the valve may be significant if the valve flap is light or the valve gap is large, or both. The magnitude of the valve delay may be determined from a consideration of the relative motion of the valve flap (which is falling under its own weight) and the valve seat on the piston (which is moving in a vertical reciprocating motion). It can be shown that the valve delay is a function of the weight of the valve flap, the height of the valve gap, and the leakage past the piston.

In the present design, the PVC piston fitted with two polyethylene piston rings slides in a cylinder slightly larger than the piston. The water-sealing action is performed by the piston rings, which are in "contact" with the cylinder wall through a thin lubricating film of water. From a consideration of the water flow in the narrow annular passage between the outer surface of the piston rings and the inner wall of the cylinder, it can be shown that the leakage past the piston rings is given by:

$$V_L = C_1 d_p h_T / N \qquad [4]$$

where C_1 is a constant for a particular set of rings.

The pressure resistance forces occur as a result of pressure drops across the piston and foot valve and may be expressed as

$$\Delta p = 0.5 k_T \rho U_o^2 \qquad [5]$$

where k_T is the pressure loss coefficient that can be determined from the geometry and velocity of water flow through the orifices in the piston and foot valve.

The above analysis has ignored the effects of acceleration and retardation of the water on the piston as well as the oscillations induced in the piston rod as a result of impact loading on sudden closure of the piston valve. It can, however, be shown that the area of the force-displacement diagram is not affected by the acceleration and retardation forces as the work done by one is canceled out by the work absorbed by the other. Similarly, it may be shown that, because the oscillations induced in the piston rod are lightly damped, energy dissipation is small. Hence, this simple analysis appears adequate as can be demonstrated by comparing the predictions with the experimental data.

Experimental Investigation

The experimental arrangement for testing the handpumps consisted essentially of a handpump assembly lifting water to a maximum of 9 m from a central constant-level reservoir. The assembly could be converted to lift water from 6 or 3 m when required. The water at the outlet of the handpump was returned to the central reservoir through a return pipe. The handpump was driven by a 1-horsepower DC motor via a reduction gear and chaindrive assembly. The rotary motion of the flywheel was converted to a reciprocating vertical motion by a pin and slide. Mounting holes at various distances from the centre of the flywheel were provided to change stroke length when required. The speed of stroke could be varied by changing the speed of the DC motor. This was achieved by varying the input voltage to the armature coil while keeping a full 240 V across the field coil of the DC motor.

The strain in the pump rod was measured by four strain gauges on a proof-ring attached to the top end of the pump rod. The displacement was measured by a 25-cm potentiometric displacement transducer connected to the pin at the slide. The output signals from the strain gauge and the displacement transducer were fed via a dynamic strain-meter to a storage oscilloscope. A Polaroid instant-film camera was used to record the strain-displacement trace on the oscilloscope screen.

It is important to ensure that the applied force and recorded strain relationship is linear. This can be checked by a calibration test. For the linear case, the area of the force-displacement loop is equal to the work input per cycle. The area may be obtained by mechanical integration using a planimeter.

Figures 3 and 4 show a sample of the predictions of volumetric and mechanical efficiencies computed from the mathematical model and the experimental results obtained from the parallel experimental investigations. Further comparisons of the predictions and the experimental data over a range of parameters showed that the predictions are in remarkable agreement with the experimental results considering the simple model used in the present analysis (Goh 1980).

The laboratory investigation showed that the leakage past the piston, the friction between the rings and pump cylinder, and the pressure drops across the piston and foot valve have a very pronounced effect on pump performance as characterized by the volumetric and mechanical efficiencies.

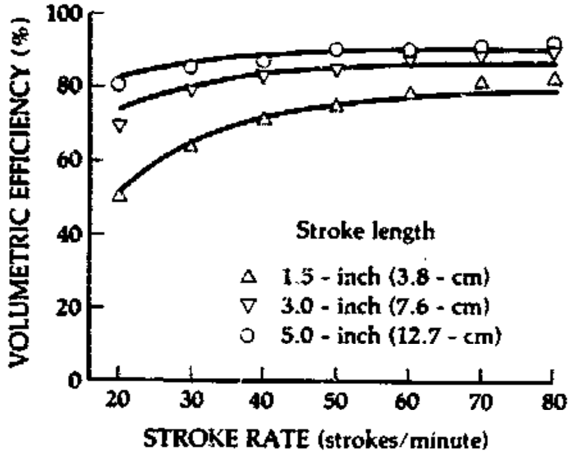


Fig. 3. *Variation of volumetric efficiency with speed of stroke application for three stroke lengths (theoretical lines and experimental data points): valve gap, 0.113 inch (2.87 mm); valve weight, 0.029 lb(force) (13.15 g); orifice/piston ratio, 16.4%; and water head, 230 inches (3.66 m).*

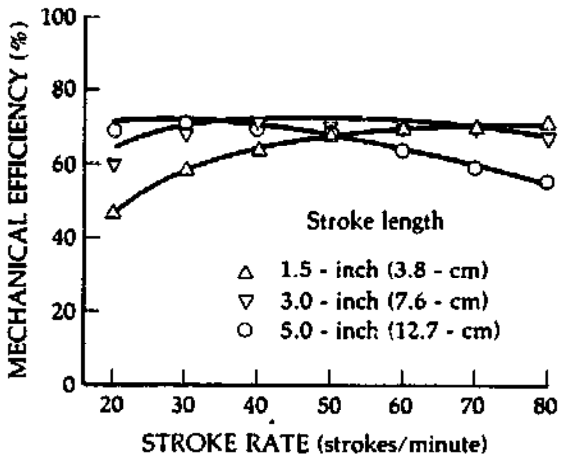


Fig. 4. *Variation of mechanical efficiency with speed of stroke application for three stroke lengths (theoretical lines and experimental data points): valve gap, 0.113 inch (2.87 mm); valve weight, 0.029 lb(force) (13.15 g); orifice/piston area ratio, 16.4%; water head, 230 inches (3.66 m).*

Optimum Design

It is difficult to specify an optimum design because, for practical reasons, it must be a compromise between a number of factors such as simplicity, ease of manufacture, and costs as well as high volumetric and mechanical efficiencies. However, the following general comments may be made on the optimum design.

The ratio of orifice areas in the piston and foot valve should be sufficiently large to prevent high pressure drops at the desired speed of operation. For the present configuration, a value in excess of 15% is satisfactory.

The piston speed, which is a product of stroke length and speed of stroke application, should be sufficiently high to ensure low leakage past the piston rings. A boy operating a handpump is observed to be able to achieve an average piston speed of the order of 300 inches (762 cm) per minute, i.e., a 5-inch (12.7-cm) stroke at 30 strokes per minute or a 3-inch (7.62-cm) stroke at 50 strokes per minute.

The valve weight must be sufficient to ensure minimal closure delay at the particular valve gap. Too small a valve gap is likely to increase the pressure drop across the piston and foot valve resulting in decreased mechanical efficiency. A valve flap weight between 0.48 and 0.96 ounce (13.6 and 27.2 g) operating with a valve gap of 0.25 inch (0.64 cm) gives satisfactory performance.

Increased water head increases the leakage past the piston rings resulting in decreased volumetric efficiency. However, if the pump is operated at a sufficiently high piston speed, the effect is much reduced.

Because the sealing action at the piston is performed by the piston rings, small dimensional variations of clearance between the piston and draw pipe have no effect on the performance characteristics. No significant deterioration in performance was observed for up to 0.1575 inch (0.4 cm) difference in diameter of piston and pump cylinder.

Because the use of a conical entry in the piston and foot valve has only a small effect on the mechanical efficiency at normal operating speeds, the simplicity of the sudden contraction entry may be retained to save cost of manufacture. However, the holes should, preferably, be slightly chamfered at the entry and outlet.

Field Investigation

In the design of pumps, there is a certain "maximum suction depth" below which it is no longer possible to draw water by suction. Below this depth, water must be raised either by lifting or some other method. This distinction is important as a suction handpump is generally simpler and less expensive than a lift pump.

In most lowland areas in Malaysia, the water table is relatively high and water may commonly be found at depths below ground that are less than the maximum suction depth of about 26 feet (8 m). In hilly areas and in some exceptional situations in lowland areas, the water table sometimes falls below the maximum suction depth. There is, therefore, a requirement in Malaysia for two variations to the basic design of the handpump, i.e., the suction handpump and the lift handpump.

Common features of the suction and lift handpumps

Figures 5 and 6 show the main features of the present design of the suction and lift handpumps. The common features of these two handpumps are: (1) a mild steel stand; (2) a leverage system consisting of timber linkages, galvanized iron joints; and galvanized iron/oil-impregnated timber bearings; (3) a PVC pump cylinder; (4) a PVC piston with two polyethylene rings; and (5) a removable PVC foot valve with a rubber seal.

The mild steel stand provides a firm support for the pumping cylinder and leverage system. Timber linkages are used because they are readily available and easy to replace. Oil-impregnated timber bearings have been tested in the laboratory (Sternberg 1978) and found to have outstanding performance characteristics. The use of a PVC piston with two polyethylene rings sliding in a PVC pump cylinder substantially reduces the friction without sacrificing high volumetric efficiency (Goh 1980). The basic PVC component for the piston and foot valve is identical. This allows for cost savings by using one injection mould for both items.

Field test

A total of 12 suction and 5 lift pumps were fabricated and installed for field testing in

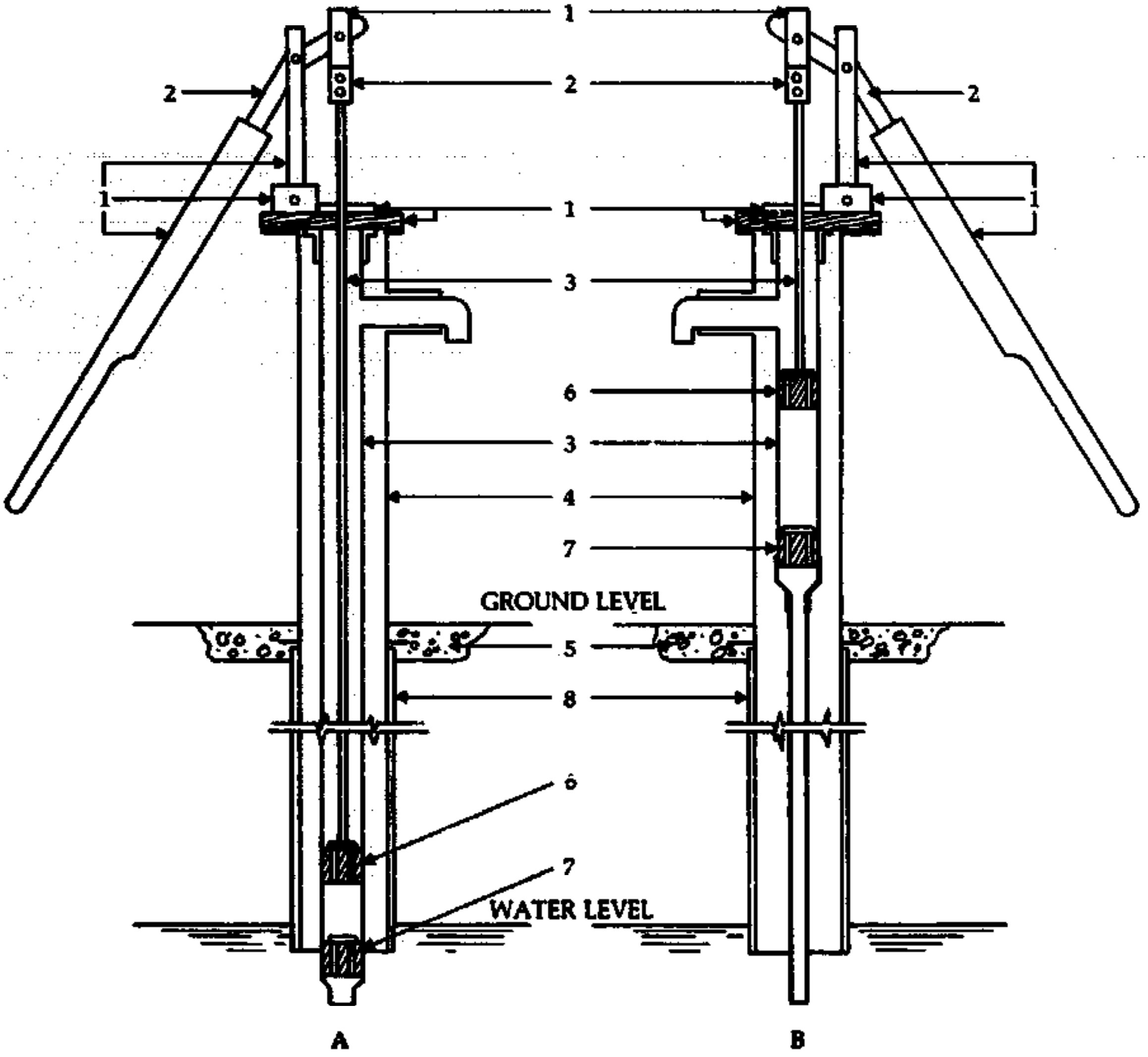


Fig. 5. *(A) Lift and (B) suction pumps: (1) wooden parts; (2) galvanized parts; (3) PVC parts; (4) mild-steel stand; (5) concrete; (6) piston; (7) foot valve; and (8) casing pipe.*

two rural areas in Malaysia. The objectives of the field-testing program were to evaluate the technical performance under field conditions and the economic feasibility of wide-scale adoption for rural use in Malaysia.

Measurement techniques for use in the field

A number of laboratory measurement techniques for the determination of the technical performance of the reciprocating piston pump cannot be used in the field either because sophisticated electronic equipment is needed or because of physical constraints at the handpump site. Several simple field measurement techniques and apparatus were developed for use in the field evaluation program.

Depth of water table In this method, the difference in the electrical resistance of water and air is employed to detect the water level in the well. The arrangement consists essentially of a sufficient length of twin-core wire and a perspex conical probe head. The twin wires are threaded into the central hole of the probe head and the ends of the wires enter two lateral holes and emerge flush with the surface on either side of the probe head. The probe head is machined with a total conical angle of 20° and the surface polished to facilitate drip-dry action when the probe is lifted out of the water. A multitest meter capable of measuring in the range of up to 300 kohms is connected to the other end of the twin-core wire to measure the resistance across the two

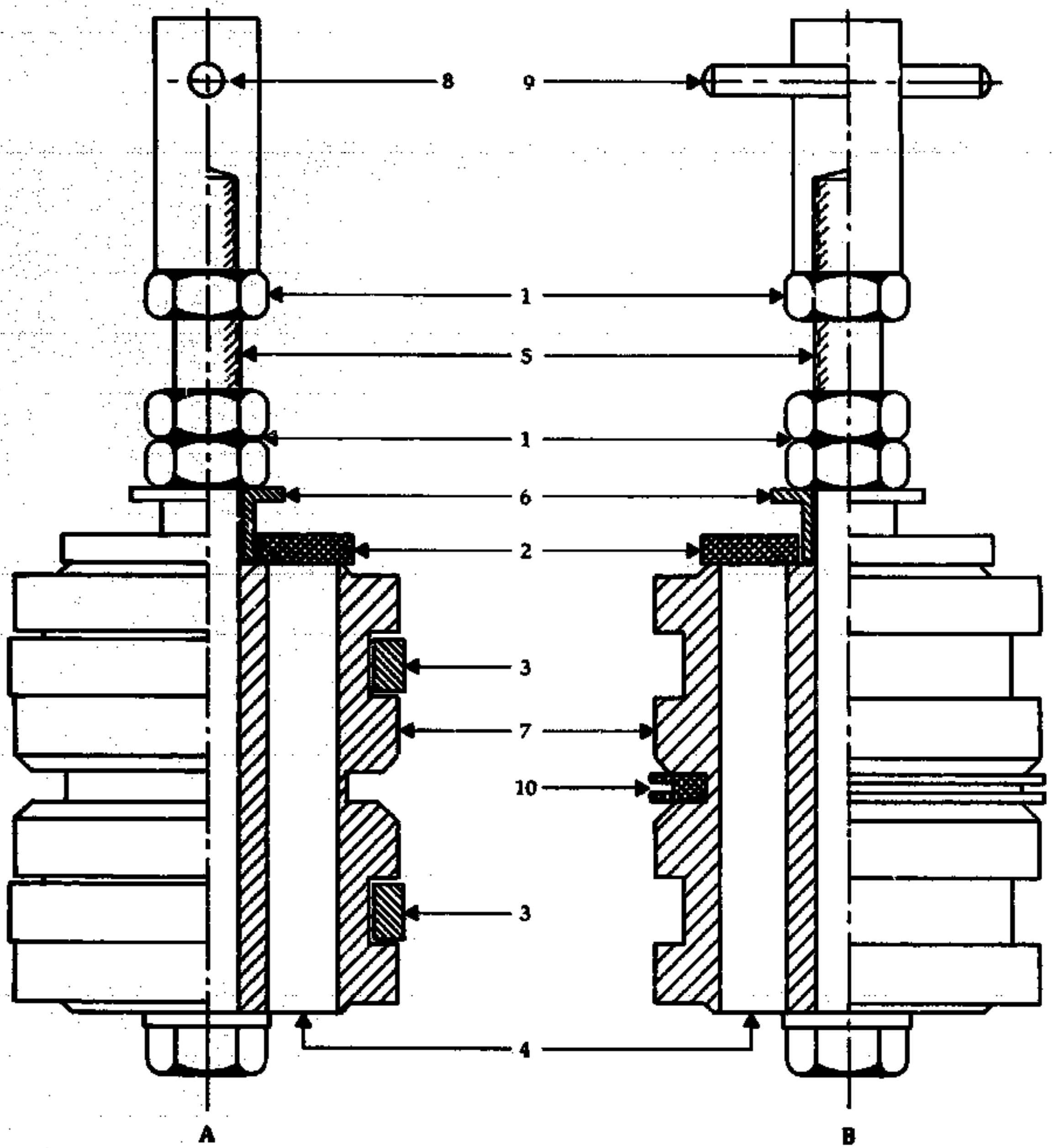


Fig. 6. *(A) Piston assembly and (B) recoverable foot valve: (1) lock nuts; (2) valve flap (natural rubber); (3) piston rings (polyethylene); (4) six equally spaced holes; (5) bolt; (6) valve stop; (7) PVC plastic; (8) hole for connecting pin; (9) recovery pin; and (10) double-lip rubber seal.*

terminals. When the terminals are exposed to air, the multitest meter reads open circuit. When the terminals are immersed in water, the meter reads in the order of 200 kohms. Discrete changes from infinity to 200 kohms can be obtained on the multitest meter for changes in the level of water of less than 0.24 inch (6 mm). The depth of the water table from the ground may be determined from the length of the wire.

Total usage of handpump For a comparative study of wear and physical deterioration of major handpump components, a measure of the total usage of the handpump in the field over the period under consideration is needed. Figure 7 shows an arrangement where a Veeder-Root totalizing counter (which does not register reversed rotation) was adapted to measure the cumulative travel of the piston rod during the useful stroke. The mounting is

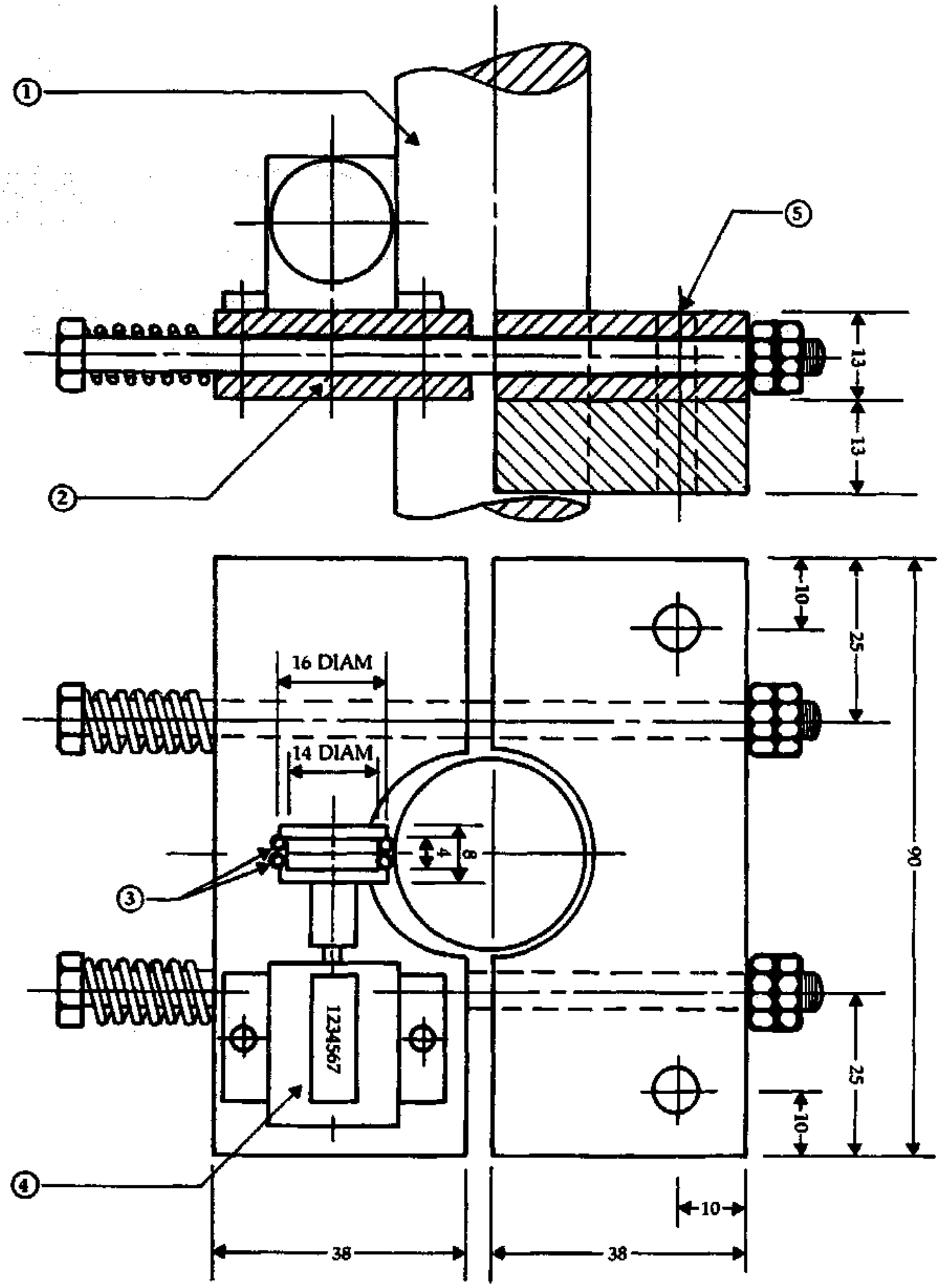


Fig. 7. *Mounting for Veeder-Root (V-R) counter on handpumps (all dimensions in mm; 10 mm = 0.3937 inch): (1) piston rod; (2) sliding fit to allow for lateral movement of counter; (3) two O-rings (13 mm ID × 2 mm diam (0.51 × 0.08 inch) cross-section); (4) V-R flange-case counter (#74-6125-001); and (5) mounting screw to top plate of handpump.*

Table 1. Summary of performance data.[a]

Pump number	Type[b]	Date installed	Number of users (persons)	Efficiency (%)		Water head (m)	Average water output (L/day)	Down time (days)	Maintenance and repairs		Period monitored
				η_{vol}	η_{mech}				Parts (US$)	Time (hours)	
PK 001S	S	19/11/80	50	95.0	-	2.6	381.0	0	9.40	0.50	6/7/81-16/3/82
PK 002S	S	18/11/80	40	98.0	-	2.4	58.9	0	0.26	0.50	6/7/81-16/3/82
PK 003S	S	19/11/80	40	95.0	-	2.8	93.8	0	-	-	7/7/81-16/3/82
PK 004L	L	2/12/80	30	89.0	-	2.5	502.7	0	-	-	7/7/81-17/3/82
PK 005L	L	2/12/80	50	98.0	-	2.7	186.2	0	8.45	1.50	7/7/81-17/3/82
PK 006S2	S	3/2/81	40	84.0	-	3.5	217.6	60	-	2.50	7/7/81-17/3/82
NS 001S	S	6/7/80	25[c]	83.5	59.6	3.7	487.5	3	-	0.50	25/6/81- 7/4/82
NS 002S	S	6/7/80	25[c]	93.7	59.1	3.7	133.5	0	-	-	25/6/81-12/4/82
NS 003L	L	24/7/80	25[c]	92.0	-	9.2	152.2	4	0.50	3.00	29/7/81-19/4/82
NS 004S	S	24/7/80	25[c]	79.2	64.0	7.0	85.2	0	-	-	29/7/81-14/4/82
NS 005S	S	28/7/80	25[c]	84.4	62.2	6.9	59.9	0	-	-	11/8/81-19/4/82
NS 006S	S	28/7/80	31	81.7	65.0	4.9	351.3	0	9.40	0.17	17/6/81-12/4/82
NS 007PS	PS	18/9/80	40	75.0	-	4.9	524.0	1	10.50	2.75	17/6/81- 9/4/82
NS 008PL	PL	25/9/80	50[c]	90.0	-	5.4	826.8	0	7.80	3.00	22/7/81- 9/4/82
NS 009L	L	2/10/80	15[c]	70.5	65.2	7.6	242.6	10	0.75	21.75	21/10/81-16/4/82
NS 010S	S	9/10/80	50[c]	95.0	70.4	4.6	718.2	0	-	-	15/6/81- 7/4/82
NS 011PS	PS	16/10/80	35[c]	79.0	-	5.8	506.0	4	12.00	7.50	20/7/81-14/4/82

[a] 1 m = 3.28 feet; 1 L = 0.22 gallon.

[b] S, suction; L, lift; PS, pressure-suction; PL, pressure-lift.

[c] The number of households rather than number of users was given. An average of five persons to a household is used as an estimate.

Table 2. Summary of maintenance and repairs for pumps at Perak (PK) and Negri Sembilan (NS).

Pump number	Date installed	Maintenance date	Down time (days)	Description	Cost of spare parts (US$)	Time required (hours)
PK 001S	19/11/80	27/1/81	0	Broken PVC spout replaced	9.40	0.50
PK 002S	18/11/80	27/1/81	0	Leaking foot valve changed to new Linard rubber valve flap	0.26	0.50
PK 003S	19/11/80	-	0	None	-	-
PK 004L	2/12/80	27/1/81	0	Wood cover cracked but no action taken	-	-
PK 005L	2/12/80	10/9/81	0	Fulcrum too loose and retightened	-	-
				Piston bolt broken during dismantling and replaced	8.45	0.50
				PVC piston rod cracked at brass pin hole; relocate new hole	-	1.00

made from a 0.5-inch (1.27-cm) thick plate. After drilling the central hole (slightly larger than the piston rod), the plate is cut into two similar halves. A third half-plate is required for mounting the assembly so that the movable half-piece is clear of the top-plate of the handpump. The Veeder-Root counter is mounted on the movable half-plate, which is spring-loaded to ensure constant contact of the roller with the piston rod. The fixed half-plate should be mounted clear of the piston rod (taking into consideration any swing or inclination of the piston rod during the applied stroke).

Work input The method used in the laboratory to determine work input is not suitable for use in the field because of the difficulty of transporting several pieces of sensitive electronic equipment and ensuring that they remain in good operating condition at the field site. Moreover, the method also requires a highly trained technician to carry out the measurements. It is, therefore, desirable to have a simpler, lighter, and more robust instrument that can be readily carried to the field and operated by a technician with minimal training.

The mechanical instrument used to measure work input at the field site consists of essentially: (1) two steel bars, held together at both ends by adjustable clamps, that deflect relative to each other when a load is applied to the midpoints of the bars; (2) a dial gauge that magnifies the deflection of the steel bars; (3) an indicator drum that rotates the tracing paper as the instrument is displaced from a fixed position; and (4) a pen connected to the dial gauge by a string that is held taut by a recoiling spring. During the operation of the pump, the relative deflection of the bars, after being magnified by the dial gauge, causes the pen to move perpendicular to the rotation of the drum. The resultant diagram traced on the paper on the drum gives a force-displacement loop that is equivalent to that obtained by the laboratory method.

The operating range of the mechanical instrument with respect to the applied force may be changed by changing the distance between the adjustable clamps so that the effective deflecting length of the steel bars is either reduced or increased.

Field monitoring procedures

Four separate sets of forms were used for monitoring pumps in the field. They were: (1) *Form K1* was designed for use by Ministry of Health personnel to record counter readings at 2-week intervals; a second copy of this form, which was updated regularly, was kept at the University; (2) *Form A (Well and Pump Specifications)* was used to record basic information on the well and pump, and was completed before the start of the monitoring period; (3) *Form B (Site Visit Data Sheet)* was the basic form used for field monitoring and was divided into four sections — (a) mechanical performance (completed at each monthly visit), (b) maintenance operations (recorded when necessary), (c) wear measurements (measured bimonthly), and (d) user feedback (whenever possible during monthly visits); and (4) *Form C (Failures and Repairs)* was completed when a pump failed and included details of repairs and other measures taken.

Although all 17 handpumps were installed and used by villagers for approximately 2 years, it was only during the last 8.5-month period that they were fully monitored.

Field performance

To facilitate comparison among handpumps, the data for all 17 were summarized (Table 1). Maintenance and repairs carried out on the pumps were also summarized (Table 2).

Performance results were computed from field data for all 17 handpumps. Figure 8 gives an example of the results of the data for one pump. To isolate the effect of water head on the volumetric efficiency, plots of $(1 - \eta_{vol})/h_T$ against calendar time were made for each handpump (see, for example, Fig. 9). There was considerable experimental scatter for small values of $(1 - \eta_{vol})/h_T$, which is equivalent to high values of η_{vol} and low values of h_T. For larger values of $(1 - \eta_{vol})/h_T$, the experimental points showed a more consistent trend. The straight lines through the experimental points were plotted using the method of least squares. For most cases, the expression $(1 - \eta_{vol})/h_T$ decreased with calendar time indicating that the sealing efficiency improves with time.

Variations of water head with calendar time showed a similar pattern of variation in each district, indicating the dry and wet seasons in the respective areas.

The average volume of water delivered per day was computed from the counter readings (which were the sum of the piston travel)

PK 006S2	3/2/81	7/7/81	60	Many problems due to well having insufficient water; lift pump replaced with suction pump	-	2.00
		10/9/81	0	Fulcrum arm/base too tight and reset	-	0.50
		10/9/81	0	Wood cover piece cracked but not replaced	-	-
NS 001S	6/7/80	30/9/81	0	Piston and foot valve cleaned of iron stains	-	0.50
		3/2/81	3	Priming inlet not closed properly	-	-
NS 002S	6/7/80	-	0	None	-	-
NS 003L	24/7/80	28/9/81	4	Piston rod broke at socket joint	0.50	3.00
NS 004S	24/7/80	-	0	None	-	-
NS 005S	28/7/80	-	0	None	-	-
NS 006S	28/7/80	25/11/81	0	Spout missing	9.40	0.17
NS 007PS	18/9/80	20/2/81	1	Broken brass piston-connecting bolt replaced with mild steel (chromed) part	6.00	2.00
		23/4/81	0	Foot-valve brass bolt broken	4.50	0.50
		17/6/81	0	Wooden fulcrum arm/base loose and retightened	-	0.25
NS 008PL	25/9/80	20/2/81	0	Replaced brass connecting bolt with mild steel part (no sign of damage)	6.00	1.00
		19/3/81	0	Brass hinge joint badly worn; hinge eliminated from the design	-	1.75
		30/9/81	0	Wood fulcrum arm cracked	1.80	0.25
NS 009L	2/10/80	19/12/80	0	Leaking foot valve replaced with Linard rubber valve flap	0.25	6.75
		9/6/81	10	PVC piston rod broken	0.50	15.00
		19/8/81	0	Nuts of wood fulcrum loose due to wear of the wood and retightened	-	-
NS 010S	9/10/80	-	0	None	-	-
NS 011PS	16/10/80	21/1/81	1	Broken brass connecting bolt replaced	6.00	2.00
		13/2/81	3	Same part broken again and replaced	6.00	3.00
		20/2/81	0	Replaced above part with mild steel part	-	2.50

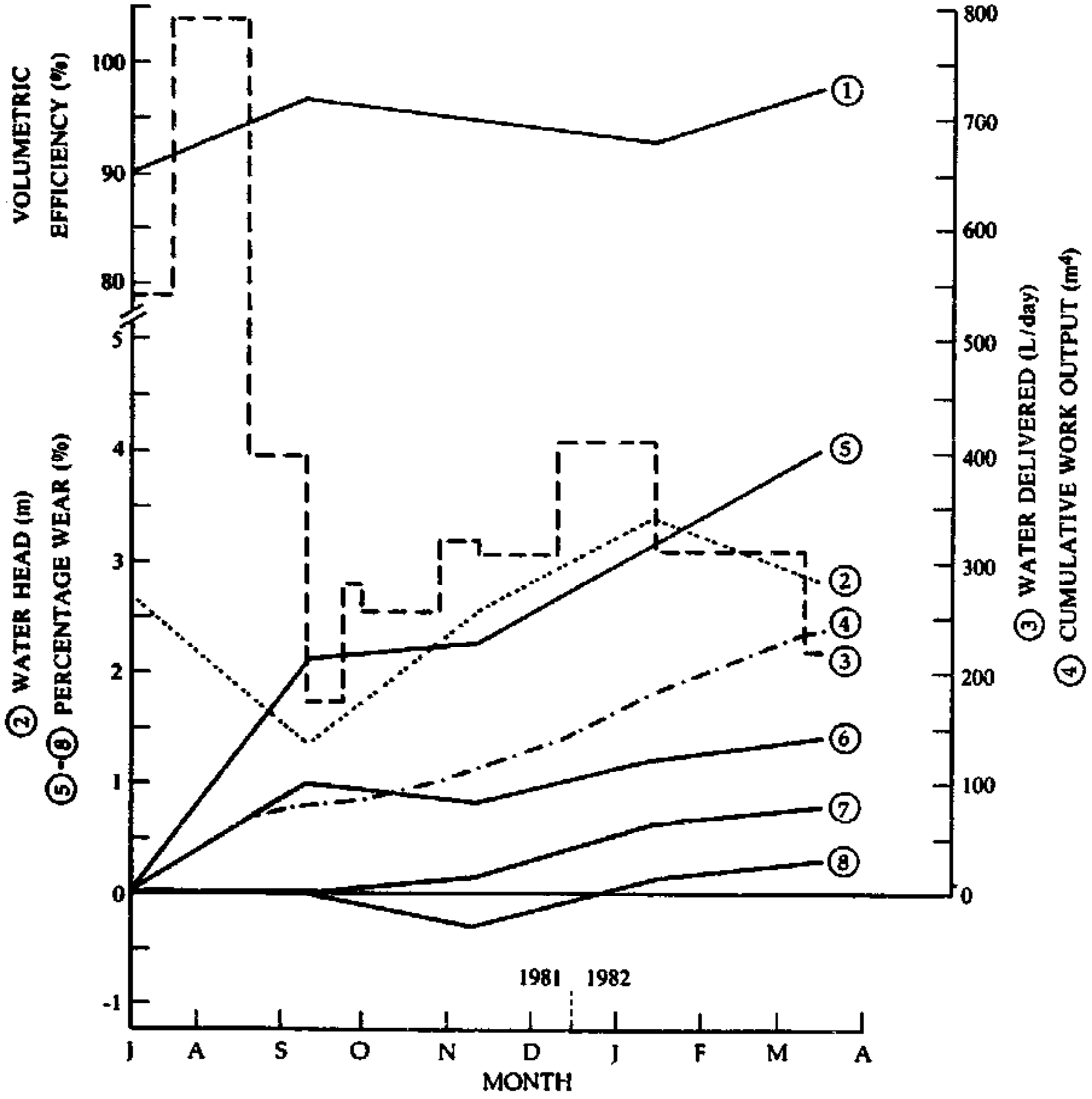


Fig. 8. *Performance characteristics of handpump PK 001S in field test: (1) volumetric efficiency; (2) water head; (3) water delivered per day; (4) cumulative (total) work output (m^4 = m^3 (volume) × m (lift)); (5) percentage wear of top wooden bushing (0°); (6) percentage wear of bottom wooden bushing (90°); (7) percentage wear of top piston ring; and (8) percentage wear of bottom piston ring.*

and the average volumetric efficiency for the period between monitoring visits. The average volume of water delivered per day varied from handpump to handpump as well as for the same handpump at different times of the year. It is interesting to note that the average volume of water delivered per day was higher when the water head was greater (which coincided with the dry season for the particular district).

The total (accumulated) work output was computed as the product of the average volume of water delivered per day and the average water head for the period between monitoring visits. The total work output for different handpumps varied considerably either because some handpumps were used more than others or because of a difference in water head. One would expect the general wear and tear of the handpumps to be more dependent on the total work output rather than calendar time.

Wear

Although wear measurements were made on a number of components, significant wear was found only in: (1) the top wooden bushing for the piston rod; (2) the piston rings; (3) the handpump cylinder; and (4) the brass pins used in the pin-joints of the piston rod. The wear of the brass pins, however, was not measured. Wear measurements in the field are not always taken under ideal conditions and some of the measurements, especially of components with very small wear, are definitely in error as indicated by negative wear readings. However, when the wear becomes large, consistent trends may be observed.

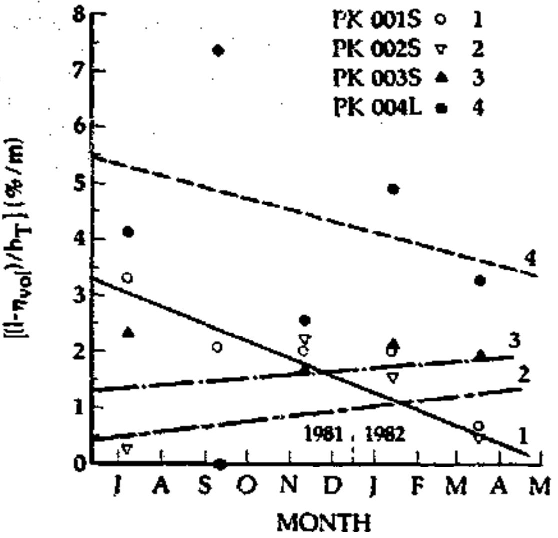


Fig. 9. *Variation of $(1 - \eta_{vol})/h_T$ with calendar time for four pumps.*

Wear in the bore of the top wooden bushing

Wear in the bore of the wooden bushing supporting the piston rod was calculated as a percentage from: (measured diameter -

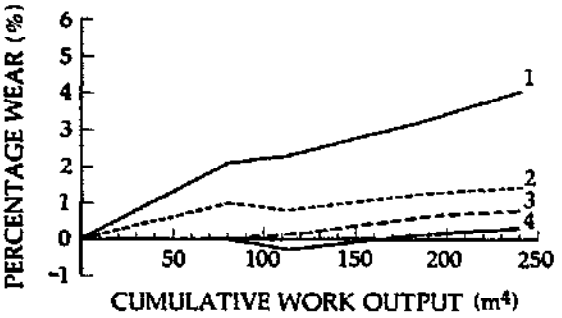


Fig. 10. *Variation of wear with cumulative (total) work output for handpump PK 001S: (1) top wooden bushing (0°); (2) bottom wooden bushing (90°); (3) top piston ring; and (4) bottom piston ring.*

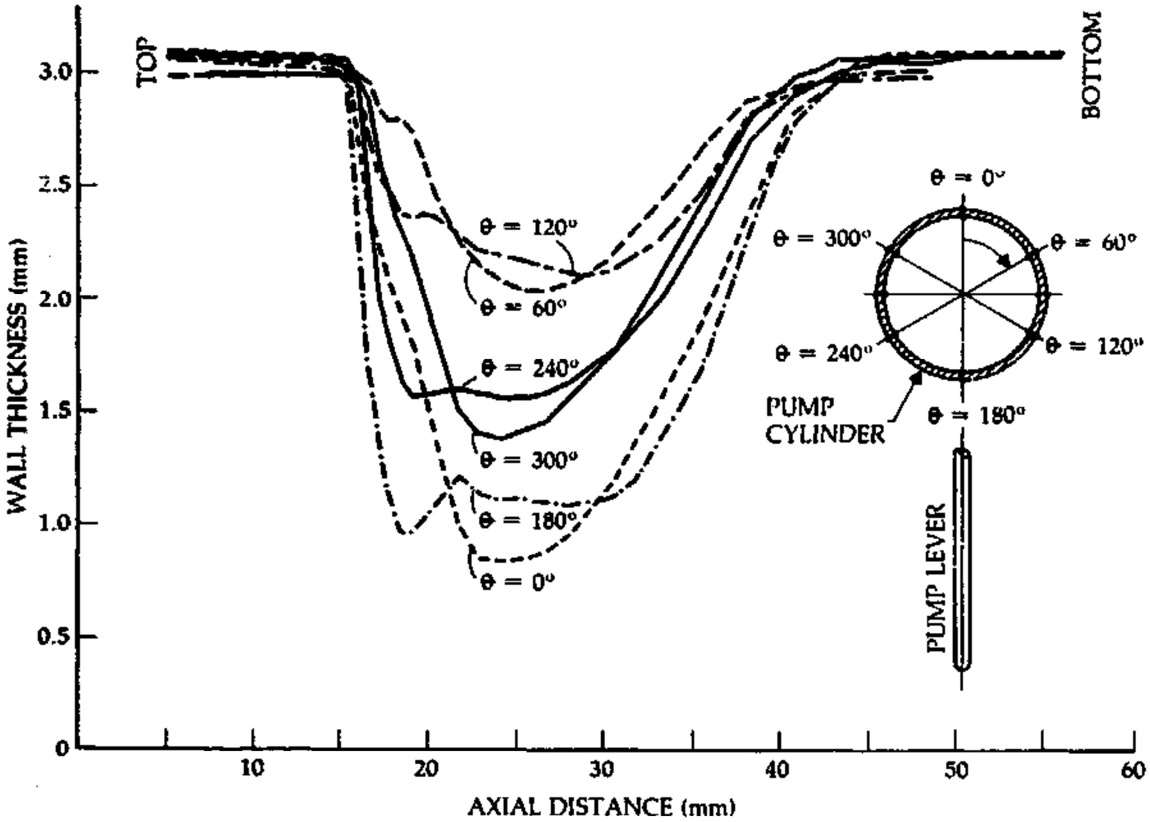


Fig. 11. *Variation of wall thickness of pump cylinder with axial distance for pump NS 010S.*

original diameter) × 100/(original diameter). The angular position of the hole was defined as θ = 0° for the diameter in the plane of the lever and θ = 90° for the diameter perpendicular to it. Wear in the bore of the wooden bushing was plotted against calendar time and against total work output (Fig. 10). As expected, the wear was more dependent on the total work output than on calendar time. The magnitude of the wear also varied from handpump to handpump depending not only on the total work output but also on the dampness of the wooden bushing and the slack in the lever system. It was also not surprising that the wear in the plane of the lever (θ = 0°) was greater than that perpendicular to it (θ = 90°).

Wear of piston rings Wear of the high density polyethylene piston rings was calculated as a percentage from: (original thickness - measured thickness) × 100/(original thickness). Wear of the piston rings was also plotted against calendar time and against total work output. Again, the wear is more a function of total work output than calendar time. The average total wear of the piston rings over the 8.5-month period was of the order of 4%.

Wear of the pumping section of the handpump cylinder At the end of the field test, the PVC pump cylinder was replaced by a new cylinder. The original pump cylinder was cut into two halves along its cylindrical axis and the wall thickness measured in the laboratory. Figure 11 shows the variation of wall thickness of the pumping section of the PVC cylinder of a handpump that had been in use in the field for approximately 2 years. Wear was very significant and had extended, in this case, to about two-thirds of the original wall thickness of the handpump cylinder. In the present design, high density polyethylene piston rings were used and the above results show that the PVC cylinder wears more than the polyethylene piston rings. This shows that the original choice of materials is not satisfactory. Because it is easier and more economical to replace the piston rings than the pumping cylinder, it is more desirable to have a combination where the piston rings wear while the pumping cylinder is more resistent to wear.

A member of the present project team, in a current experimental investigation, has shown that low density polyethylene wears about 10 times faster than high density polyethylene when rubbing against PVC material in clear water. However, until further tests are carried out to determine whether piston rings made from low density polyethylene or some other material can reduce wear in the PVC cylinder significantly in a field environment, a temporary solution to the cylinder wear problem is to raise the piston to a new, unworn, section of the pumping cylinder after every 2 years of use.

Conclusions

After approximately 2 years of use in the field, except for severe wear of the PVC pumping cylinder, the handpump of the present design appears to have withstood the wear and tear of everyday use and required only minor maintenance and repair. Routine maintenance is required after every 2 years either to replace the worn section of the cylinder or to raise the piston to an unworn section of the cylinder.

Because the major components of the present handpump are made from plastics, the use of injection moulding techniques offers great promise for cost reduction when the handpump is produced in large numbers.

Acknowledgment This project was funded by a grant from the International Development Research Centre. This is gratefully acknowledged. The author would like to thank the local Ministry of Health personnel in Ipoh, Seremban, and Kuala Pilah for their cooperation in getting the handpumps installed and monitored during the field test. Last, but not least, our appreciation goes to the village users of our present handpumps for their patience and tolerance during the field tests.

References

Goh, S.Y. 1980. The performance characteristics of a reciprocating piston water lift pump. Ottawa, Ont., Canada: International Development Research Centre. Interim progress report, Water pumping technology — Global project.

Sternberg, Y. 1978. Testing of wood bearings for handpumps. Washington, DC, USA: International Bank for Reconstruction and Development. Research Working Paper Series, P.U. Report No. RES 13.

Overview of Technical Performance

Goh Sing Yau

After the Consumers' Association laboratory tests, a proposed design of the pumping element with a piston and a foot valve was accepted by the International Development Research Centre (IDRC) for testing in the IDRC Asian network of handpump projects.

Development of the IDRC Design

The piston assembly consists essentially of a polyvinyl chloride (PVC) piston with two polyethylene rings (see Fig. 1A). Laboratory tests were carried out in Thailand and Malaysia to determine the critical values of: (1) orifice/piston and orifice/foot valve area ratios; (2) valve weight; (3) valve gap; (4) stroke length; and (5) the stroke rate needed to obtain optimum performance as characterized by high volumetric and mechanical efficiencies. The results of the laboratory tests were incorporated into the modified versions of the piston (see fig. 6 of the Malaysian paper, page 45).

Initial laboratory and field tests of the foot valve (see Fig. 1) in Thailand, Sri Lanka, and the Philippines showed that the original polyethylene cup seals did not provide an effective water-tight seal and leakage was excessive. To overcome this problem, a nonremovable foot valve (see fig. 7 of the Thailand paper, page 28) was used, with the foot valve solvent-welded or bolted to the pump cylinder. Later, a double-lipped rubber seal was developed by the Malaysian group to replace the polyethylene cup seal for use in a removable foot valve (see fig. 6 of the Malaysian paper, page 45).

The original IDRC design recommended a PVC or polyethylene valve flap. The use of these valve flaps caused excessive leakage that was particularly noticeable in the foot valve. The initial modification carried out by Thailand was to use a rubber disc with a brass backing-plate glued on to it. To prevent accumulation of sand at the valve seat, elevated lips were cut on the valve seat. The seal could be further improved with a spring to press the valve flap onto the seat. However, laboratory tests in Malaysia indicated that the spring-loaded valve flap increased the work input substantially and hence decreased the mechanical efficiency.

It was discovered after several months of use that the glued-on brass backing-plate detached itself from the rubber disc. A further modification was subsequently successfully introduced in Thailand by replacing the previous valve flap design with a single rubber disk 0.25 inch (0.64 cm) thick without the backing plate or the spring. This modification was also found to be successful in the Malaysian project.

In Sri Lanka, where there was difficulty in obtaining polyethylene rods, leather cup seals were used in place of polyethylene rings and cup seals.

Development of the Above-Ground Components

Different configurations of the above-ground components were used in the four countries; these are summarized in Table 1.

The concrete pedestal adopted by the Philippines appears to be a simple, cheap alternative to the traditional pump stand.

Timber lever handles (used in Malaysia and the Philippines) and timber/galvanized-iron bearings (used in model L3 in Sri Lanka and in Malaysia) have been found to be practical and durable. When cheap timber is available, timber components appear to be the obvious choice. The use of timber components also simplifies maintenance and repairs by handpump users at the village level.

Field Tests

A mid-project review meeting attended by investigators from each of the participating countries was held in Kuala Lumpur from 26-28 August 1980 to exchange experiences gained in laboratory and field tests and also to propose a common field-monitoring proce-

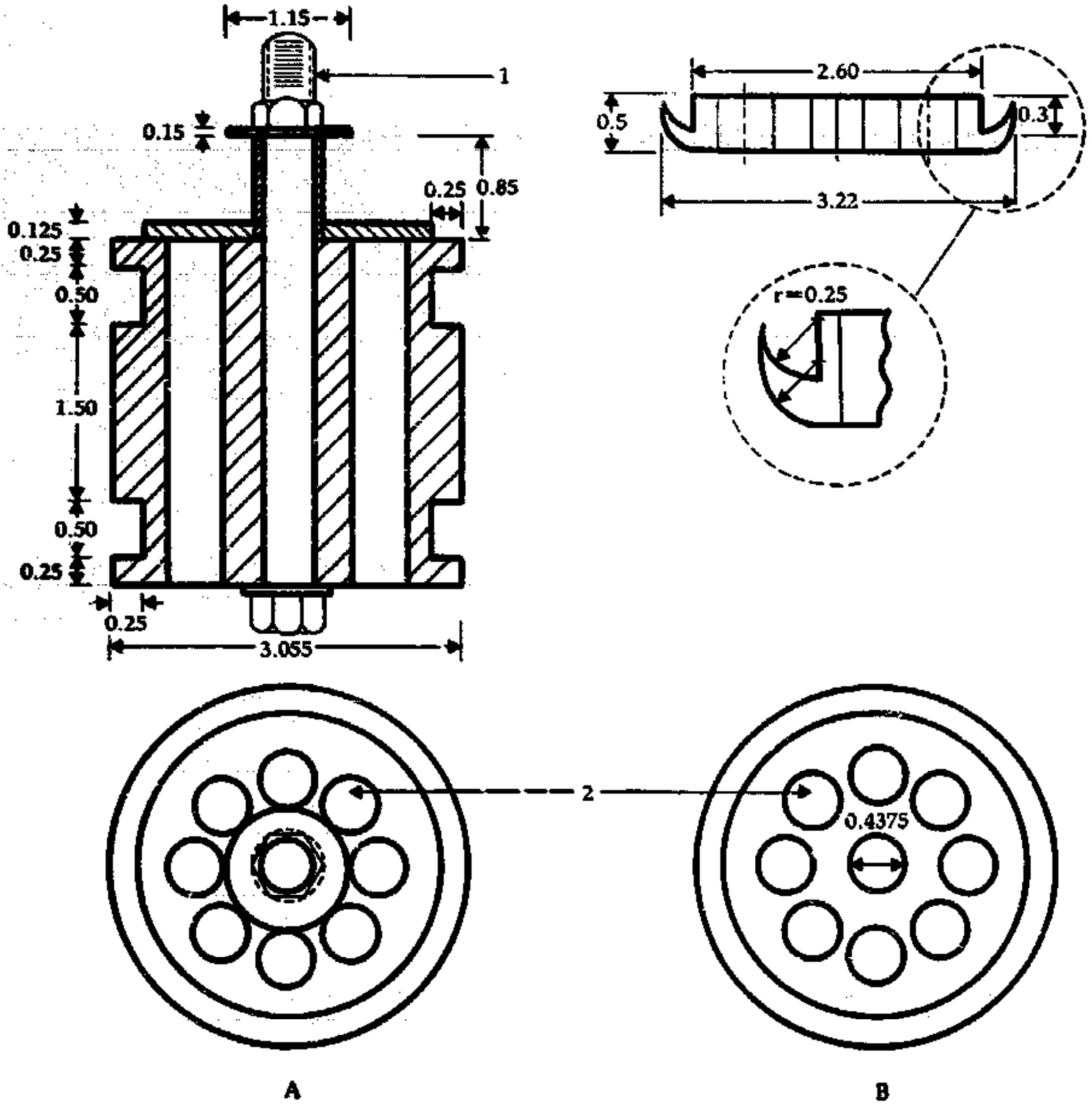


Fig. 1. *Design of original (A) piston and (B) foot-valve adaptor tested in the Asian handpump network (all dimensions in inches; 1 inch = 25.4 mm): (1) 7/16-inch (1.11-cm) diameter bolt, 5.5 inches (13.97 cm) long; (2) 0.5-inch (1.27-cm) holes at 1.53-inch (3.89-cm) pitch diameter.*

dure for the four projects. Two important instruments required for the field-monitoring program were subsequently developed to measure the average water delivered per day over the monitored period (a totalizing counter) and the work input of the pump (a mechanical plotter). These two instruments are described in detail by Goh (1980).

The detailed field monitoring procedure, as proposed in the mid-project meeting, was carried out only in Sri Lanka and Malaysia. By the time the instrumentation required for the field monitoring was developed, the Thailand program had come to an end and the project in the Philippines encountered problems in the foot valve and the well.

The handpumps in Sri Lanka and Malaysia were in the field for more than 2 years. However, because of the delay in the development of the field monitoring instrumentation, the field monitoring program was carried out only for the last 13 months in Sri Lanka and the last 8.5 months in Malaysia. The results of these monitoring studies are reported in the country papers.

The volumetric efficiency of the hand-

Table 1. Summary of above-ground systems.*

Country and model	Pedestal	Leverage system	Handle	Top bushing	Piston rod	Water head (m)
Sri Lanka						
L1	Angle-iron frame	Brass bushing	25-mm GI pipe	GI reducer	25-mm PVC pipe	2-7
L3	Metal cage	Timber bearings	25-mm GI pipe	Timber	25-mm PVC pipe	2-8
V1	GI pipe	Direct lift	Timber	Timber	25-mm PVC pipe	1-4
Thailand						
DMR (modified)	Cast-iron pipe	Cast-iron lever arm with metal bushing	Cast-iron pipe	Stuffing box	11-mm diam steel rod	2-21
ARD (modified)	Cast-iron pipe	Cast-iron rack and pinion gear	Cast-iron pipe	Metal packing nut	11-mm diam steel rod	2-10
AIT-PVC	Mild steel pipe	Cast-metal lever arm with ball bearings	50-mm GI pipe	Stuffing box	11-mm diam steel rod	2-7
Philippines						
Lift	Concrete	Concrete pedestal with brass bushing	Timber	GI reducer	Mild steel rod	2-8
Malaysia						
Suction/lift	Mild steel pipe	Timber linkages and bearings	Timber	Timber	Top 1 m 25-mm GI pipe, remainder 25-mm PVC pipe	2-11

*10 mm = 0.39 inch; 1 m = 3.28 feet.

pumps after approximately 2 years of use was still relatively high showing that the piston ring seals were still effective. The mechanical efficiency measured at the piston rod was of the order of 60% after about 2 years of use in the field. This compares very favourably with the results of mechanical efficiency measurements on new handpumps for 23-foot (7-m) water heads at the Consumers' Association laboratories (UNDP/World Bank 1982).

Although wear measurements were made of most moving parts, wear was generally slight except for the top wooden or metal bushing and the pump cylinder. After 2 years of use with an equivalent of 100 000 gallons (450 000 L) of water output, the cylinder wall of one pump had worn by approximately 70%. The wear in the corresponding piston rings was only about 1%. For the present design, where high density polyethylene rings were used with PVC cylinders, it is recommended that the pump cylinder be inspected for wear every 2 years or after an output of 100 000 gallons (450 000 L) of water.

Concluding Remarks

The detailed results of the projects in Malaysia, the Philippines, Sri Lanka, and Thailand are given in the end-of-project reports. However, overall, the following general remarks may be made.

The PVC handpump has been applied successfully for use in wells up to a maximum water head of 33 feet (10 m).

The results of the field tests indicate that: (a) a concrete pedestal; (b) timber handles, bearings, and bushings; and (c) PVC pump rods and cylinders are practical alternatives to the traditional cast or welded metal designs of handpumps used for water heads of up to 33 feet (10 m).

There is insufficient field monitoring data on the PVC handpump for water heads greater than 33 feet (10 m) to be able to make a positive statement on its use for such depths.

References

Goh, S.Y. 1980. The performance characteristics of a reciprocating piston water lift pump. Ottawa, Ont., Canada: International Development Research Centre. Interim progress report, Water pumping technology — Global project.

UNDP/World Bank. 1982. Laboratory tests on hand-operated water pumps for use in developing countries. Washington, DC, USA: UNDP/World Bank. Rural water supply handpumps program, Report No. 1.

Economic Analysis and Potential Markets

Tan Bock Thiam

Of the people in developing countries, 75% do not have access to adequate supplies of clean water (IRC 1982). The use of handpumps in areas where there are adequate supplies of ground water is the simplest, least costly method of providing the rural population with clean water. As increased attention is paid by governments and international organizations to the provision of safe sources of drinking water to the people in the rural areas, the demand for handpumps in nearly all developing countries will increase.

The potential market in these countries has been estimated at 20 million for this decade (Modern Asia 1982). However, although there is an obvious demand for handpumps, the installation rate of these pumps appears to be hindered by the lack of a pump that can be maintained easily at the village level. Such a pump, which is ideally suited for the rural areas, is described as a village-level operation and maintenance (VLOM) pump.

The average maintenance cost for handpumps in East Africa is $400[1] per pump per year (World Water 1982). In some instances, the maintenance cost accounts for 85% of the amortized cost of installing a rural-water supply. Thus, although the use of handpumps offers a low-cost alternative to the provision of clean water in rural areas, the high incidence of pump breakdown and the problem of providing adequate maintenance deter the wider use of these pumps in rural areas.

The objectives of this study were threefold: first, to conduct a financial and economic analysis of the cost effectiveness of the polyvinyl chloride (PVC) handpumps being tested by the International Development Research Centre (IDRC) network, as compared with other handpumps in use in these countries; second, to analyze the sources of water supply for rural areas and make projections regarding the percentage of rural households to be served by piped water by the year 1990; and, third, to undertake a preliminary assessment of the market for handpumps for the next 10 years and assess the potential market for the handpump being tested by the network in these four countries.

Some of the information on the cost of the handpumps was obtained from the project interim reports. Additional information was secured using a questionnaire and from discussions with the project leaders in each of the four countries. Information on the second and third objectives of this study was gathered from interviews with the project leaders, government officials, and other interested individuals from various organizations.

One of the major limitations of this study was the limited time spent in Sri Lanka, Thailand, and the Philippines. Therefore, it was possible to obtain only a preliminary assessment of the overall situation regarding rural water supply in general, and the role of handpumps in particular. Nevertheless, with the active cooperation of each country's project team and information obtained from interviews and published sources, it was possible to arrive at a fair assessment of the situation prevailing in these four countries.

The cost information available for the IDRC-PVC pumps was for experimental or individually fabricated units. Thus, it was not meaningful to use the data for comparison with other pumps produced on a large scale. It was only possible in one country (Malaysia) to obtain the estimated cost of the PVC pump if it were to be produced in large quantities. Thus, a detailed financial analysis was only carried out for Malaysia because of the lack of data from the other countries.

Country Analysis

Sri Lanka

The project team installed about 21 pumps, primarily in the southern part of the island. Each pump served a cluster of four to five households or about 30 people. All the pumps that were installed are still functioning and they are being maintained by the Sarvodaya

---

[1] All costs are in US$. The exchange rates used here are: US$1.00 = $2.30 Malaysian, P8.50 Philippines, B23.00 Thailand, and R20.00 Sri Lanka.

movement, which has several workshops in the area. These pumps were installed in hand-dug, 4.9-foot (1.5-m) diameter wells. The wells were lined with a concrete casing and covered with a removable concrete cover; thus, if the pump breaks down, the villagers can continue to obtain water with a bucket.

Two factors appear to influence the installation of the pumps in this manner. First, because the pumps are still experimental and may fail, this type of well offers some assurance of a constant water supply. Second, because villagers are not familiar with the method of drilling bore-hole wells, there was no local expertise available for trying this method of installation.

The construction of open wells increases the installation cost and places a limit on the depth that can be obtained. The average depth of 100 wells examined was about 16–23 feet (5–7 m) and the static water level was 10–16 feet (3–5 m) below the surface.

The Sarvodaya movement plans to install an additional 250 handpumps in various villages. The cost of installation will probably be borne by foreign-based aid agencies.

Economic analysis

Financial and technical information regarding the three handpump models are shown in Table 1. These pumps differ in their aboveground components, although the below-ground components are essentially the same.

Installation charges are nearly 300% of the cost of the pump, whereas yearly maintenance charges are about 23% of the total pump cost.

Water supply situation

Of the 12.7 million people in Sri Lanka in 1980, 73% lived in rural areas. There were 1 420 000 rural households, each containing an average of seven persons, and only 2% of the rural population was currently served by treated piped water.

The use of handpumps is a relatively new phenomenon, only about 2500 have been installed in Sri Lanka. Of these, only about 1500 (60%) are still functioning. If it is assumed that one handpump serves about 50 families, then only 75 000 families or about 5% of the rural population is currently being served.

The United Nations Children's Fund (UNICEF) is currently involved in a program to install a sizeable number of deep-well handpumps in the northern half of the island. To date, 600 holes have been dug and 300 pumps installed. These wells, which average more than 49 feet (15 m) deep, are situated about 0.5 mile (800 m) apart and each one serves about 50 households. The most common pump is the India Mark II, which costs approximately $400 per pump (excluding tax). UNICEF plans to have a two-tier program for the maintenance of these pumps: a village pump mechanic to attend to minor repairs and a regional pump inspector responsible for major repairs. The truck-mounted drilling rig required for this program was imported from Europe at a cost of about $250 000. A rig can drill up to about 80 holes per year at an estimated cost of $1000–1500 per well.

Table 1. Information on three handpump models tested in Sri Lanka.[a]

Item	Model V1	Model L1	Model L3
Installation ($)	283	269	241
Pump ($)	60	100	120
Yearly maintenance ($)	17	25	21
Expected life (years)	7	9	9
Persons served/pump	20	40	25
Avg water use/ person/day (L)	25	66	35
Water pumping rate (L/minute)	8	8	8

Note: Installation cost estimated for an average depth of 5 m (16.4 feet). Expected life is based on the project leader's estimates.

[a] 1 L = 0.22 gallon.

Potential markets

The potential market for handpumps in Sri Lanka is sizeable. The only limitation appears to be that 75% of the country is relatively dry; however, 70% of the population is concentrated in the wet zone. If 50% of the rural population were served by handpumps, the estimated number of additional handpumps required in Sri Lanka would be approximately 14 000, 15 000, and 17 000 in 1982, 1985, and 1990, respectively. These estimates are derived from the assumptions that the rural population is growing at an annual rate of 2.5% and that the number of families served per pump remains at 50. If the objective were to provide one handpump per 10 families, these estimates would have to be increased by 500%.

The government apparently places high priority on handpump development for the rural areas of the country. However, its program is being curtailed by the lack of the 30% counterpart financing that is a prerequisite for obtaining "soft" loans from the World Bank (World Water 1982).

Only a limited number of handpumps exist at present, whether locally manufactured or imported. The imported pumps come either from India or Bangladesh and, for shallow wells, cost about $100-250 each. In view of their limited usage and the lack of experience in their construction, there are no data on either their cost or reliability.

Provided that funds are not a constraint, the potential demand for the IDRC-sponsored PVC pumps is approximately 20000 pumps per year between now and 1990. This is based on the assumption that at least half the rural population can be served by shallow wells and that each pump serves five households.

Thailand

After some laboratory testing, a modified version of the below-ground component of the IDRC-sponsored PVC pump was installed in 54 selected wells in central, northeastern, and northern Thailand. These wells were being used daily by villagers, and had been fitted with a Department of Mineral Resources (DMR) (Demster or Red Jacket) or an Accelerated Rural Development (ARD) (modified Korat) pump. The project team retained the above-ground components of these 54 pumps and only altered the below-ground components. Thus the pump that was tested was made up of a combination of plastic and cast-iron components.

These pumps were field tested for 15 months and the results were generally satisfactory. The major problem encountered initially was that of foot-valve leakage, especially in sandy areas where sand particles lodged under the plate valve and caused the leakage. However, after some modifications to the design, this problem appears to have been solved.

The Asian Institute of Technology (AIT) group also designed a new PVC pump that had both above- and below-ground components of PVC, but only three of these pumps were tested in the field. The project team considers that the IDRC-PVC handpump can be used for wells to a maximum depth of 65 feet (20 m).

The drilled depth of the selected wells ranged from 52 to 112 feet (16-34 m). However, the water level ranged from 4.9 to 52 feet (1.5-16 m). The water level in most wells was less than 16 feet (5 m) in depth.

Economic analysis

The cost of the AIT-designed PVC handpump is comparable to the cost of the DMR and ARD handpumps. Excluding the cost of the riser pipe, which varies with the depth of the well, the cost of the AIT-PVC handpump is $135 as compared with $122 for the DMR and $139 for the ARD handpumps. The AIT-PVC handpump cost is for individually fabricated models, whereas the cost for the DMR and ARD pumps is for mass production. Hence, it would be possible to reduce the AIT-PVC handpump cost substantially if it were produced on a large scale.

Water supply situation

Nearly 30% of Thailand's population of 38 million people live in rural areas and 60% of these rural inhabitants, or 2.6 million households, do not have access to clean water. Although there is no definite figure on the number of handpumps installed in Thailand, it has been estimated that over 5 million people in the country depend on handpumps for water. If it is assumed that 200 people are served by one pump on average, then an estimated 25000 handpumps are currently being used in Thailand. Of this total, 19000 handpumps have been installed by various governmental agencies. The major problem faced by government agencies is that, on any particular day, 25% of these handpumps will be out of service. The average cost of maintenance for each of these handpumps is $71 per year.

The main government agencies involved in the rural handpump program are: Department of Mineral Resources in the Ministry of Industry; Department of Health in the Ministry of Public Health; and Department of Public Works and the Office of Accelerated Rural Development in the Ministry of the Interior.

Each of these agencies has adopted its own handpump design and the pumps are produced locally, i.e., by local manufacturing firms who are awarded government contracts for such pumps. Their design is essentially similar to models imported from western countries, but they incorporate some minor modifications.

These agencies are also involved in drilling wells and installing handpumps in the rural areas. To date, they have installed about

19000 handpumps, two-thirds of which are for deep wells, more than 65 feet (20 m). About 10% of these wells have been fitted with motorized pumps. In the last 2 years, the annual target has been increased from 1000 to at least 2000 wells per year.

The Department of Mineral Resources uses a modified Demster pump that they are installing on 6-inch (15-cm) tube wells drilled to a depth of about 115 feet (35 m). This costs about $3300 and includes expenses for both the drilling and the handpump, which costs $150. The maintenance and repair cost is $125 per pump per year. Each pump serves about 250 people and provides water throughout the year, whereas shallow wells often run dry. The Department plans to increase its pace to drill 4500 wells annually to reach the target of a total of 20000 deep wells by 1990.

The Accelerated Rural Development Office utilizes a modified Korat pump that costs about $139. It differs from the original Korat pump in that it has a 3-inch (7.5-cm) cylinder made of PVC and a 1.25-inch (3-cm) drop pipe. These pumps are normally used for shallow wells, less than 50 feet (15 m) deep.

The Department of Health's Division of Rural Water Supply is the main agency involved in the installation of pumps in rural areas. It installs handpumps for both deep and shallow wells. To date, it has installed about 600 deep-well pumps to draw water from an average depth of 115 feet (35 m). The modified Korat handpump that they use costs $150 and its annual maintenance cost is $130. Each well serves a group of 40-50 households. The drilling and installation cost is approximately $1500.

The Division of Rural Water Supply has also established about 1000 shallow wells in central Thailand. The pump used is called the A-pump or Lucky pump and costs about $30-40. The average depth of these wells is 33 feet (10 m). The average digging and installation cost is about $250, whereas the annual maintenance cost is only $8 per pump. The Division plans to install between 800 and 1000 of these pumps per year for the next few years. Last year, the Division, in cooperation with Chulalongkorn University, was involved in a project to develop and test a PVC handpump. This pump was manufactured locally and has been installed in 100 shallow and 20 deep wells. The cost of the pump is $50 for shallow wells and $100 for deep wells. The performance of these pumps is now being monitored.

Potential market

There are an estimated 2.6 million households in Thailand that do not have access to clean water for domestic consumption. Based on the assumption that the rural population is growing at a rate of 2.5% per year, by 1990, 66000 handpumps would be required if handpumps were to be provided to this population at a rate of one pump per 50 families. If the target is to provide every 10 households with a pump, the potential demand would be 330000. These figures do not include replacement pumps.

There is generally a preference for deep wells in Thailand because this assures that water is available throughout the year. For some parts of the country, particularly in the drier areas, water from shallow wells is available for only about 8 months of the year. Assuming that 50% of the handpumps that will be installed will be for shallow wells, the potential market for an IDRC-PVC pump is about 4500-18000 units per year between now and 1990 depending upon the number of families to be served per pump (see Table 7).

Philippines

Thirty pumps based on the Waterloo design were fabricated by a local contractor and installed in various locations on Luzon Island. No laboratory testing was conducted and the pump that was installed was essentially similar to the Waterloo type. The above-ground component, however, used a concrete stand that was relatively economical.

The average casing depth was 39 feet, range 20-59 feet (12 m; range 6-18 m), and the average water depth was 13 feet, range 3-26 feet (4 m; range 1-8 m). Of the 30 pumps installed, only 4 are still functioning. The rest have been either abandoned or dismantled because of foot-valve leakage or the collapse of the wells.

Economic analysis

The cost of the IDRC-PVC pump was $267. Materials required for its fabrication constituted 92% of this cost, while the fabrication expense itself represented 8% of total cost. Well-drilling and pump-installation charges were relatively inexpensive, only $353 for an average depth of 39 feet (12 m).

One factor leading to the lower installation cost was the use of PVC pipe as the casing cylinder: PVC is one-third the cost of galvanized pipe. Another reason for the lower cost was the availability of local contractors experienced in well drilling and installation of handpumps. Also, a small motorized rig costing $4000 was used in well drilling operations.

Water supply situation

In 1980, only 43% or 21.2 million people out of a total population of 49.4 million were served by piped water supplies. Of the rural population of 34.1 million people, 33% obtained water from public supply systems, whereas the rest depended on handpumps, open wells, rainwater cisterns, and streams.

According to UNICEF statistics, there are 23 572 public artesian wells serving about 4 million people. Only 16 000 of them are operational and their average drilled depth is 197 feet (60 m) (World Water 1982). The Philippines has a large reserve of ground water and a high average annual precipitation, 89 inches (2260 mm).

The use of handpumps has a long history in the Philippines. In some areas, the majority of households have installed their own handpumps. Estimates of the numbers of rural households of a total of 5.68 million obtaining water by various means in 1980 are: from public water supply, 1.87 million; from artesian wells, 0.39 million; and from privately owned handpumps, 0.30 million.

These estimates are based on two assumptions: that an average household includes six persons; and that there are 30 000 privately owned shallow wells each serving 10 households. Based on these estimates, over three million households are still without clean water for domestic purposes.

To overcome this problem, the Philippines government has launched a 20-year program to provide safe and accessible water to all households. The two main agencies involved in this rural water supply program are the Rural Waterworks Development Corporation (RWDC) and the Ministry of Public Works (MPW).

Their program is centred on the formation of beneficiary committees into self-reliant water-supply associations or cooperatives. These associations are required to contribute to the capital cost and undertake the operation and maintenance of the water-supply system. The government agencies provide the technical and institutional assistance as well as contribute toward the bulk of the cost, including 10% of the operating and maintenance expenses.

Three levels of services have been proposed, depending on the population size of the area, the source of water supply, the development cost, and the community's ability to pay. The government will provide 90% of the capital cost for Level 1 and loans covering 90% of the capital cost are available for Levels 2 and 3.

The main emphasis for Level 1 is to develop point sources such as artesian wells and protected springs. Each shallow well is designed to serve a cluster of 15 households, whereas each deep well will cater to 50 households. The average installation cost per household is $12.33 (or $185 per well) for shallow wells and $98.82 (or $4941 per well) for deep wells. The annual maintenance cost is estimated at $0.82 per household.

Level 2 is essentially the same as Level 1 but includes a system of communal faucets. Its overall design is for a cluster of 100 households, and the cost per household is $71, excluding the cost of source development.

Level 3 provides for individual house connections and the overall design is for urban households. The capital cost per household is $247.

The Level 1 program will focus almost exclusively on the construction and rehabilitation of shallow and deep wells. The average depth of shallow wells is 30 feet (9 m), whereas the deep wells average 200 feet (60 m). By 1990, the RWDC and the MPW plan to install a total of 169 000 shallow wells and 87 500 deep wells throughout the country. In addition, a total of 26 000 existing wells will be rehabilitated.

Potential markets

An indication of the potential market for a low-cost efficient PVC pump can be obtained by examining the MPW and the RWDC targets for well construction (Table 2).

The cost of financing the program is estimated at $368 million. It is expected that part of this amount will be obtained from loan or aid programs of various international agencies. Failure to secure adequate funds may delay the implementation of this program.

The rural population in the Philippines is expected to rise to 43.1 million people or 7.2 million households by 1990. Assuming that all the proposed pumps are installed by 1990,

Table 2. Well construction and rehabilitation targets for the Ministry of Public Works (MPW) and the Rural Waterworks Development Corporation (RWDC).

Year	Shallow wells	Deep wells	Rehabilitation
1980	10000	1691	1274
1981	13000	5000	2000
1982	45000	13000	2500
1983	40000	14000	2500
1984	41000	15000	2500
1985	16000	15000	2500
1986–1990	4000	23800	12500

Source: Government of Philippines. 1980. Integrated water supply program, 1980-2000; and RWDC — The Philippines rural water supply program.

the country will have approximately 200 000 shallow wells and 110 000 deep wells. If all the shallow wells and 70% of the deep wells are located in the rural areas, each shallow well will be used by about 17 households and each deep well will cater to about 50 households. Thus, for a target of one shallow well for every five households, there will be a need for an additional 480 000 shallow wells by 1990.

Malaysia

After extensive laboratory investigations, nine suction, two pressure-suction, one pressure-lift, and five lift pumps were fabricated and installed in two rural areas — Kuala Pilah and Ipoh. These pumps have been field tested for over 1 year, and no major problems have been encountered so far. All of them are still functioning, and from preliminary observations, it appears that the villagers are satisfied with their performance. The major distinctive features of these pumps include: a PVC cylinder fitted with a sliding PVC piston and a stationary, but removable, PVC foot valve; and a leverage system consisting of timber linkages and galvanized iron/oil-impregnated timber bearings.

These PVC handpumps were installed in existing wells that had handpumps that were condemned from further use. The wells averaged 30 feet (9 m) deep and the water depth was usually 10-23 feet (3-7 m) below the ground. Each handpump served a cluster of four to five households. The pressure-suction and pressure-lift pumps, however, had individual household connections to each of the four or five households. Thus, every user could pump the water directly into a water tank installed at their own house.

Economic analysis

A financial analysis was conducted to compare the cost of the PVC pump (both experimental cost and projected production cost) with the cost of the two existing pumps (Gibson and Fuji).

The results of this analysis showed that the present worth and equivalent cost of the PVC pump were lower than the existing pumps (Table 3). This difference was especially significant when the cost of the PVC production model was compared with the cost of the existing handpumps. Using the present-worth and annual-equivalent-cost concepts, the cost of the PVC production model was

Table 3. Summary of various measures of pump cost (US$).

Type of pump	Capital cost	Present worth	Annual equivalent cost
Gibson	31	148.11	79.74
Fuji	61	155.48	28.40
IDRC			
Experimental	134	145.72	27.33
Production	74	85.72	15.99

Note: The analysis for present worth and annual equivalent cost is based on the format prepared by J. Majumdar and discussed at the mid-project meeting in August 1980 (Goh 1980).

Table 4. Basic information on handpumps (1980 constant dollars).

			IDRC models[a]	
Item	Gibson	Fuji	Experimental	Production
Installation cost[b]				
Material	85	85	85	85
Labour	49	49	49	49
Transport cost[c]	1	1	1	1
Pump and coupling	30	60	133	73
Installed capital cost	31	61	134	74
Annual repair cost[d]	9	9	2	2
Period of operation (years)	0.5–2.5	3–5	7–9	7–9
Economic life (years)	2	4	8	8
Rate of discount (%)	10	10	10	10
Salvage value at end of year	0	0	0	0

[a] A breakdown of the major cost components of both models is given in Table 5.

[b] For a 30-foot (9-m) well, the costs are: auger, $18; labour (14 days at $3.50 per day), $49; cement, $10; and casing and pipe, $57. These costs are the same for all pumps.

[c] Assuming a distance of 62 miles (100 km) from port and that the pumps are transported in bulk. The total fixed costs, including installation, are: Gibson, $165; Fuji, $195; IDRC experimental, $268; and IDRC production, $208.

[d] Repair cost is for parts only. Assumed that labour is provided by either the user or the government.

about 50% of the cost of the existing pumps.

The basic data available in the Malaysian case are shown in Table 4. Several points should be noted.

- Only the IDRC-University of Malaya (UM) experimental pump could be accurately assessed in terms of cost (Table 5). This is likely to appear high in view of the limited number of pumps produced and the research element involved in the design and construction. The mass-production cost of the IDRC-UM model can only be estimated at present and is based on quotations obtained from local plastic manufacturers regarding bulk orders of the different pump components. By experimenting with different manufacturing processes, it may be possible to find ways to reduce these prices.
- Data on other pumps (Gibson and Fuji) are obtained from the Ministry of Health records and from field interviews.
- The life recorded in the field for non-IDRC pumps is extremely short, ranging from 6 months to 5 years.
- All 12 suction pumps installed in the field in the past 2 years are still in operation. Hence, there are no figures available on the actual lifespan of these pumps. An estimate of 7-9 years is used for the purpose of this analysis.
- The nonusable pumps are kept for spare parts. Thus there is no definite salvage value for the pumps. Therefore, the salvage value is assumed to be zero at the end of the economic life of the pump.
- Cost data obtained from 1978 to 1981 showed no significant increase in cost due to inflation. These cost figures are assumed to be in 1980 constant dollars.

Table 5. Major cost components ($) of experimental and production version of IDRC-UM handpump.

Component	Experimental	Production
Piston and foot valve	59.00	8.40
Spout	4.10	4.10
Piston cylinder	20.20	8.70
Drop pipe and piston-rod assembly	9.80	9.80
Metal stand	17.40	17.40
Leverage assembly	16.40	16.40
Bolts and washers	6.10	8.20
Total cost	133.00	73.00

Water supply situation

Only 43% of rural households in Malaysia are served with piped water (Table 6). However, this figure will rise to 58% by 1985 if current plans under the Fourth Malaysia Plan are implemented. In terms of the number of rural households, this means that a total of 994 000 households in 1980 and 833 000 households in 1985 will still have to rely on traditional sources for their daily water requirements.

The Ministry of Health has, since the late 1960s, supplied handpumps to a limited number of rural households. At present, a total of about 5500 wells serving about 22 000 households have been constructed. This figure is, however, only about 50% of the target set in the Third Malaysia Plan. One of the main reasons for this shortfall is the difficulty in obtaining handpumps. At present, all the handpumps used by the Ministry of Health have to be imported: these include pumps such as the Dragon, Fuji, Gibson, and SGP. These pumps are relatively cheap but the experience of the Ministry is that they rarely last for more than 1 year. Also, there is a lack of spare parts whenever the pumps break down.

The program under the Fourth Malaysia Plan is to increase the number of handpumps installed by 12 382 to serve about 60 000

Table 6. Number ('000) and percentage of rural households served by piped water.[a]

	No. of rural households			No. served with piped water			% served with piped water		
	1980	1985	1990	1980	1985	1990	1980	1985	1990
Peninsular Malaysia	1485	1656	1801	698	1043	1388	47	63	77
Sabah	102	159	175	18	62	106	18	39	61
Sarawak	164	189	208	41	66	91	25	35	44
Total	1751	2004	2184	757	1171	1585	43	58	73

Source: Government of Malaysia. 1981. Fourth Malaysia Plan.

[a] It is assumed that rural households will constitute 60% of population in 1990 as compared to 38% in 1985; and that the number of rural households that will be served with piped water for 1985-1990 will be the same as that for 1980-1985, i.e., 414 000 households.

households by the end of 1985. However, because of the delays in obtaining pumps from overseas, there is some doubt that this target can be achieved. The government of Malaysia plans to invest large sums of money to supply piped water to over 70% of the rural population by the year 1990. However, even with this ambitious program, about 600 000 households will continue to depend on other sources of water supply in 1990.

Potential markets

The Ministry of Health is the main government agency involved in installing handpumps in rural areas. The entire cost of drilling the well and installing the handpump (including the cost of the pump itself) is borne by the government. To date, the government has also provided a free repair and maintenance service for the bulk of the handpumps installed. This policy may be discontinued in the near future and users will be required to undertake maintenance, repair, and rehabilitation of their own handpumps. The current practice is to supply one well with a handpump to a cluster of four to six households. These wells are, on the whole, shallow, with an average depth of 16-50 feet (5-15 m).

The government target is to install about 2500 handpumps per year to cater to about 12 500 households. However, the number of rural households without access to piped water is currently about 1 million. This figure is expected to fall to about 600 000 by 1990. If it is assumed that a total of 400 000 households will still have to depend on water from handpumps in 1990, there will be a need for an additional 80 000 handpumps to be established throughout the country between now and the year 1990. This implies a potential market of approximately 10 000 handpumps per year for the rest of this decade.

Main Findings and Conclusion

Cost of handpumps

The cost of the IDRC-PVC handpump ranged from $93 to $267 in the four countries. This cost was derived from experimental cost figures and it is likely that it could be reduced to one-third or even to one-half of the present cost if the pump were to be produced on a large commercial scale by mass-production techniques. It is significant that the experimental pump costs only 17% more than comparable existing handpumps.

The cost factor does not constitute the major constraint to the IDRC-PVC handpump gaining wider acceptance in the four countries. In Thailand and the Philippines, for example, it was found that technical problems remain to be solved before the pump can be regarded as being sufficiently reliable for regular use. This, however, illustrates the importance of field testing to thoroughly understand the technology. The situation in Sri Lanka and Malaysia is more favourable and the pumps tested in these countries could, with some modifications, form the basis for commercial production and widespread utilization. It is interesting to note that, in both of these countries, technical problems were initially encountered; however, these were solved during the course of the field testing. The Thailand and Philippines projects did not go through this same extensive testing process.

In the Philippines, it is unrealistic to do a cost-effectiveness comparison between the IDRC-PVC pumps and the other existing handpumps because the IDRC-PVC pumps still possess some serious design faults that require remedies. In the case of Sri Lanka, the IDRC-PVC handpumps are functioning satisfactorily, but there is an absence of other comparable pumps. Hence, in this case, data are not available for comparison. Although Thailand now appears to have solved the problem of leaky foot valves, the field-testing program was incomplete at the time the project terminated. Only in Malaysia, was it possible to compare the IDRC-PVC pump with other handpumps.

In this comparison, the IDRC-PVC handpumps emerged quite favourably compared with other handpumps. Using the estimated cost of the IDRC-PVC handpump (as if it were produced on a large scale), it can be shown that the pump is only about half the cost of the existing handpumps. Although, in the Malaysian case, conversion factors were available, an economic analysis was not undertaken because there is no government tax on imported pumps but the tax on imported PVC ranged from 10 to 25%. In view of this, the results of the economic analysis will not differ significantly from that of the financial analysis.

In all these four countries, the demand for handpumps is high, especially for those suit-

Table 7. Summary of important handpump statistics in the four countries.

Item	Malaysia	Philippines	Sri Lanka	Thailand	Average or Total[a]
Cost of IDRC pump	134	267	93	135	157
Installation charges[b]	134	165	476	225	275
Pump plus installation cost					
IDRC	268	532	569	360	432
Existing pumps	180	450	651	356	409
Rural households without clean water (million)	0.99	3.12	1.32	2.60	8.03
Existing handpumps (1982 figures)	6000	55000	2500	25000	88500
Potential market annually (1982-1990)					
1 shallow well/20 households	2000	18000	5000	4500	29500
1 shallow well/5 households	8000	72000	20000	18000	118000

[a] All cost figures are averages in US$.

[b] The same installation charges are assumed for the IDRC and existing pumps. This cost is for a well with a depth of 9 m (29.5 feet).

able for drawing water from both deep and shallow wells. The IDRC handpump is better suited for wells of up to 50 feet (15 m) in depth or for shallow wells. It is estimated that there is a combined annual market for 29500-118000 handpumps for shallow wells in these four countries. The biggest market is in the Philippines (Table 7).

Water supply situation

Both Thailand and the Philippines have had long-term experience in the use of handpumps. Thus their rural water projects place great importance on well drilling and handpump installation. In both these countries, the handpump projects are heavily funded by international aid or loan agencies.

On the other hand, the use of handpumps appears to be a recent development in Sri Lanka and Malaysia. However, the progress of the rural water program in Sri Lanka, including the handpump program, is somewhat constrained by the lack of government funds. In contrast, the Malaysian program tends to be directed more toward supplying rural households with piped water, rather than toward the substantial increase in the number of handpumps. However, this is extremely expensive and may change in the future.

Shallow and deep wells

The demand is for handpumps that can draw water from both shallow and deep wells. The distinction between a shallow and a deep well is ambiguous, but it is generally accepted that a shallow well is less than 50-66 feet (15-20 m) in depth: this is the drill depth. The depth of the water table, however, varies considerably between wells. Thus, even in the case of a deep well of 100 feet (30 m), the water level may be only 16-32 feet (5-10 m) below the surface. In this case, a pump designed for shallow wells can still be used.

Water tables fluctuate depending on the pattern of rainfall prevailing in each region. Thus, some shallow wells may run dry during periods of drought. In the case of deeper wells, the water table may fall considerably so that it is no longer possible to draw water from the well with a pump that is designed for shallow depths.

All the pumps tested in the IDRC program are essentially meant for shallow wells, that is, for wells with a drilled depth of 50-66 feet (15-20 m). Thus, in assessing the potential markets for the IDRC-PVC handpump, it is more appropriate to consider only the market for shallow wells instead of for both deep and shallow wells. Future work on the IDRC-PVC pump may extend the range of the pump and, in this event, its potential market will be expanded.

Acknowledgments The support and assistance of the International Development Research Centre (IDRC) are gratefully acknowledged. The project teams in the four countries cooperated willingly in supplying all the basic information used in the preparation of this study. The project leaders, Pathirana Dharmadasa of Sri Lanka, Pisidhi Karasudhi of Thailand, Antonio Bravo of the Philippines, and Goh Sing Yau of Malaysia, gave guidance and insights on the overall handpump situation in their respective countries. Their assistance in these areas is acknowledged. Thanks are also due to the various officials in the four countries who consented to being interviewed regarding the relevant program of their institutions.

References

Goh, S.Y. 1980. The performance characteristics of a reciprocating piston water lift pump. Ottawa, Ont., Canada: International Development Research Centre. Interim progress report, Water pumping technology — Global project.

IRC (International Reference Centre for Community Water Supply). 1977. Handpumps. The Hague, Netherlands: IRC. Technical Paper No. 10.

Modern Asia. 1982. Wanted: 20 million pumps for the Third World. Washington, DC, USA. April issue, p. 29.

World Water. 1982. 1981–1990 decade. Liverpool, U.K.: Thomas Telfield Ltd. pp. 11–15, 47–50.

Conclusions

In an era of rapid development and population expansion, the challenge to improve environmental health confronts every nation. In the Third World, this problem is made more acute by limited resources. Provision of adequate, safe water supplies to rural populations by 1990, an official target of the International Drinking Water Supply and Sanitation Decade, means that an estimated 20 million or more new handpumps may be needed by the year 2000 if the goal of bringing potable water to the millions of rural inhabitants of the World is to be achieved. These pumps must be able to withstand the use and abuse of the many who depend upon their proper functioning for their daily water supply.

When a handpump breaks down and remains out of service, the economic loss is considerable. The replacement parts, and the possibility of vandalism and disappearance of parts if the pump is out of operation for more than a few days, result in considerable cost and loss of financial investment, not to mention the hardship and inconvenience to those who have to walk long distances to obtain water. One solution to this problem is to focus efforts on the development of locally fabricated handpumps that are inexpensive to manufacture and can be easily repaired at the village level with a minimum amount of expertise.

The Waterloo design, developed in 1976, does just this. The piston and foot valve are produced from polyvinyl chloride (PVC), a material that is readily available in most developing countries. Their design is such that the piston and foot valve are interchangeable, i.e., the piston can be used as a foot valve and vice versa.

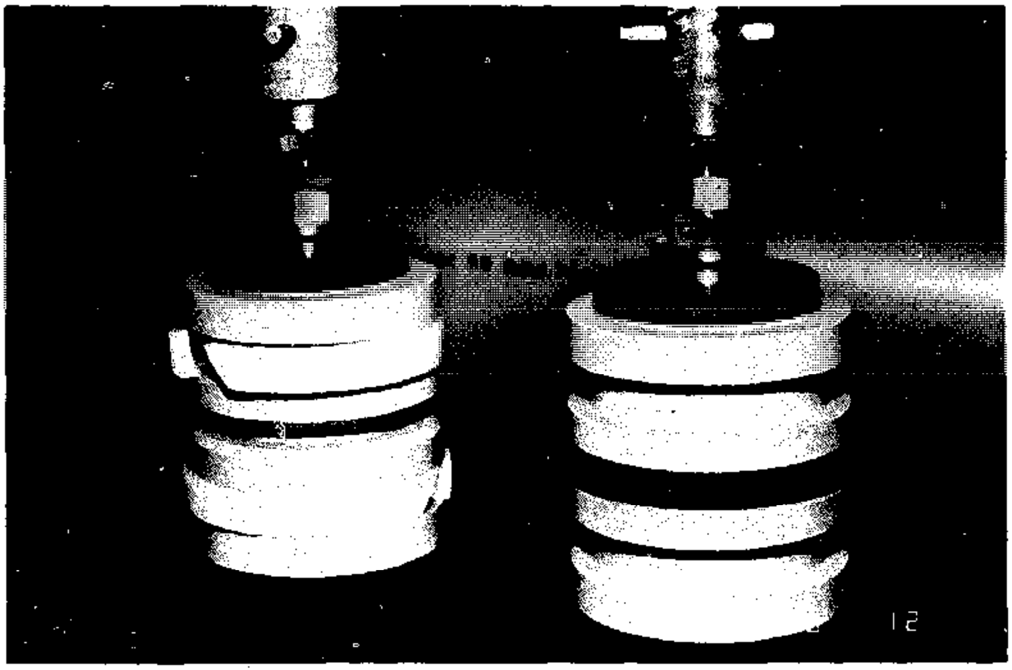
This greatly reduces the number of spare parts needed for repair or replacement purposes. Another advantage of the Waterloo design is that it incorporates polyethylene piston rings, similar in design to those in an automobile engine. These can be replaced easily when worn. Finally, the design takes advantage of a PVC pipe as the riser pipe and the cylinder section, the place where the piston slides up and down, is the riser pipe itself. If this section becomes worn, the piston can simply be moved to a new position in the riser pipe. A smaller diameter PVC pipe is used for the piston rod. The above-ground components are of local design, utilizing locally available materials. These designs vary from the direct-action type demonstrated by the Sri Lankan project to more complex steel lever-action arrangements demonstrated by the Thai project. Inexpensive concrete pedestals were used by the Philippine project, a concept that deserves further investigation.

The technology developed and tested with support from the International Development Research Centre (IDRC) through these projects clearly indicates that no universal design will function adequately under all conditions with all user groups. Moreover, it was not the intent of this research to find such a design. Although the basic principle of the pump remained the same with all four projects, there were individual variations and modifications. The results of this research have brought to light the fact that this technology, or any other handpump technology, must first be tested under local conditions and modified according to the needs and opinions of the user group, environmental conditions, available materials, and level of expertise of those expected to adopt it and maintain it. Without this testing, the technology cannot be expected to meet the needs of the target group and will most probably fail.

Once successfully field-tested, there must be a concerted effort to sensitize and educate all users not only on how the pump works but also on its limitations. A handpump is a system with several components. If one of those components malfunctions, the entire system breaks down and water no longer can be delivered. Therefore, a thorough understanding of such facts as how this pump functions, what can go wrong, and what components wear out the fastest, is essential for adequate maintenance. This understanding is also essential for preventive maintenance, an aspect of handpump technology that unfortunately has been neglected.

However, this workshop on village-level handpump technology should not be considered the completion of a network of research projects. It is the beginning of a new phase that will now seek to bring this concept to the people who need it most, the rural poor. The concept of using inexpensive plastics as pump components has been successfully demonstrated. However, large-scale commercial production by means of injection moulding has yet to be investigated. The feasibility of small-scale production through cottage industries must also be fully examined. Research must continue on the use of new materials and modified designs and various options for low-cost above-ground components must also be tried and tested. More importantly, however, if this technology is to be applied at the village level, efforts must be focused on obtaining feedback from the "end users," the villagers themselves. Sociological and economic studies must be carried out in all those locations where the pump is to be installed, and a scientific approach must be used to develop common methodologies for these studies. In addition, training programs for rural people must be implemented that are supported by the development and testing of learning materials suitable for use by village-level workers. Finally, appropriate infrastructures must be established or strengthened and management techniques must be developed that are not only geared toward institutionalizing the concept of village-level operation and maintenance (VLOM) but also are capable of providing follow-up through continuous monitoring services and educational programs for users.

Mass-production techniques should substantially reduce the cost of this PVC pump; however, this has yet to be tested. Dr Goh Sing Yau of the University of



The Waterloo piston (left) and foot valve (right) are moulded from solid PVC. Except for the piston rings and the rubber seal on the foot valve, they are interchangeable.

Malaya proposes to address this question as well as some of the others mentioned above. His idea, which is intended to bridge the gap between developmental research and commercialization, is to investigate various manufacturing processes in detail by developing a small-scale fabrication unit. The project would also seek to:

- thoroughly understand the manufacturing processes and the actual costs involved in producing each component;
- develop the necessary expertise required to consult with manufacturing units on production procedures;
- conduct cost assessments of various manufacturing options; for example, subcontracting versus manufacture at point of assembly;
- establish quality control guidelines and standards;
- field-test (utilizing Ministry of Health personnel) mass-produced models of the pump and evaluate their technical performance;
- develop appropriate manuals for transferring the technologies to other interested groups; and
- support complementary projects by providing prototypes, training, and research on solving any problems that may occur.

It is expected that this project would ultimately result in the establishment of a research and training centre that could be the focal point of a network of projects aimed at investigating such concepts as village-level maintenance schemes, community financing schemes, community acceptance strategies (social marketing), and the various options for manufacture and assembly.

The discussions during this workshop revealed that this PVC pump may be the answer for many thousands of rural communities for many years to come. However, it is only one of many technical choices, all of which have their place in the long list of options. In some communities and countries, the PVC pump may serve as an interim technology, until something better comes along. In other communities, due to varying social, economic, and environmental conditions, it may not be acceptable at all. In still other communities, a more sophisticated level of technology may be more suitable.

For the many millions of the world's rural population who do not have an option, this technology is a beginning, a contribution to the target of clean water for all by 1990. But, the future of the Waterloo design now depends upon the interest of researchers in investigating the problems of implementation. In this age of limited resources, it is becoming increasingly clear that the future of handpump technology lies with the villagers themselves. Still, one question remains: how can this technology and the desire to maintain it best be transferred to those who need it most?

Research Needs

The following research priorities were identified during the workshop. On the behavioural or "software" side, research should be conducted on:

- development of methodologies designed to promote community acceptance;
- development and implementation of various maintenance schemes;
- development and testing of community financing and self-help schemes;
- development of instructional packages designed for village-level use;
- investigation of water-use behavioural patterns and the development of health education programs designed to change those behavioural patterns where necessary; and
- development of training programs on the management of water resources and the development of information systems designed to monitor those resources.

On the technological or "hardware" side, there is a need for research on:

- development of appropriate, inexpensive, well-drilling technologies;
- development of simplified, inexpensive, water-exploration equipment;

- adaptation and testing of the Waterloo design for use in wells greater than 165 feet (50 m) deep;
- development and institutionalization of a classification system for water sources that incorporates not only water quality criteria but also sanitary protection, construction, and state of repair;
- investigation of the use of new materials and other types of plastics such as acrylonitrile/butadine/styrene (ABS);
- studies on the performance of various above-ground configurations; and
- studies on how water becomes contaminated from the well to the home and how behaviour can be changed (with the help of technological interventions) to reduce the risk of contamination.

Participants

ZAINUDDIN ARSHAD, Ministry of Health, 3rd Floor, Block E, Jalan Dungun, Kuala Lumpur, Malaysia.

ANTONIO BRAVO, Institute for Small-Scale Industries, University of the Philippines, Enrique T. Virata Hall, Emilio Jacinto Street, UP Campus, Diliman, Quezon City, Philippines.

CHAN BOON TEIK, Director, Water Supply Division, Department of Public Works, Ministry of Public Works and Utilities, Jalan Dato Onn, Kuala Lumpur, Malaysia.

CHEE KIM MENG, Plant Manager, Johnson and Johnson Sdn Bdh, Jalan Tandang, Petaling Jaya, Selangor, Malaysia.

CHETPAN KARNKAEW, Chief, Rural Water Supply Division, Department of Health, Ministry of Public Health, Devavesm Palace, Samsen Road, Bangkok 2, Thailand.

CHO JOY LEONG, Federal Land Development Authority (FELDA), Jalan Gurney, Kuala Lumpur, Malaysia.

CHONG KAH LIN, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Pantai Valley, Kuala Lumpur 22-11, Malaysia.

PATHIRANA DHARMADASA, Lanka Jathika Sarvodaya Shramadana Sangamaya (Inc.), 77 de Soysa Road, Moratuwa, Sri Lanka.

ERNESTO D. GARILAO, Executive Director, Philippines Business for Social Progress, 4th Floor, Yutiro Building, 270 Dasmarinas Binondo, Manila, Philippines.

GOH SING YAU, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Pantai Valley, Kuala Lumpur 22-11, Malaysia.

MICHAEL GRAHAM, Regional Liaison Officer, Communications Division, International Development Research Centre, Tanglin P.O. Box 101, Singapore 9124.

ZAINAL HAJI HASHIM, RISDA, Risda Building, Jalan Ampang, Kuala Lumpur, Malaysia.

RUS ISMAIL, State RISDA Office, Jalan Pengkalan Rama, Malacca, Malaysia.

TIM JOURNEY, The World Bank, 222 New Eskaton Road, Dhaka, Bangladesh.

LEE KAM WING, Program Officer, Health Sciences Division, International Development Research Centre, Tanglin P.O. Box 101, Singapore 9124.

LEE KWOK MENG, Federal Land Consolidation and Rehabilitation Authority (FELCRA), P.O. Box 2254, Kuala Lumpur, Malaysia.

LUM WENG KEE, Senior Public Health Engineer, Ministry of Health, 3rd Floor, Block E, Jalan Dungun, Kuala Lumpur, Malaysia.

PETER LUTTIK, Programme Officer, UNDP, P.O. Box 2544, Kuala Lumpur 11-04, Malaysia.

UZIR A. MALIK, Department of Agriculture and Resource Economics, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia.

ZULAZMI MAMDY, Proyek Pedesaan, Universitas Indonesia, Salemba Raya 4, Jakarta, Indonesia.

CHARLES NAKAU, Appropriate Technology Development Institute, P.O. Box 793, Lae, Papua New Guinea.

PICHAI NIMITYONGSKUL, Division of Structural Engineering and Construction, Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand.

PRASERT SAISITHI, Director, Institute of Food Research and Product Development, Kasetsart University, P.O. Box 4-170, Bangkok 4, Thailand.

KAMAROL ZAMAN ABDOL RAHMAN, Department of Agricultural and Resource Economics, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia.

SAW KIM HOCK, RISDA, Risda Building, Jalan Ampang, Kuala Lumpur, Malaysia.

DONALD SHARP, Program Officer, Health Sciences Division, International Development Research Centre, P.O. Box 8500, Ottawa, Ontario, Canada K1G 3H9.

C.J.A. STAMBO, Chief Engineer, Ground Water, National Water Supply and Drainage Board, Galle Road, Ratmalana, Colombo, Sri Lanka.

WILLY SUWITO, Engineer, Directorate of Sanitary Engineering, 4th Floor, Main Building, Jalan Pattimura 20, Kebayoran Baru, Jakarta, Indonesia.

TAN BOCK THIAM, Faculty of Economics and Administration, University of Malaya, Pantai Valley, Kuala Lumpur 22-11, Malaysia.

TEE TIAM TING, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Pantai Valley, Kuala Lumpur 22-11, Malaysia.

TEO BENG HOE, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Pantai Valley, Kuala Lumpur 22-11, Malaysia.

CECILIA C. VERZOSA, PIACT/PATH, MCC P.O. Box 189, Makati 3117, Metro Manila, Philippines.

DONALD WAUGH, Office of the Comptroller General and Treasurer, International Development Research Centre, P.O. Box 8500, Ottawa, Ontario, Canada K1G 3H9.

WIMUT KASEMSUP, Head, Water Resource Unit, Community Based Appropriate Technology and Development Services (CBATDS), Population and Community Development Association, 8 Sukhumvit 12, Bangkok 11, Thailand.

K.M. YAO, Water Quality Management Advisor, PEPAS/WHO, P.O. Box 2550, Kuala Lumpur, Malaysia.

CESAR E. YNIGUEZ, Manager, Engineering Department, Rural Waterworks Development Corporation, Vibal Building, 865-E de los Santos Avenue, Diliman, Quezon City, Philippines.

AHMAD ZAINI BIN MAT YUSOP, Ministry of National and Rural Development, Bangunan Bank Raayat, 1st Floor, Jalan Tangsi, Kuala Lumpur, Malaysia.