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Hand Pumps

Technical Paper No. 10

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Hand Pumps

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ABSTRACT

"Hand Pumps for Use in Drinking Water Supplies in Developing Countries". Technical Paper No. 10, International Reference Centre for Community Water Supply, Voorburg (The Hague), the Netherlands. Various paging (approx. 210 pp.). July 1977.

A state of the art report. Topics discussed include rationale for use of hand pumps, history of hand pumps, description of various types of hand pumps (including reciprocating, diaphragm, rotary, helical rotary, bucket, chain, windlass, and various traditional low lift, slowmoving water lifting devices used since ancient times).

The principles of operation; nomenclature; hydraulic, structural, and energy analysis; and the design of each component of reciprocating hand pumps are described with examples. Also administration of hand pump programmes with emphasis on installation and maintenance practices. Recent handpump research and indigenous pumps manufactured with plastic, steel, wood, and bamboo components. A final chapter described manufacture of pumps in foundries, machine shops, and using intermediate technology.

Key words: Hand pumps, rural water supply, developing countries, reciprocating pumps, appropriate technology, hand pump design, hand pump maintenance, hand pump manufacture, hand pump research and development.

Established in 1968 at the Netherlands' National Institute for Water Supply in Voorburg (The Hague), the WHO International Reference Centre for Community Water Supply (IRC) is based on an agreement between the World Health Organization and the Netherlands Government. In close contact with WHO, the IRC operates as the nexus of a world-wide network of regional and national collaborating institutions, both in developing and industrialized countries.

The general objective of the IRC is to promote international cooperation in the field of community water supply. Operating as a catalyst, the IRC works closely together with its collaborating institutions as well as international agencies, national entities and individuals.

Requests for information on the IRC, or enquiries on specific problems may be directed to the International Reference Centre for Community Water Supply, Information Section, P.O. Box 140, 2260 AC Leidschendam, the Netherlands.

**INTERNATIONAL REFERENCE CENTRE
FOR
COMMUNITY WATER SUPPLY**

**H A N D P U M P S
FOR USE IN DRINKING WATER SUPPLIES
IN DEVELOPING COUNTRIES**

PREPARED BY F. EUGENE McJUNKIN

Published under the joint sponsorship
of the
UNITED NATIONS ENVIRONMENT PROGRAMME
and the
WORLD HEALTH ORGANIZATION

**Technical Paper no. 10
July 1977**

**Nw. Havenstraat 6, Voorburg (The Hague)
The Netherlands**

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The information on hand pumps as consolidated in this handbook, has been collected in the course of several years. The material was reviewed and evaluated during 1976 and the first half of 1977. Every attempt has been made to include all information considered pertinent.

While comprehensive on the subject of hand pumps, the handbook is not claimed to be either exhaustive or final. Certain hand pump development work, research efforts or test programmes may have escaped the search for information. Besides, new information and data of relevance will no doubt continue to result from on-going hand pump programmes.

The present document, therefore, is likely to require revision at some future stage. It is intended to undertake this work when appropriate.

Readers are invited to give their comments and suggestions for any changes, corrections and additions which they consider necessary or useful. Such contributions will be gratefully accepted and used in the future revision of the handbook, and will be duly acknowledged therein.

Communications should be directed to: International Reference Centre for Community Water Supply, P.O. Box 140, 2260 AC Leidschendam, the Netherlands.

E.H.A. Hofkes
Project Coordinator

This report is issued on the responsibility of the WHO International Reference Centre for Community Water Supply. It does not necessarily represent the decisions or the stated policy of either the World Health Organization or the United Nations Environment Programme.

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PREFACE

Drinking water supplies in developing countries are receiving increased attention. In many circumstances, safe water can be provided from tubewells or dug wells and greater attention is being focused on hand pumps used to draw the water.

Comprehensive and reliable information on hand pumps is more in demand than ever, but as yet not readily available.

On the request of the World Health Organization (WHO), the United Nations Environment Programme (UNEP), in April 1975, agreed to partially finance the preparation of a handbook on handpumps. Following consultations with WHO, the International Reference Centre for Community Water Supply (IRC) agreed to undertake the project.

Under an agreement with the IRC, Mr. F.E. McJunkin prepared the present report, and to him credit should go in the first place. Appreciation is expressed for the devoted and extensive work he did in gathering, evaluating and assembling information and writing this report.

Credit is also due to Mr. L.A. Orihuela and his staff, of the Community Water Supply and Sanitation Unit of WHO, Geneva. In particular, Dr. R.C. Ballance is thanked for his continuous support and assistance.

In the draft stage, the handbook was thoroughly reviewed in a meeting of experts held in Voorburg (The Hague), the Netherlands, from 12 - 16 July 1976. The many comments and suggestions contributed by the participants in the meeting are incorporated in the report and gratefully acknowledged. The names of those who participated are listed in Annex A.

The cooperation of many persons through interviews and access to written material was of major assistance in the preparation of the report. Also much appreciated were responses of officials of national governments, international organizations and hand pump manufacturers who commented on a preliminary draft which was circulated for review.

The present document is intended to serve public health officials, engineers, and field staff who are planning and implementing water supply programmes with hand pumps. It is hoped that the handbook will provide improved access to information on hand pumps, thereby contributing to a general improvement in the state of the art, and facilitating the selection of existing pumps as well as the development of new ones.

EXECUTIVE SUMMARY

BACKGROUND

Several hundred million people already depend on hand pumps* for their drinking water. Major hand pump programs are underway or planned in many countries. There is a growing awareness of the important role hand pumps will realistically play, for a long time to come, in providing an acceptable drinking water supply to many millions in rural areas of developing countries.

However, experience shows that many existing hand pump supplies are deficient or have been abandoned altogether because of inadequacies in design, manufacture, installation, operation and maintenance. A pump's failure may render a well useless. Design criteria are needed that can be used, particularly by developing countries, in meeting prevailing operating conditions as well as sanitary requirements. Pumps are needed which are more durable, trouble-free, sanitary, and inexpensive; which require maintenance within the limitations of local capabilities; are easily operated and acceptable to users, including women and children; and are suitable for local manufacture using local materials, equipment, and manpower.

The objectives of this document include:

- (1) To assemble and review information on hand pumps currently being produced in both developing and industrialized countries.
- (2) To assemble and review available information on simple pumps that are suitable for manufacture by village artisans using locally procurable materials.
- (3) To assemble and review information on hand pump development and field

* A hand pump as used herein is any simple water lifting device, powered by human energy, and used in rural village drinking water supplies.

trials, especially those programs that have attempted to determine the causes of pump failures or malfunctions including deficiencies of design, manufacture, operation, and maintenance.

(4) Based on analysis and interpretation of the above information, to draft guidelines and recommendations on design and selection, manufacture, and maintenance of hand pumps.

(5) To provide basic documentation for hand pump development work and working meetings on hand pumps.

PUMP TECHNOLOGY

Water lifting devices or pumps powered by human energy have been in use since the dawn of history. The most common and widespread pump of this type is that known as the "single action, reciprocating, positive displacement pump".* Or more familiarly, the "farmyard pump" shown in the following photograph.

The technology of reciprocating hand pumps may be further subdivided into two types: the shallow well hand pump and the deep well hand pump. In both pumps a plunger or piston, enclosed within a cylinder, lifts the water to the pump spout.

In the shallow well pump, the plunger and its cylinder are located above the water level - usually within the pump stand itself. This pump relies on atmospheric pressure to lift the water to the cylinder; thus it is limited to water lifts of about 22 feet (6.7 meters).

In the deep well pump the cylinder and plunger are located below the water level in the well. This pump can lift water from wells as deep as 600 feet (180 meters). The forces and wear created by the hydraulic

* The rope and bucket may be more numerous but is inadequate for use as a village water supply.



"THE FARMYARD PUMP"

A typical "lever operated, single action (cylinder), reciprocating (plunger), positive displacement hand pump" of the type first developed in Europe and North America and today widely used in developing countries for rural water supplies. The operators of these pumps are predominantly women and children.

(Photo: WHO/Peru)

head^{**} increase with the depth to the water table. Also, the maintenance and repair problems associated with reaching the cylinders deep within the well are much more difficult than in shallow well pumps. Thus the design and costs of pumps for deep well use are more critical than for shallow wells

^{**} The vertical distance which the water must be raised from its level in the well to the point of free-flowing discharge, e.g., the pump spout.

The hydraulic design of the pumps is concerned with the rate of discharge, the head to be overcome in lifting the water, the structural forces generated by the lift, the energy input required, and the length and frequency of the plunger strokes transmitted by the handle. These factors affect the design of the handle assembly, the pump stand, the bearings at handle assembly pivot points, the pump rod connecting the handle and the plunger assembly, the cylinder, and the water seal ("cup" or "bucket") between the plunger and the cylinder wall.

Five major constraints are operative:

- (1) Energy input is limited, less than 0.1 horsepower (75 watts) for adult males.
- (2) Hand pumps must withstand severe use, typically 250 users per pump and sometimes over 1,000. Plus livestock.
- (3) Capital for pump purchase is severely limited in developing countries, with hard currencies for imports even more limited.
- (4) Manufacturing quality may be poor.
- (5) Maintenance resources are generally limited.

The basic technology is well known. Pumps of the reciprocating type were known in ancient times and have been in common use at least 200 years. Pumps of the late 1800's are quite similar to those in use today. The theoretical understanding of their operation was well known by the early 1900's.

MAINTENANCE

Considering the age of hand pump technology, why today's concern? Basically for three reasons. First, today's hand pumps are largely descended from European and North American pumps developed for single family use whereas, in the developing countries, a single hand pump must often

supply the water needs of hundreds of people. Second, the quality of hand pump manufacture is often poor. Third, the poverty of the developing countries which makes the use of hand pumps necessary also means that the unit cost of hand pumps must be low. The technology exists to manufacture durable, almost maintenance-free hand pumps but at what cost?*

Thus heavy use, poor quality, and low cost combine to require extraordinary maintenance for successful and effective use of hand pumps in the developing countries. The lack of maintenance and/or of pumps of sufficient quality to be maintained has been a major (many authorities say the major) problem in hand pump programs.

RESEARCH AND DEVELOPMENT

International efforts to develop rural water supplies for developing countries over the past decade have stimulated several major pump development activities. These include:

- (1) The AID/Battelle Pump. A five year program to develop a sturdy, dependable pump for shallow and deep wells for universal application in developing countries. While never placed in mass production, its research findings have stimulated and influenced most other hand pump development programs.
- (2) The Bangalore Pump. Developed by the government of India with WHO assistance, this deep well pump is still in the experimental prototype stage. It incorporates several design novelties including some developed in India by "Mission" agencies in the "Jalna type" pumps.
- (3) New No. 6 Pump. A shallow well pump developed in Bangladesh with UNICEF assistance, this pump is now in mass production. It incorporates many Battelle features and has replaced leather seals with plastic (PVC) seals.

* Indeed some existing pumps approach this quality but their cost prohibits universal acceptance.

generally be much more important due to its capacity for mass production of more durable, more interchangeable pumps.

Hand pumps are made of many dissimilar components. Thus a complex of suppliers of castings, leathers, rods, pipe, valves, pins, nuts, bolts, and other parts may be necessary to assemble the complete pump. Manufacturers of bodies for hand pumps should also be capable of manufacturing hydraulic rams, valve and meter boxes, manhole covers, and other castings used in water supply and sanitation.

Guidelines for foundry and shop practice and specifications for iron, coke, and other materials are outlined in the report. Alternative shop production of pumps from steel, plastic, and wood components is also described. Also the technical requirements for establishment of ancillary operations such as leather shops.

The concluding section discusses production of hand pumps by village artisans with several examples, including bamboo pumps, chain pumps, diaphragm pumps, rope pumps, and windlass pumps. Local production of pump leathers and wooden handles for conventional pumps is also described.

BIBLIOGRAPHY

An extensive bibliography is appended.

DIRECTORY OF MANUFACTURERS

A worldwide directory of some 90 hand pump manufacturers, known to the author as of June 1977, is appended. Additional information is sought and welcomed. Inclusion of a manufacturer on the list does not constitute endorsement nor does omission imply rejection.

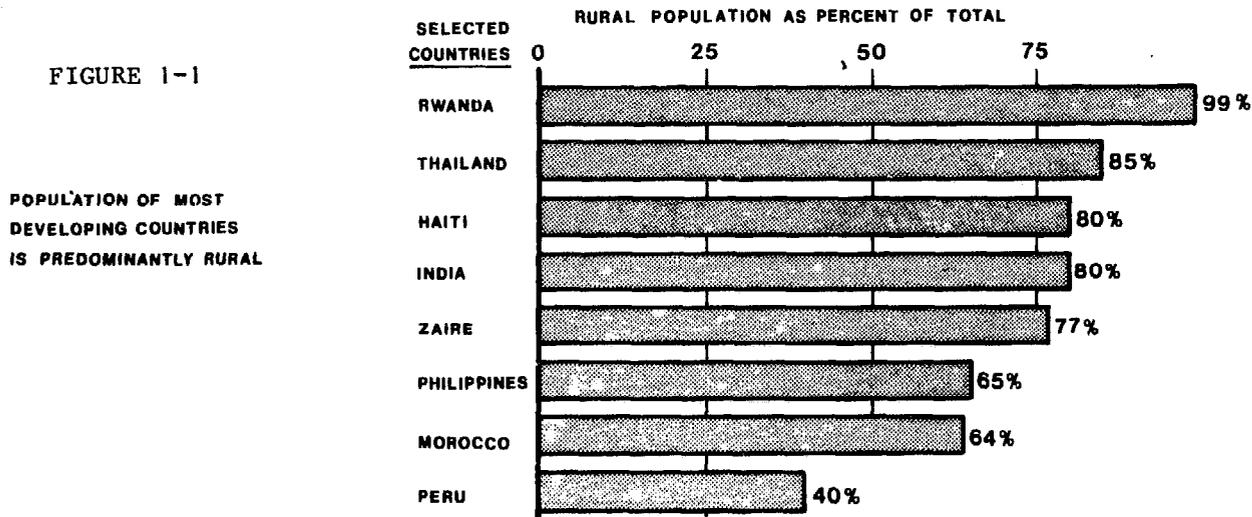
1. INTRODUCTION

1.1 BACKGROUND

A recent survey by the World Health Organization (WHO, 1973) indicates that as of 1970 over one thousand million people living in rural areas of developing countries lacked reasonable access to safe drinking water. Numerous epidemiological studies have identified contaminated water as a principal agent in transmission of typhoid, cholera, bacillary dysentery, and other diarrheal diseases. In many developing countries, waterborne or water-related diseases are among the top three causes of sickness and death. Furthermore, even these unsafe waters may require many hours daily toil for their collection.

A United Nations Second Development Decade goal is to bring the percentage of the rural population with ready access to safe water up to 36 percent. Even this modest goal would require 6.5 thousand million dollars in capital expenditures in areas where per capita incomes are generally low. Every effort must be made to keep down the capita costs of water supply if an appreciable proportion of this growing population is ever to have adequate water.

FIGURE 1-1



Many knowledgeable observers agree with a recent analysis by the World Bank that "In areas where groundwater is readily available at moderate depth, constructing a number of wells fitted with hand pumps is by far the cheapest means of providing a good water supply". (IBRD, p. 16, 1975). Depending on the cost of the well and population density, a hand pump water supply program may be provided for as little as US \$0.5 to \$3.00 per capita. Although community water systems piped under pressure to households and public standposts are an ultimate goal, many of the unserved billion will realistically have to use hand pumps as an interim if not a final measure.

Another factor is that electricity is not available in many areas, thus power pumping may imply use of internal combustion engines. For the necessary degree of reliability this means diesel engines and these are not made smaller than about 4.5 horsepower. If used they burn costly, imported oil, represent in many instances excess capacity or frequent starting and stopping with consequent wear and labor. Their capital cost is 4 times or more that of hand pumps (Allison).

Several hundred million people already depend on hand pumps for drinking water. Major hand pump programs are underway or planned in many countries, including Afghanistan, Bangladesh, Burma, India, Indonesia, Pakistan, the Philippines, and Thailand; Ethiopia, Ghana, Kenya, Malagasy Republic, Malawi, Mali, Tanzania, Tunisia, and Zambia; Bolivia, Costa Rica, Honduras, Ecuador, and Nicaragua. Bangladesh alone plans to install over 400,000 hand pumps during this decade.

Unfortunately experience shows that many hand pump supplies already in being are deficient or have been abandoned because of inadequacies in design, manufacture, installation, and operation and maintenance of the pumps. Design criteria are needed that can be used, particularly by developing countries, in meeting prevailing operating conditions. Most current hand technology represents pump designs that evolved over 50 years ago for family

farmyards in the United States and Europe whereas in India, for example, a single hand pump may be used regularly by as many as 1,000 people. (Emmanuel). Pumps are needed which are more durable, trouble-free, and require maintenance within limitations of local capabilities; sanitary; inexpensive; easily operated and acceptable to users, including women and children; and suitable for local manufacture, including materials, equipment, and manpower.

Within the past ten years, several studies of different types of hand pumps have been sponsored by international agencies, pump manufacturers, and others, under varying conditions. Also several organizations have directed their attention to simple methods of lifting water using pumps made by local artisans. Many of these pumps offer promise for use in other locations with or without minor design adaptations.

1.2 SOURCES OF INFORMATION

Information on hand pumps available from conventional sources such as recent scientific journals is nil. Information on hand pumps is found in what is sometimes termed "fugitive literature", i.e., literature that never appears in abstracts or review periodicals because of its informal, limited, restricted, or private publication. Much of the information obtained appeared in mimeographed or xeroxed reports, memoranda, correspondence, or documents distributed in very few copies and prepared by employees of international agencies. About one third of the information base consisted of documents provided by WHO and UNICEF. A second source was late 19th and early 20th century U.S. studies at agricultural experiment stations, agricultural schools, and government research centers. A third source was textbooks and manuals of the same era. The facilities of the Library of Congress (the national library of the United States) and of North Carolina State University were invaluable for the latter two sources. A fourth source was manufacturers' literature. An extensive bibliography was developed and appears at the end of this report.* Another fruitful source of information was personal interviews with a number of people knowledgeable about hand pumps in a developing country context.

The expert group, previously acknowledged, that was assembled for the International Workshop on Hand Pumps held at the International Reference

* Readers are asked to send copies of their own or others' publications on hand pumps, if not listed in the Bibliography, to the International Reference Centre (IRC) for use in future hand pump programs including periodic updating of this document.

Centre for Community Water Supply (IRC) in July 1976 was also an excellent source, both as a group and as individuals.

1.3 LIMITATION OF THE REPORT

This report, by design, covers only a part of the hand pump system. As Figure 1-2 suggests, a working hand pump program requires satisfactory relationships between users, technology and institutional structures. Or as a PAHO engineer with a long experience in rural water supplies has said: "A hand pump is a small technological instrument in a large sociological system". Future studies will have to address these issues.

This report focuses on pump technology, manufacture, installation, and maintenance. This is not to deny the importance of other factors, management, users, and water sources and well technology. * Indeed in Figure 1-2, the user is deliberately placed in the center. This report, like the hand pump is imperfect. And like the hand pump, too important to wait for perfection.

Even on the subjects covered, there are as many questions as answers. Indeed there are no single answers, only options which must ultimately be selected by those persons closest to the problem.

* An extensive Bibliography provides access to many uncovered subjects, e.g., Pisharoti on health education.

HOW A HAND PUMP (SYSTEM) WORKS

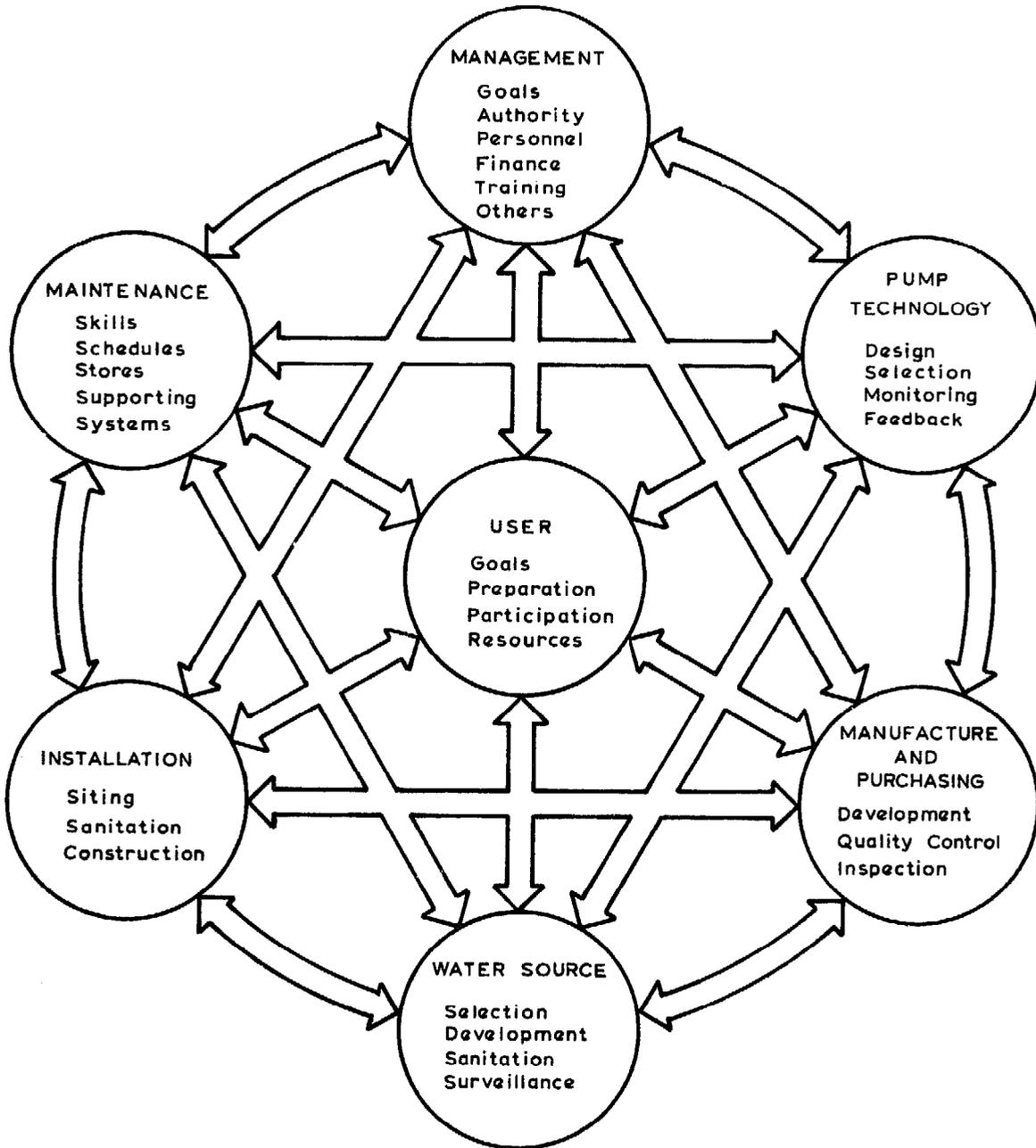


FIGURE 1-2

2. TYPES OF HAND PUMPS

2.1 HISTORY

If pumps are defined as water lifting devices, then our first ancestor who cupped his hand to drink invented the hand pump. However, the type of hand pump used most frequently for community water supply is the type known as the reciprocating, positive displacement, plunger pump - of more recent provenance than the hand.

The origin of the reciprocating pump is obscure but is sometimes attributed to Ctesibius, circa 275 B.C. His pump was a twin cylinder lift type, with external valves and without packing between the plunger and the cylinder wall, and used for fire fighting. Hero (2nd Century B.C.) and Vitruvius (1st Century B.C.) were familiar with this pump. Archeological remnants of reciprocating pumps from late Roman times are occasionally found in Europe.

Ewbank in his "History of Hydraulics", (1856), states that a reciprocating pump of wood was used as a ship's pump in the early Greek and Roman navies. The construction of these pumps is uncertain, but they may have been similar to those described by Agricola in the sixteenth century.

Agricola (1556) clearly shows the design used in Saxony in the sixteenth century. At this time, in addition to the conical leather plunger or bucket, plungers in the form of a perforated wood or iron disc were commonly used, the perforations being covered by a disc of leather which acted as a valve. The foot valve was a hinged metal flap and was attached to a metal seating. The pump was usually made in three sections, the middle being the working barrel, while the short bottom section contained the suction valve. These early wooden pumps were of the lifting type, but when made in metal, in order to economise material and cost of manufacture, the working barrel was usually placed at the top and a narrow suction pipe used. The suction valve was

placed at the bottom of the barrel. The lead suction pump made in this way was commonly used in the sixteenth century.

In 17th-century England, reciprocating pumps made of wood or lead and with the plunger packed with leather were in common use. It was not until about the middle of the nineteenth century that improved transport and communications made it economical to manufacture cast, machined, metal hand pumps for distribution over a wide area. (Westcott).

In the late 19th and early 20th centuries, a tremendous number of different pump models were produced. Perhaps 3000 manufacturers produced hand pumps in the U.S. alone. All these pumps utilized the same basic operating principles and differed little from those in use today - with one major exception - they were primarily used on single farms by single families and their livestock. They were often connected to windmills and tanks. Eubanks (1971) has many drawings of hand pumps from that era.

Today marks the renaissance of the hand pump. The importance of its role in rural water supplies in many developing countries, villages as well as farms, is widely recognized. Section 5 outlines many recent efforts to improve the hand pump for this role.

2.2 SHALLOW WELL RECIPROCATING LIFT PUMP

Figure 2-1 shows a hand-operated shallow well lift pump. The body of the pump (See B) contains a valved plunger or piston which moves up and down, i.e., reciprocates. The principle of its operation may be followed by examination of Figure 2-2.

Its operation is as follows:

- (1) With the pump primed, as shown at A, the plunger is raised. As air cannot pass the plunger owing to the water seal, a partial vacuum is created in the cylinder thereby reducing the air pressure on the surface of the water in the suction pipe. The atmospheric pressure on the water in the well is now greater than the air pressure on the water in the pipe, thereby forcing the air and water in the pipe upward, following the plunger upward. The space in the cylinder below the plunger fills with air from the pipe.

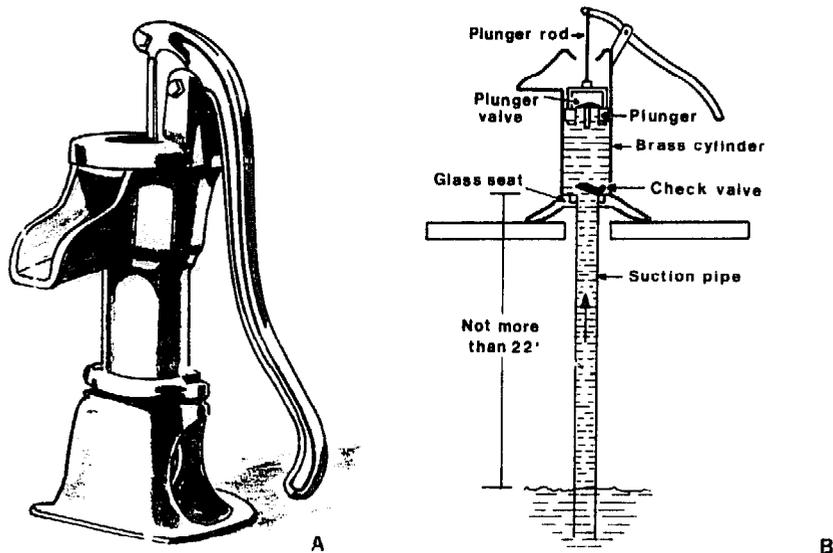


FIGURE 2-1 TYPICAL SHALLOW WELL LIFT PUMP

- (2) At the top of the cylinder the plunger stops, and the check valve closes of its own weight, thus trapping air in the cylinder.
- (3) On the next downstroke the entrapped air is compressed between the plunger and the bottom of the cylinder. When the pressure becomes greater than the atmospheric pressure above the plunger, plus the weight of the valve and of the priming water, the air will lift the plunger valve and escape through the priming water as shown at B.
- (4) On the next upstroke more air will be drawn out of the pipe and the water will rise higher, eventually flowing into the cylinder under the plunger as shown at C.
- (5) With the cylinder and pipe full of water as at C, the check valve closes by gravity, trapping water in the cylinder.
- (6) On the next downstroke the plunger and valve pass through the water as shown at D.
- (7) When the plunger reaches the bottom of the cylinder and stops, the plunger valve closes, thus trapping the water above the plunger, as shown at E.
- (8) On the next upstroke the water above the plunger is lifted out of the pump as shown at F. At the same time more water is forced into the cylinder through the check valve.
- (9) On each successive downstroke step E is repeated, and on each successive upstroke step F is repeated. Thus the pump delivers water on each upstroke.

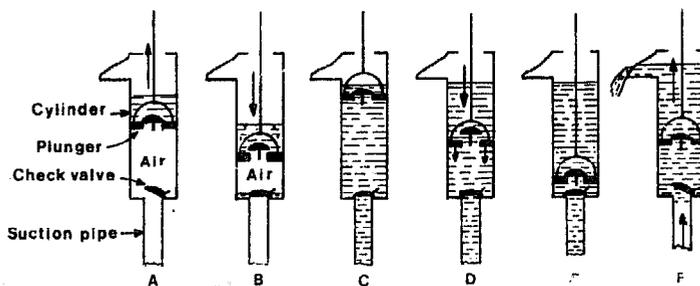


FIGURE 2-2 ILLUSTRATION OF OPERATION OF PLUNGER-TYPE PUMP

Contrary to popular opinion, pumps do not "lift" water up from the source. Rather the pump reduces the atmospheric pressure on the water in the suction pipe and the atmospheric pressure on the water outside of the suction pipe pushes the water up and into the pump. The principle is the same as that of drawing soda water through a straw or of filling a syringe.

Because of its reliance on atmospheric pressure to push water up the suction pipe, use of shallow well pumps is limited to conditions where the water table during pumping is within 22 feet (6.7 meters) of the suction valve even though "standard atmospheric pressure" is about 34 feet (10.4 meters). (See Table 3-1).

2.3 DEEP WELL RECIPROCATING LIFT PUMP

This pump is shown in Figure 2-3.

Deep well pumps operate in the same manner as described in the foregoing. The principal difference is in the location of the cylinder. The cylinder is usually submerged in the water as shown in order to prevent loss of priming. This pump can pump from water level depths greater than 22 feet below the pump spout.

Deep or shallow well in terms of hand pump selection refers to the distance of the water level in the well below the surface, not the depth of the borehole or the well casing. For example, a well drilled 300 feet (91.5 meters) deep but in which the water table is 15 feet (4.6 meters) below the surface may use a shallow well hand pump. Or a deep well hand pump. Conversely, a well drilled only 40 feet (12.2 meters) but whose water level is 35 feet (11.7 meters) below the surface will require a deep well pump with its cylinder set at least 35 minus 22 or 13 feet (11.7 meters) below the surface; preferably below the water table, i.e., more than 35 feet (11.7 meters) below the surface. A shallow well pump will not work on the second well.

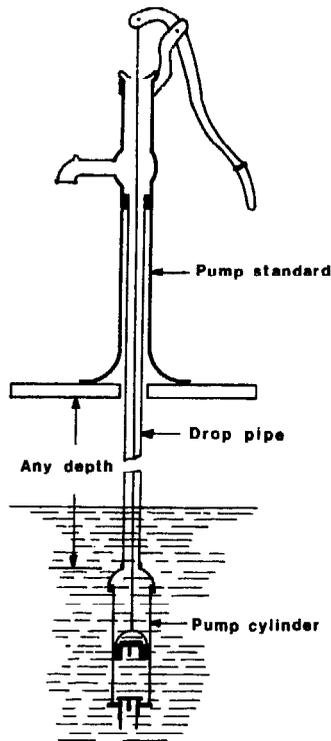


FIGURE 2-3 DEEP WELL LIFT PUMP

2.4 RECIPROCATING FORCE PUMPS

Force pumps are designed to pump water from a source and to deliver it to a higher elevation or against pressure. They are used primarily to pump water into reservoirs and pressure tanks. All pressure-type water systems use force pumps. They are enclosed so that the water can be forced to flow against pressure. They are available for use on shallow or deep wells.

These pumps are illustrated in Figure 2-4.

A shallow well force pump is illustrated in Figure 2-4A. Its principle of operation is the same as that of the single-acting plunger type of lift pump except that it is enclosed at the top and therefore can be used to force the water to elevations higher than the pump, either through a separate connection or through a hose or pipe attached to the spout. Only

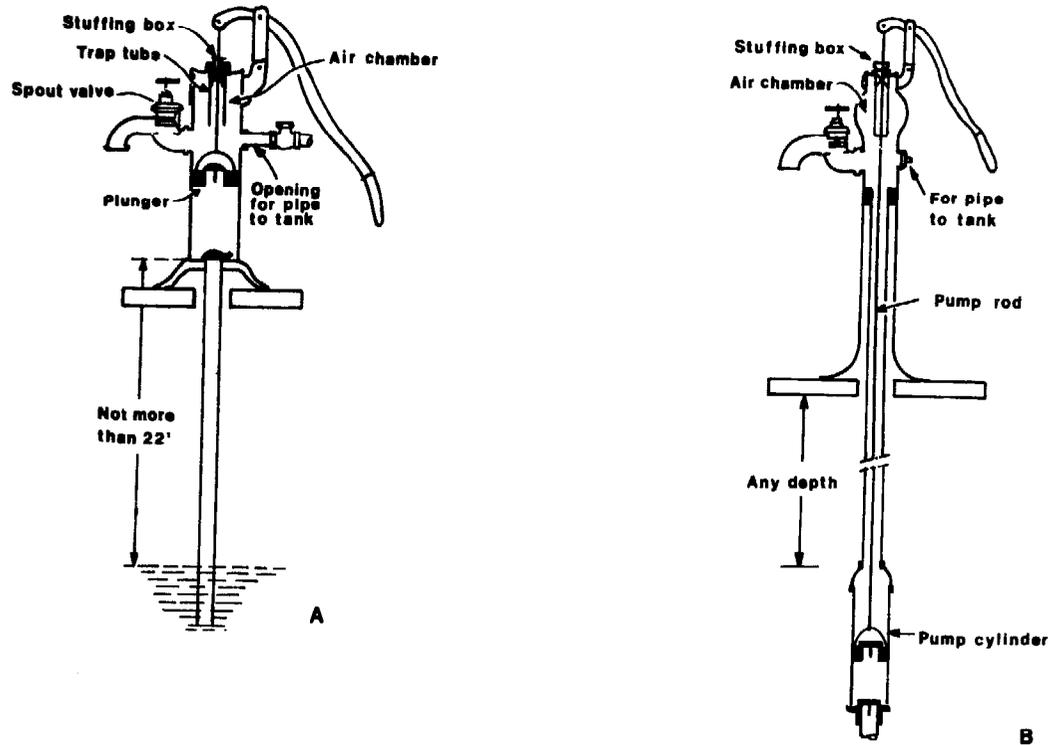


FIGURE 2-4 FORCE PUMPS

force pumps need valved spouts, either to allow use of a second outlet or as a check valve between the pump and a tank. Also, such pumps usually have an air chamber to even out the discharge flow. On the upstroke of the plunger the air in the air chamber is compressed and on the downstroke the air expands to maintain a flow at the discharge while the plunger goes down. The trap tube serves to trap air in the air chamber, preventing it from leaking out around the plunger rod.

The operation of deep well force pumps is the same as that of Figure 2-4A. The principal difference is in the location of the cylinder. With the cylinder down in the well it can pump from a depth greater than 22 feet (6.7 meters). See Figure 2-4B. Therefore it is a deep-well pump.

2.5 DIAPHRAGM FORCE PUMP

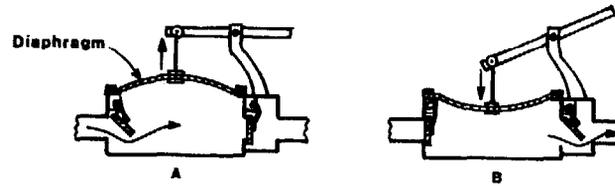


FIGURE 2-5 CROSS-SECTION OF A DIAPHRAGM PUMP

Another type of positive displacement pump, which may use a reciprocating handle is the diaphragm pump, invented in 1730, and widely used as an automotive fuel pump. As the diaphragm (an elastic membrane) is lifted, liquid is drawn in through the inlet valve at the left as shown. When the diaphragm is depressed, liquid is forced out at the right. The Vergnet pump and the Petro pump, both described in Section 5, are new variations of this principle which have potential promise as hand pumps for rural water supply.

2.6 ROTARY PUMP

Pumps which employ high speed rotor(s) within a fixed casing or stator are commonly called rotary pumps. One example consists of two rotating gears meshed together in a housing with close clearances as shown in Figure 2-6.

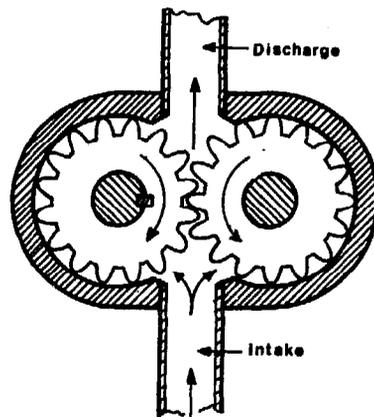


FIGURE 2-6 CROSS-SECTION OF A ROTARY PUMP

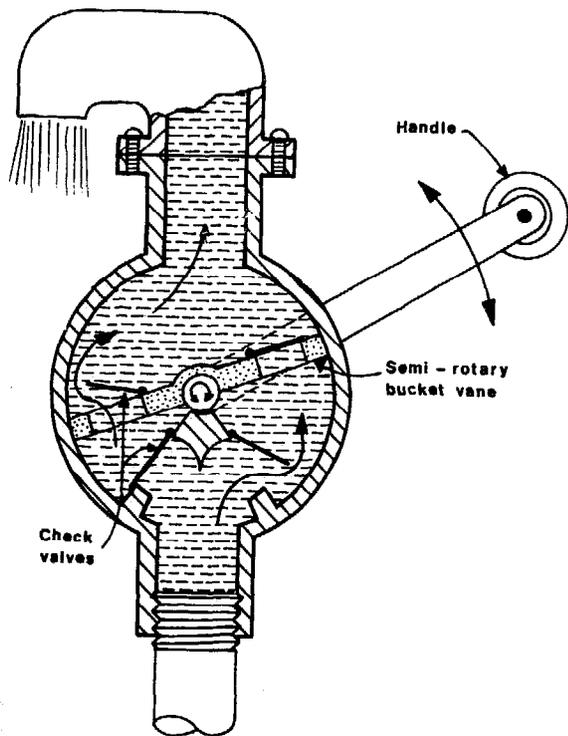


FIGURE 2-7
CROSS SECTION OF
SEMI-ROTARY PUMP

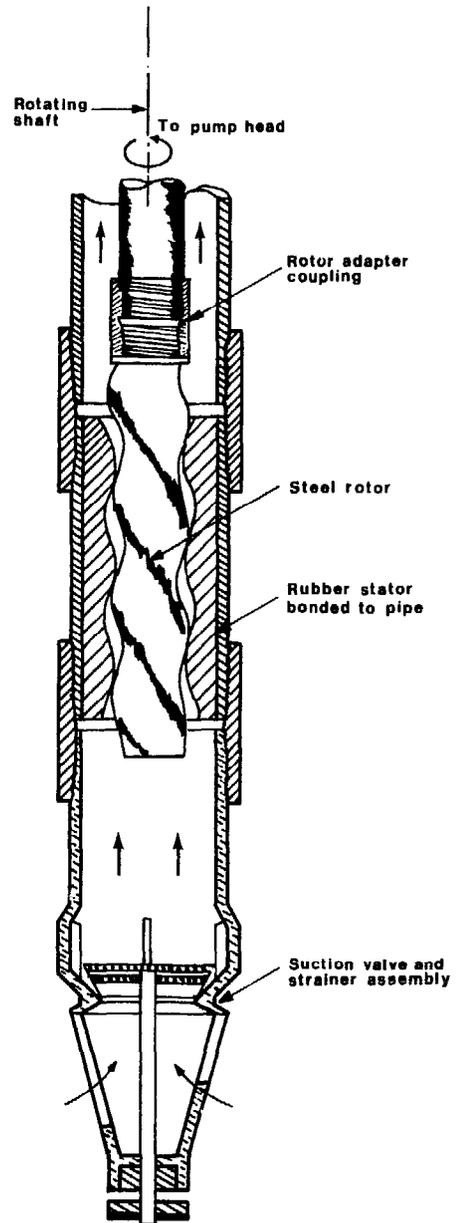


FIGURE 2-8
CROSS SECTION OF
HELICAL ROTOR PUMP

Power is applied to only one of the gears, which in turn drives the other gear. This pump operates as follows: rotating in the direction shown, when the teeth disengage, a partial vacuum is created over the intake. This permits atmospheric pressure to force liquid into the pump, filling up the spaces between the teeth; as rotation continues, the liquid between the teeth is carried around the outer sides of the pump to the point where the teeth remesh. As the teeth remesh the liquid between them is squeezed out, thus building up a pressure under the discharge. Having no valves, they are well adapted for pumping viscous liquids and, for this reason, are universally used as oil pumps. Hand operated rotary pumps are often used for emptying oil drums and tanks. A "semi-rotary" pump occasionally used in water supply is shown in Figure 2-7.

Another of the rotary pumps, the helical rotary, often termed the progressive cavity pump, consists of a single thread helical rotor turning within a double thread helical stator. (See Figure 2-8). The meshing helical surfaces push the liquid ahead (up) with uniform movement similar to a slow moving piston in a cylinder of infinite length. Because the rotor to stator contact provides an effective, continuous seal, the helical rotary pump requires no valves. Hand operated helical rotary pumps are available for use in 3-inch (75 mm) or larger boreholes. Although relatively expensive, it has given good deal well service in parts of Africa and Asia where it is known as the "Mono" pump after its English manufacturer.

2.7 BUCKET PUMPS**

Another type of positive displacement, hand operated pump is the bucket pump. An example is shown in Figure 2-9.

** Not to be confused with the name "bucket pump" sometimes given reciprocating well pumps whose plunger to cylinder seals are sometimes called "buckets".

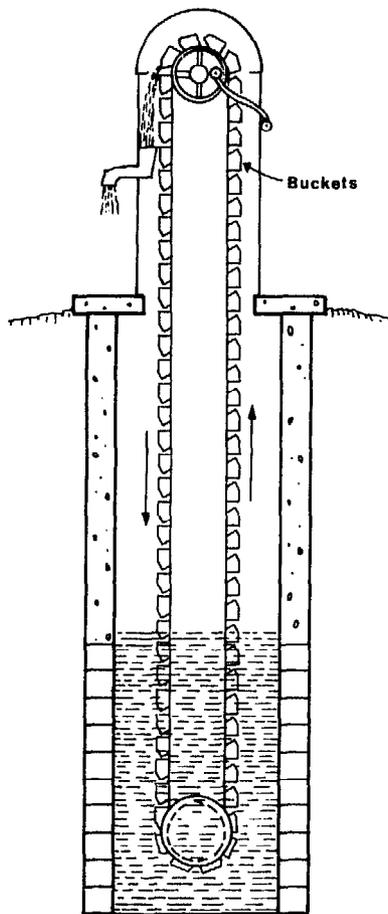
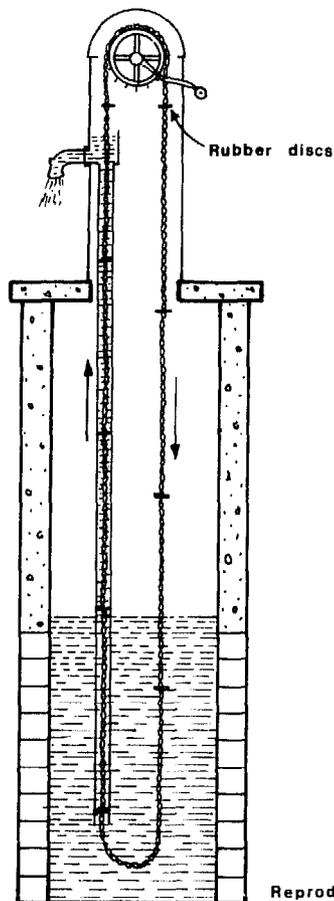


FIGURE 2-9 BUCKET PUMP



Reproduced from
WHO Monograph No. 42

FIGURE 2-10 CHAIN PUMP

Small buckets attached to an endless chain are rotated over sprockets as shown so that each bucket dips water from the source at the bottom, carries it to the top, and empties it into the spout as it passes over the top sprocket. At least one manufacturer makes a pump using a sponge-like belt in lieu of the buckets with a squeegee at the top to remove the lifted water. Another handmade version uses a rope driven by a bicycle wheel with a sharp bend at the top to discharge the water by centrifugal force. These pumps are used mostly on cisterns and shallow dug wells.

The same operating principle is used in "traditional" animal-powered low-lift irrigation pumps such as the Persian wheel, sakia, noria, and others in which the buckets may be replaced by earthenware jars or wooden

or metal boxes and the circular, horizontal movement of the animals converted by beveled or toothed gears to rotary vertical motion to drive the endless chain.

2.8 CHAIN PUMPS

In the chain pump, rubber discs attached to an endless chain running over a sprocket at the top are pulled upward through a pipe to lift water mechanically up to the spout. Like the bucket pump, it is used mostly on cisterns and shallow dug wells. This type of pump is readily adaptable to manufacture by village artisans. See Figure 2-10.

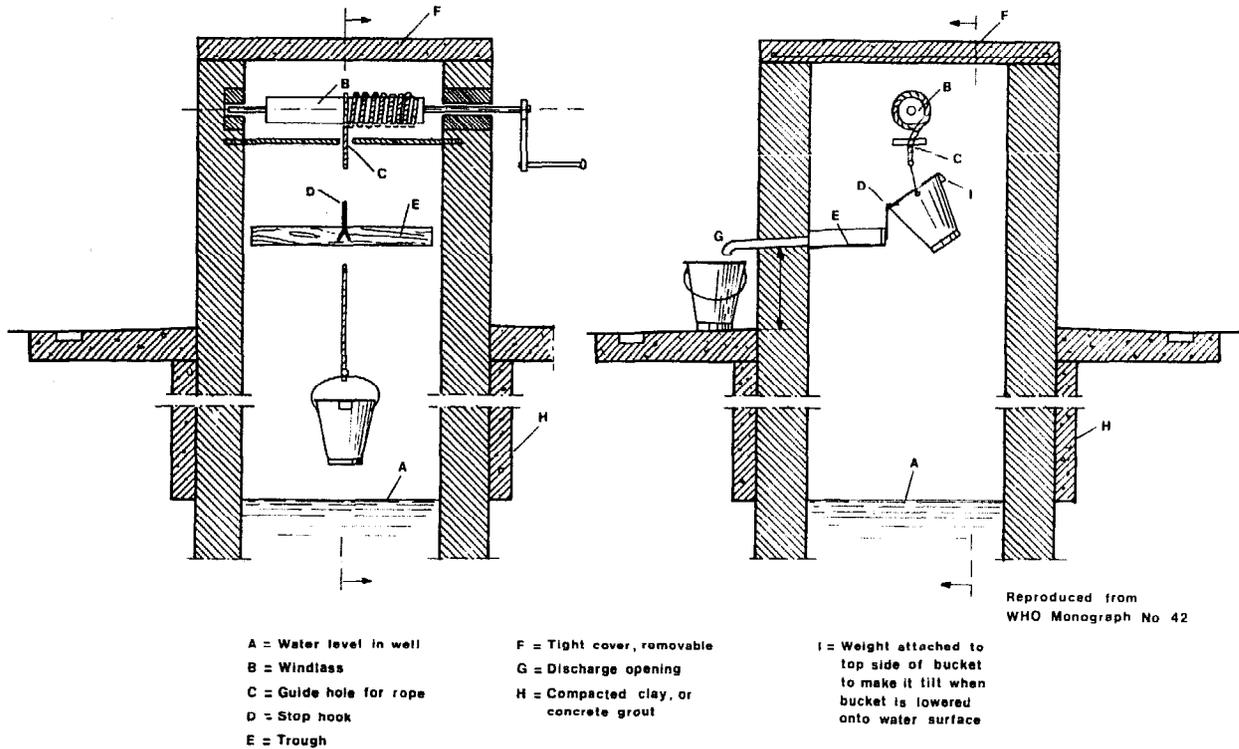
Chain pumps using rags and balls in lieu of discs were commonly used for draining mines in Agricola's time (1556). Animal-powered chain pumps are apparently widely used in China for irrigation pumping (Watt, circa 1975).

2.9 SANITARY ROPE AND BUCKET MECHANISM

The design developed by WHO (Wagner and Lanoix) and shown in Figure 2-11 should not be overlooked. This design, for use with dug wells, is simple to maintain. When carefully built, this simple pumping arrangement gives good service, and will protect the well from pollution. Because it is fairly simple, details can be easily changed to fit local conditions. For ease of maintenance, the cover should be removable. A reinforced concrete slab four inches thick and three feet in diameter can be moved by two men.

The obvious disadvantage of this type of water-lifting arrangement is its low rate of discharge. But as a village community water source, it will perform satisfactorily.

FIGURE 2-11 A SANITARY ROPE AND BUCKET WELL



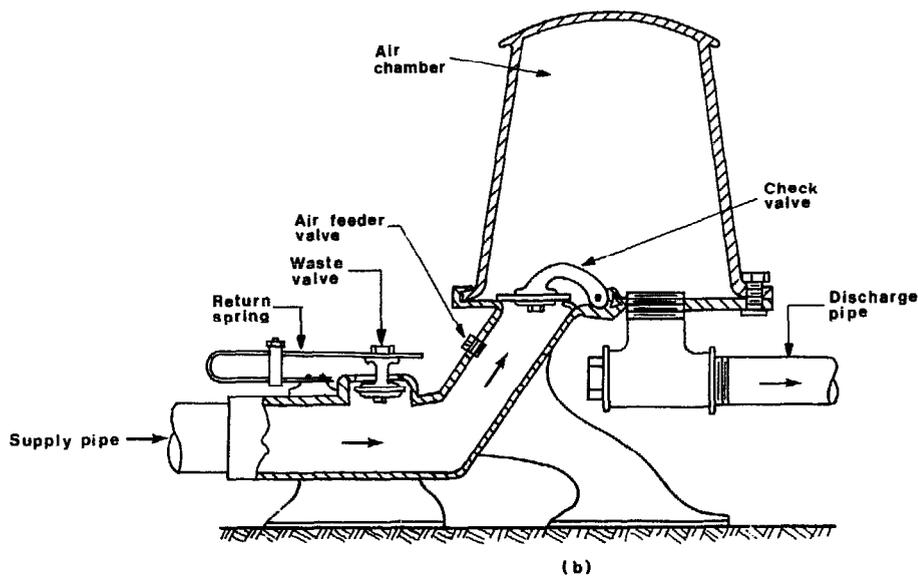
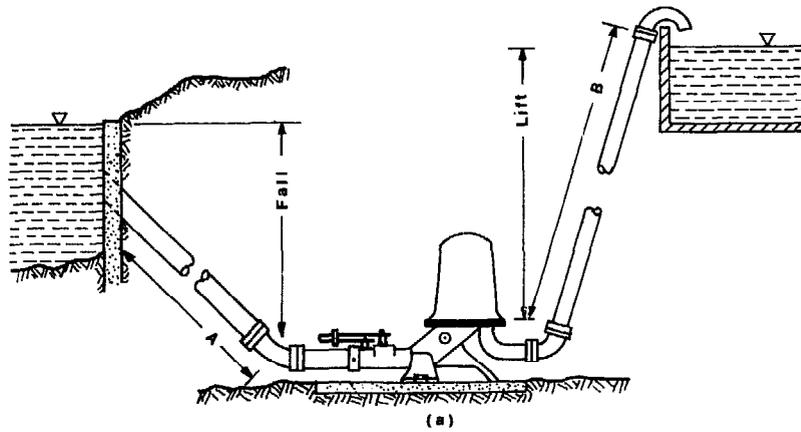
2.10 HYDRAULIC RAM

Where several times as much water as may be needed is available and with some available head, the potential energy of the wasted water can be captured using a hydraulic ram to drive a portion of the water to a higher elevation. (See Figure 2-12). Although not a hand pump, most foundries capable of making hand pumps should be capable of manufacturing rams. They can also be manufactured from "off the shelf" components (Kindal; Watt, 1974). After the initial cost, from about \$200 to \$3000 (US) plus the cost of the drive and delivery piping, the rams operate 24 hours a day, year after year, with relatively little maintenance.

The ram is constructed with the waste valve facing up, the check valve facing down. At the beginning of the working cycle of the ram, the waste valve has just been opened, either by hand to begin operation or automatically

FIGURE 2-12 TYPICAL HYDPAULIC RAM

(a) Installation, and (b) Cross section



Reproduced from
Wood, A.D. Water Lifters and
Pump for the Developing World, 1976

later. The column of water in the supply pipe accelerates under the supply head, the discharge valve remains seated under the discharge pressure. Water from the supply pipe is now running straight to waste. As the flow rate through the valve increases, the dynamic pressure on the waste valve rapidly reaches a value sufficient to close the waste valve almost instantaneously. The water hammer effect of the slamming of the waste valve** almost immediately forces the discharge valve open. Flow continues through the discharge valve until the original kinetic energy of the water column in the supply pipe is exhausted. The momentary pressure drop in the valve chamber results in the closure of the discharge valve, the opening of the waste valve, and repetition of the cycle.

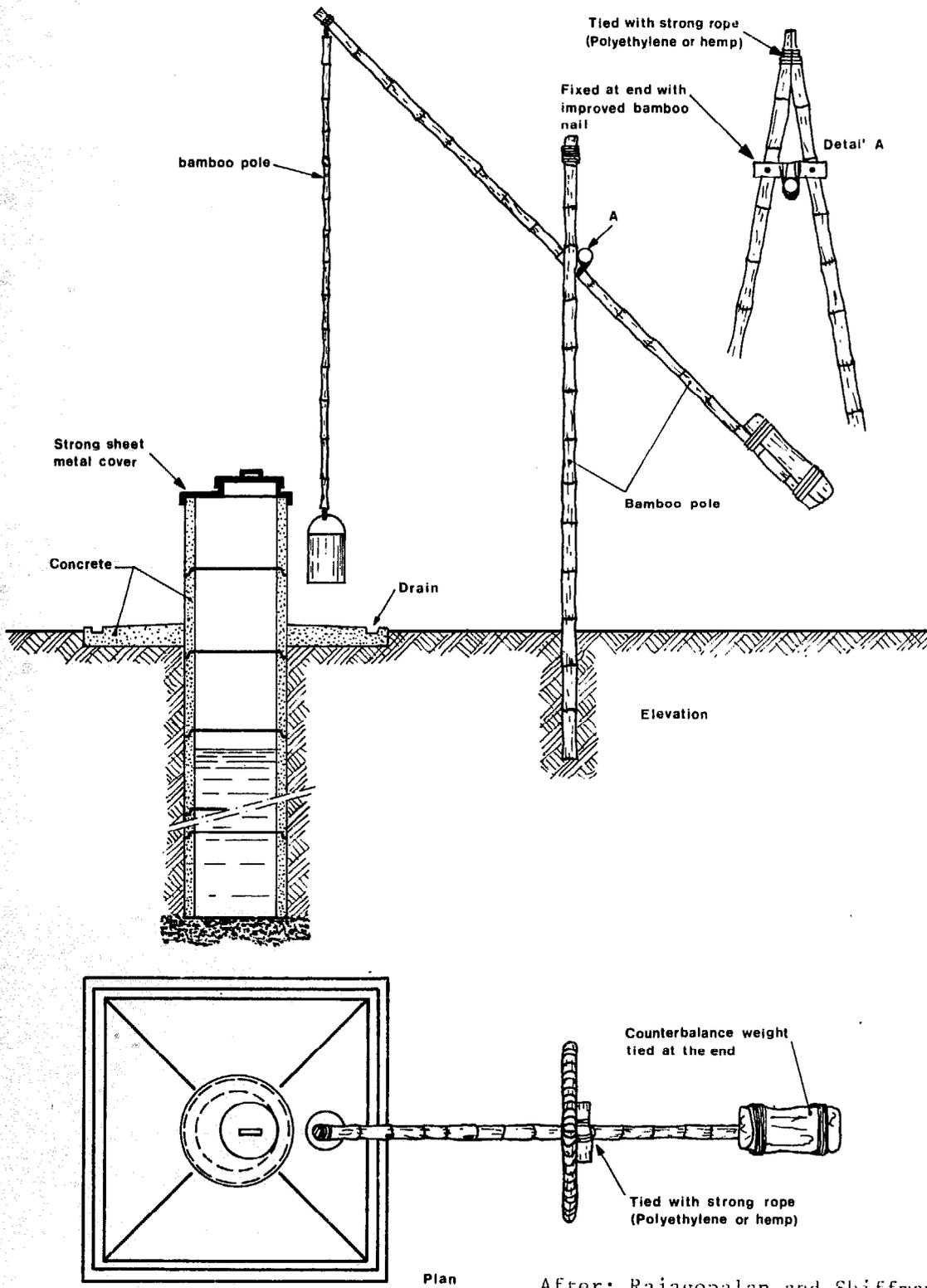
2.11 TRADITIONAL WATER LIFTING DEVICES

There are numerous other water lifting devices which could be mentioned, for example, the Archimedes screws; rope and bucket devices such as the mohte, charsa, ramioko, daly, delu, and mota; counterpoise lifts known variously as the shadouf, shaduf, shadoof, chadouf, khetara, kerkaz, kheeraz, guenina, cigoñal, bascule, dhenkali, dhenkli, dhingli, picottah, lat, picottas, guimbalete, swape, sweep, et al.; the hinged channel or gutter, doon, baldeo balti, and jantu; paddle wheels; water ladders; and the various chain pumps and wheel pumps previously mentioned.

These are widely used for lowlift irrigation pumping, many are animal powered. However the great majority of manually operated pumps for village drinking water supplies will be one of the types previously described.

The shadouf, or counterweighted bailer, was modified and effectively used in a recent WHO cholera project (Rajagopalan and Shiffman) as shown in Figure 2-13.

** One disadvantage of rams is their noisiness; the valves slam shut 25 to 100 times per minute.



After: Rajagopalan and Shiffman.
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 World Health Organization

FIGURE 2-13 IMPROVED DUG WELL AND COUNTERWEIGHTED BAILER USED IN THE PHILIPPINES

3. HAND PUMPS: STATE OF THE TECHNOLOGY

3.1 GENERAL

Most village hand pumps are of the reciprocating plunger types described in the previous section. Reciprocating hand pumps in use today represent the evolutionary, empirical products of over a century of design modifications. Many are copies of commercially successful pumps. Except for very large orders, selection from among the models readily available is more economical than a special, new hand pump design. However, whether designing new or selecting from existing models, the same principles apply to hand pump analysis and evaluation.

While this section focuses on reciprocating plunger pumps, the fundamental principles outlined also apply to other types of pumps, particularly other positive displacement types such as the "Petro", the "Pompe Vergnet", and chain pumps.

3.2 NOMENCLATURE

The component assemblies of a reciprocating pump used for pumping from wells and boreholes can be arbitrarily divided by function into three categories: (1) the pump stand assembly atop the well; (2) the pump cylinder assembly in contact with the water; and (3) the connecting assembly which joins the pump stand and the cylinder. (See Figure 3-1). In deep wells, these three assemblies are separately located; in shallow wells, the cylinder assembly and connecting rod may be located within the pump stand. (See Figures 2-1, 2-2 and 2-4).

These three component assemblies can be and often are purchased separately. For example, a locally manufactured pump stand assembly may be combined with an imported cylinder assembly. Connecting assemblies (pump rod and drop pipe) are often purchased and stocked separately.

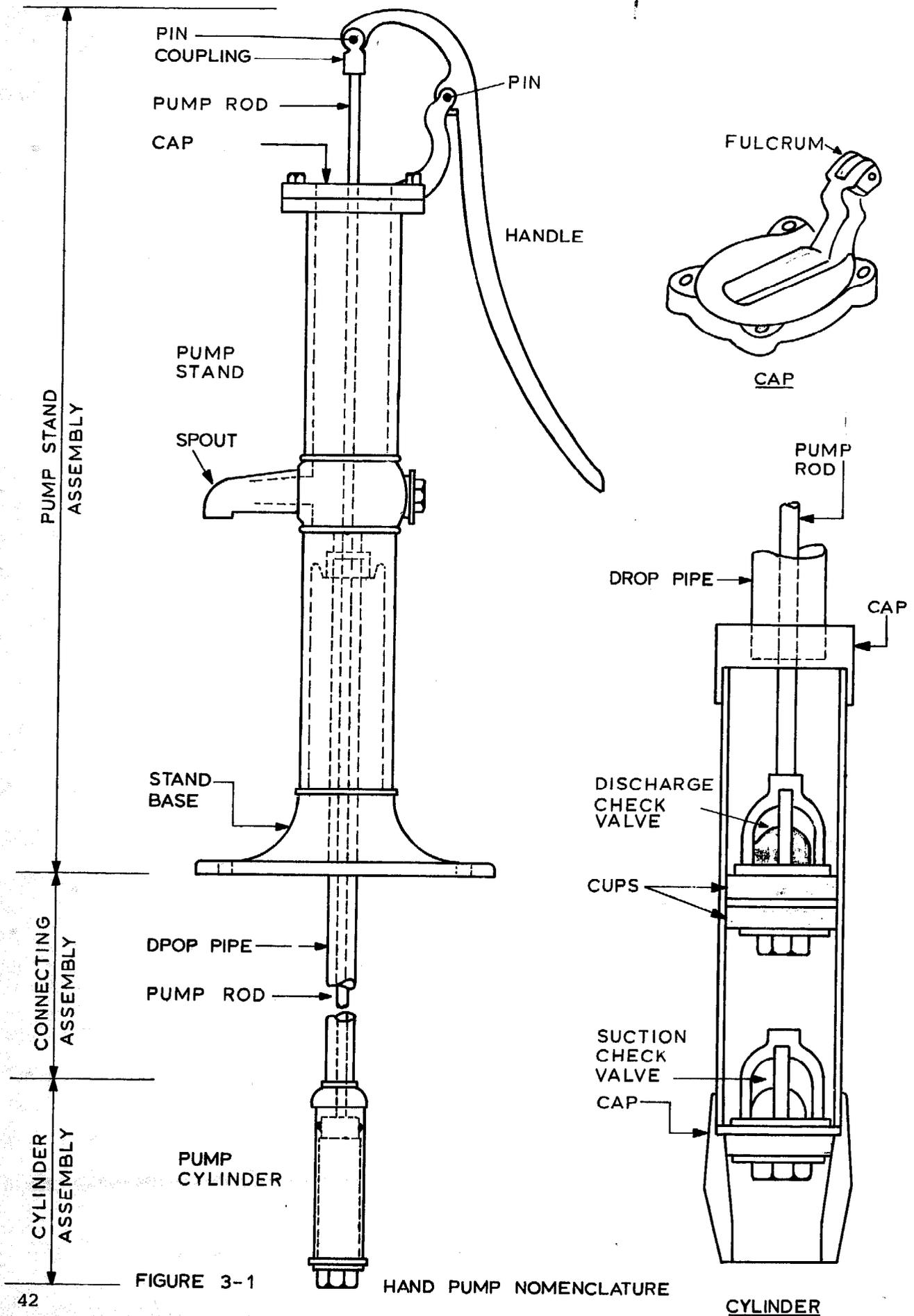


FIGURE 3-1

HAND PUMP NOMENCLATURE

CYLINDER

Hand pump nomenclature varies widely by and even within countries. The nomenclature used herein is that most frequently encountered. Alternate names are shown in parenthesis in subject headings in this section. Units of measurement most frequently encountered in hand pump programs are on the foot (inch)-pound-second-gallon system. Metric units are added in parenthesis where measurements are used.

3.2.1 Pump Stand Assembly (Standard, Pump Head, Operating Head, Hydrant, Barrel)

The pump stand assembly serves three functions: (1) transmittal of motive power to the pump rod; (2) provision of a discharge point (spout); and (3) sanitary protection of the water source. Except for a small part of the pump rod, this is the only visible component. It includes the handle, handle linkage, stand, stand base, cap ring, stuffing box and gland, and the spout. These components are defined later herein.

3.2.2 Cylinder Assembly

The cylinder assembly is the actual pumping element (See Figures 2-2 and 3-1). It includes the plunger assembly, the cup seals, the suction and discharge valves, and typically a separate cylinder with caps as shown in Figure 3-1 and defined later herein. The interior walls of the pump stand may serve this purpose in shallow well pumps. In some deep well pump configurations the well casing or the drop pipe may also serve as the cylinder wall.

3.2.3 Connecting Assembly (See Pump Rod and Drop Pipe)

The connecting assembly consists primarily of the pump rod and the drop pipe. The pump rod transmits forces between the handle and the plunger and the drop pipe carries water from the plunger to the spout.

3.3 FUNDAMENTAL HYDRAULICS

3.3.1 Rate of Discharge (Q)

The theoretical rate of discharge of a single acting reciprocating hand pump is a function of the cylinder volume (V) swept by the plunger during its

upward, pumping stroke and the number of plunger pumping strokes per unit time (N). That is: $Q = VN$. As shown in Figure 3-2, the volume (V) is the product of the horizontal cross sectional area (A) and the length of the plunger stroke (S). Rewriting for Q in terms of the cylinder diameter (D) and the ratio of the cylinder circumference to its diameter (π or π):

$$Q = \frac{\pi}{4} D^2 NS \dots\dots\dots(3-1)$$

The nomograph shown in Figure 3-3 is a solution of Equation 3-1 in both inch-gallon-minute and in millimetre-litre-minute units.

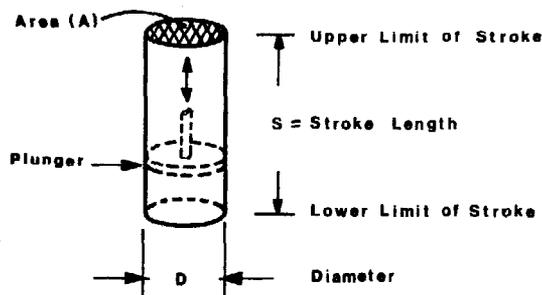


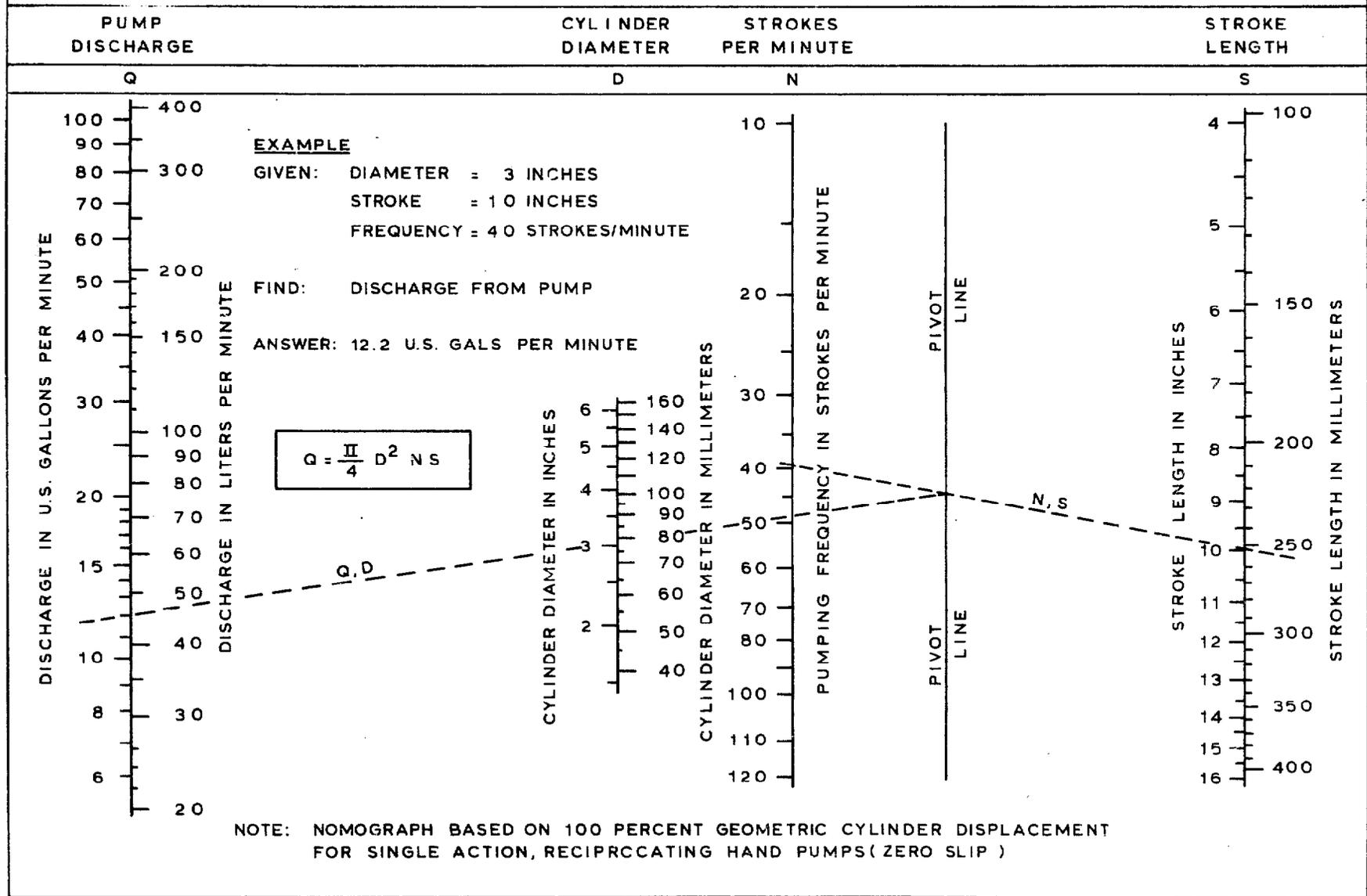
FIGURE 3-2 SWEPT CYLINDER VOLUME

The actual rate of discharge normally varies slightly from the theoretical discharge given by Equation 3-1 due to failure of the valves to close instantly when the plunger changes direction and to back leakage between the plunger and the cylinder wall during pumping. This difference is known as slip and is defined as the difference between theoretical discharge (Q_t) and actual discharge (Q_a) as a percentage of the theoretical discharge, that is:

$$\text{Slip} = \frac{Q_t - Q_a}{Q_t} (100) \dots\dots\dots(3-2)$$

Slip should not exceed 15 percent, preferably 5 percent, in a well designed and maintained pump. Negative slip is possible; the actual discharge may exceed the theoretical discharge (in terms of swept cylinder volume)

FIGURE 3.3 NOMOGRAPH FOR HAND PUMP DISCHARGE



under certain conditions. For example a long suction pipe of small diameter, below the cylinder, may result in a sufficiently high flow velocity to keep open the plunger discharge valve during part of its upward movement. Although this may yield a hydraulic efficiency exceeding 100 percent, it may lead to excessive "pounding" and even cavitation if the dynamic suction head losses lower the water pressure immediately below the plunger below its vapor pressure (Wilson). Hydraulic efficiency in terms of swept cylinder volume should not be confused with mechanical efficiency which can never exceed 100 percent.

The product of the number of plunger pumping strokes per unit time (N) and the length of the pumping plunger stroke (S) is known as the pump or plunger running speed, that is:

$$\text{Plunger Running Speed} = NS \dots\dots\dots(3-3)$$

In virtually all reciprocating hand pumps, the plunger discharges only during its upward movement. Discharge (on pumps without air chambers) during the downstroke is negligible. Reciprocating pumps with plungers which discharge only in one direction are termed single acting. Pumps which discharge during both directions of piston or plunger travel are termed double acting. These are generally mechanically powered, top of the well cylinder assemblies, often with two or more cylinders, each with two sets of suction and discharge valves.

In a single acting pump, running speed NS in Equations 3-1 and 3-3 is the average plunger speed in one direction during a plunger cycle. The actual average absolute (regardless of direction) speed is 2NS. In Equation 3-1, N is the number of pumping cycles as well as the number of plunger pumping strokes per unit time.

Rules of thumb for running speed are extant for mechanically powered reciprocating pumps but apparently not for hand powered pumps where the limitations of human muscle are more binding. Nevertheless, the running speed concept has some usefulness in understanding hand pump operation. For example,

other things remaining equal (Q and D), reducing the stroke length by one-half means that the number of strokes per minute must be doubled. Also note that discharge Q is directly proportional to N or to S .

3.3.2 Static Head

The static head is the vertical distance that the water must be raised from its static, at rest, lower level to its ultimate uppermost level at free discharge at the spout or to an elevated tank. Determination of the static head to be overcome is illustrated in Figure 3-4.

In Case I as shown in Figure 3-4, the pump cylinder is submerged. The plunger must lift a column of water to the pump spout, distance D as shown. A column of water with head S exerts an upward force on the plunger. The head on the plunger is the net resultant of D and S , that is $D - S$ or W .

In Case II as shown, the cylinder is located above the water table in the well. The total static head is the vertical distance $D + S$ or W between static water level and the pump spout.

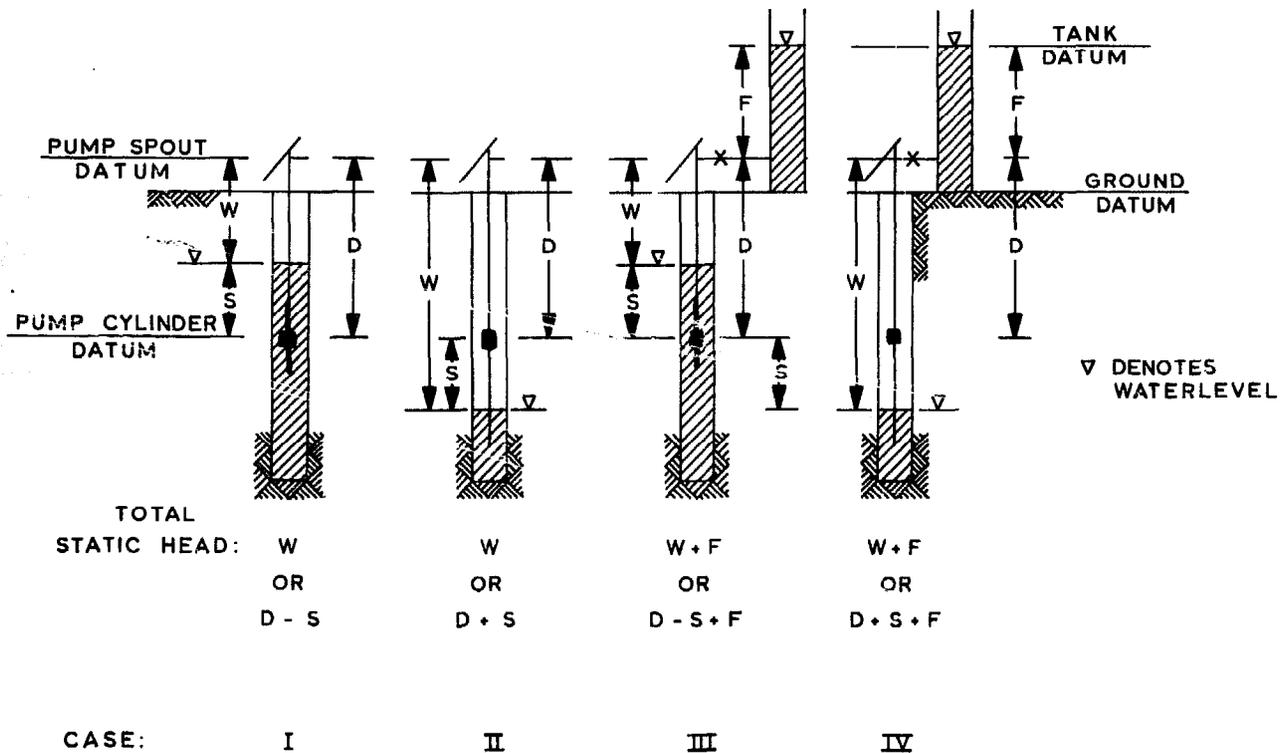


FIGURE 3-4 STATIC HEAD FOR HAND PUMPS

Cases III and IV are for force pumps and show the increase F in static head for pumping to elevated tanks.

Cases II and IV could also represent a shallow well installation when the cylinder is incorporated into the pump stand assembly.

3.3.3 Drawdown

When pumping starts the water level in the well will drop, the rate and distance of the drop or drawdown depending on the rate of pumping and the rate of groundwater recharge of the well.

3.3.4 Friction Head

During pumping, additional energy will be required to overcome (1) the hydraulic friction between the flowing water and the walls of the suction and discharge or drop pipes, cylinder spout, et al; (2) the hydraulic turbulence associated with contraction and expansion of flow through changes in cross sections in valves, screens, cylinder, et al.; and (3) turbulence due to inertial losses inherent in reciprocating flows including constant acceleration and deceleration of flow. The friction losses described in (1) above can be approximately estimated using standard pipe flow formulas. The losses of (2) and (3) can be roughly estimated as a percentage of the velocity head at each flow obstruction.

Generally in hand pump installations with adequately sized suction and discharge piping, with pumps with well-designed valves, and with submerged cylinders, friction head losses are negligible.

3.3.5 Suction Head

Deep well pump cylinders should be installed at sufficient depth to insure their remaining submerged year around, dry season and wet, dawn and dusk. This practice eliminates the necessity (and the hazards to health) of priming the pump and lengthens the life of the cylinder assembly.

However in shallow well hand pumps, the economy and maintenance accessibility of cylinders incorporated within the pump stand assembly may dictate

cylinder location above the water level within the well. How far above the water level can the cylinder be placed and still pump water as in Figure 2-2? What is the maximum suction head?

The "ideal" maximum suction head or lift is dependent on the barometric pressure and the temperature and vapor pressure of the water. At sea level and 60°F (15.6°C) the barometric pressure is equivalent to 14.7 psi (1.03 kg/cm²) or in equivalent head of water, 34.0 feet (10.36 meters). This pressure pushes the water into the pump as described in Section 2-2. The "ideal" maximum suction head then is about 34 feet (10 meters).

The maximum suction head decreases with increasing altitude and water temperature, about three percent for each 1,000 feet (300 meters) rise in elevation, about one percent for each 10°F (4°C) rise in temperature in the relevant range. For most well waters used for drinking, temperature is not critical. However high altitudes, as shown in Table 3-1, may significantly lower the allowable suction head.

Practically speaking, the allowable suction heads must also be reduced to allow for friction head losses and suction velocity head. This can be approximately calculated for each installation or measured in a hydraulic testing laboratory. A common practical value for the design maximum suction head is two-thirds (2/3) of the ideal. If drawdown, daily or seasonal, is significant, the values shown in Table 3-1 should be reduced accordingly.

3.4 STRUCTURAL ANALYSIS

3.4.1 Hydraulic Force

The major structural load on the pump plunger, pump rod, couplings, handle assembly, bearings, and pump stand occurs during the pumping (upward) stroke of the plunger and is exerted by the water pressure on the plunger resisting its movement, by the submerged weight of the pump rod and plunger assembly, and by sliding friction at bearings and cup seals.

TABLE 3-1

MAXIMUM SUCTION HEAD OF RECIPROCATING HAND PUMPS
AT DIFFERENT ALTITUDES FOR WATER AT 60°F (15.6°C)

Altitude Above Mean Sea Level		Barometric Pressure			Practical Suction Head of Pump	
		Air	Equiv. Head of Water			
Feet	Meters	Psi	Feet	Meters	Feet	Meters
0	0	14.7	34.0	10.36	22.6	6.91
1000	305	14.2	32.8	10.00	21.9	6.67
2000	610	13.7	31.5	9.60	21.0	6.40
3000	914	13.2	30.4	9.27	20.3	6.18
4000	1219	12.7	29.2	8.90	19.5	5.93
6000	1829	11.8	27.2	8.29	18.1	5.53
8000	2438	10.9	25.2	7.68	16.8	5.12
10000	3048	10.1	23.4	7.13	15.6	4.75

The net hydraulic force (F) on the plunger is the product of the net hydraulic pressure (P) and the cross-sectional area (A) in the horizontal plane, that is, $F = PA$. The net hydraulic pressure (P) is the product of the head (H) and the specific weight (γ) of water, that is, $P = \gamma H$. For a circular plunger, its area (A) expressed in terms of plunger diameter (D) is $A = \pi D^2/4$. Summarizing:

$$F = PA = \frac{\gamma H \pi D^2}{4} \dots\dots\dots(3-4)$$

To the hydraulic force must be added the submerged weight of the pump rod. The weight of other components can generally be neglected.

Example: Given a hand pump with a three-inch (76 mm) cylinder set 60 feet (21.3 meters) below the pump. The pumping head is 50 feet (15.2 meters). (Not given, but assumed, is the specific weight of water: 62.4 lb/ft³ (998 kg/m³) at 60°F (15.6°C) and one atmosphere pressure). The steel pump rod is ½-inch (12.7 mm) in diameter.

$$F = \frac{\gamma H \pi D^2}{4} = \frac{(62.4 \text{ lb/ft}^3)(50 \text{ ft})(3.14)(3/12 \text{ ft})^2}{4}$$

Hydraulic Force $F = 153$ pounds (69.5 kg)

The weight of the pump rod varies slightly with the type and number of couplings. The weight of the water displaced by the rod should theoretically be subtracted but can be ignored; it and the plunger assembly weight roughly cancel each other out. From a manufacturer's catalog, his ½-inch threaded and coupled steel pump rod weighs 0.685 lb per ft (1.02 kg per meter).

Pump Rod Weight = 60 feet x 0.685 lb/ft = 41 pounds (18.7 kg)

Total Calculated Force = 153 lb + 41 lb = 194 lb (88.2 kg)

Worth noting in the above example is that the force is predominately a function of head rather than cylinder depth. Also the calculated force is independent of discharge.

The calculated force is the average over the pumping cycle. Actually pump testing using dynamometers (Hood, et al.) indicates that peak forces may be two or three times the calculated forces. Obviously the pump rod, couplings, threaded connectors and pins must have sufficient strength to withstand peak stresses; thus generous safety factors are indicated.

Figure 3-5 is an example of how pump rod tension might vary during the stroke cycle of a particular hand pump. The solid line abcd shows "ideal" friction and turbulence free performance. At position "a" the plunger is at the bottom of the cylinder. Pump rod tension is zero - the "ideal" pump rod and plunger are weightless. Pumping begins, the plunger begins its upward movement; instantaneously the pump rod tension increases to "b" in accordance with Equation 3-4. This tension is constant as the plunger moves to the top of the cylinder at "c". As the plunger stops at the top of the cylinder at "c", no more work is being done and the tension returns to level "d", the

same as "a". The plunger returns to "a".

More typically the pump rod tension at the beginning of the upward plunger stroke does not increase instantaneously. As the plunger accelerates upward, pump rod and coupling slack is taken up and the pump rod tension increases rapidly as from "e" to "f". The inertial forces required to accelerate the water from "rest" cause the maximum tension "f" to exceed the calculated value "b". From "f" to "g" the now moving water reduces the external force required. The "kink" from "g" to "h" is the closing of the plunger valve. By "i" the plunger is decelerating and has reversed direction by "j". The weight of the pump rod results in some pump rod tension as the plunger returns from "j" to "e".

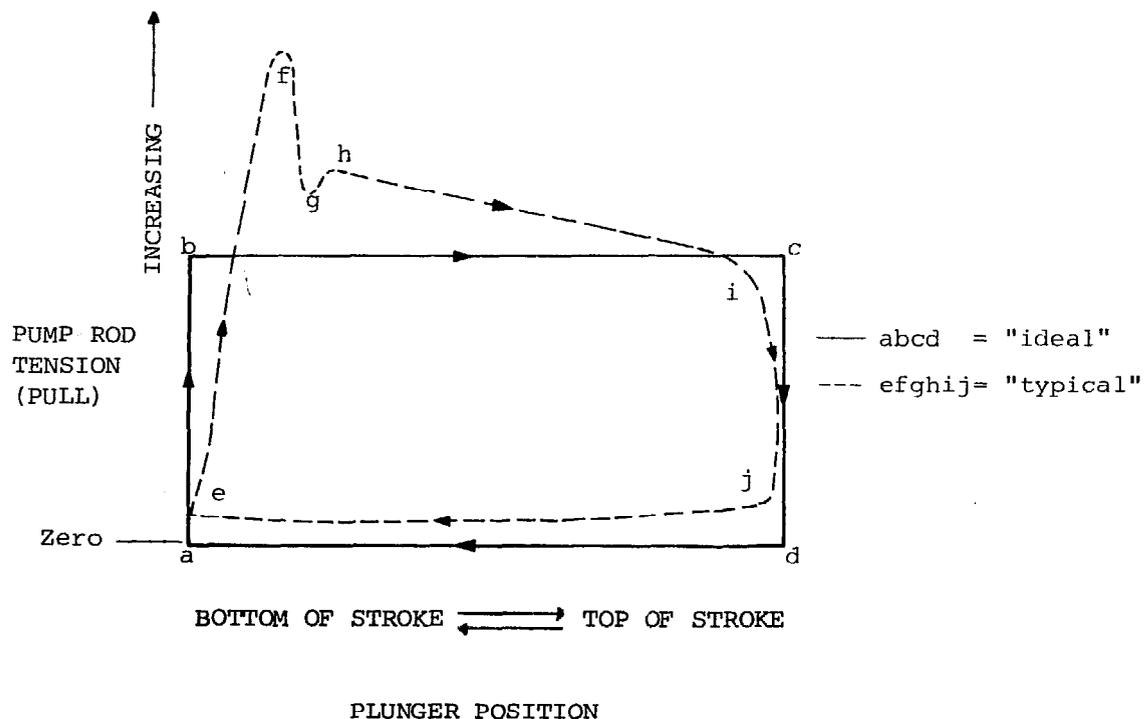


FIGURE 3-5 DYNAMOMETER MEASURED PUMP ROD TENSION

3.4.2 Mechanical Advantage

As shown in the example of the previous section, the force exerted on a pump rod and, through the rod to the pump handle may easily exceed 100 lb. (45.4 kg). However the muscular force available for continuous pumping by an individual person is generally limited to 20 to 40 pounds (9 to 18 kilograms).^{*} Through the principle of mechanical advantage, muscle power can be multiplied to successfully operate hand pumps in wells up to even 600 feet (180 meters) in depth.

Consider the lever-type pump handle shown in Figure 3-6. It pivots freely about the fulcrum pin. At one end, L_p distant from the fulcrum, the handle is connected by a pin to the pump rod. Through this pin the force exerted by the pump rod, F_p , pulls on the handle. At the other end of the handle, L_h distant from the fulcrum, the hand pushes down the handle with a force, F_h

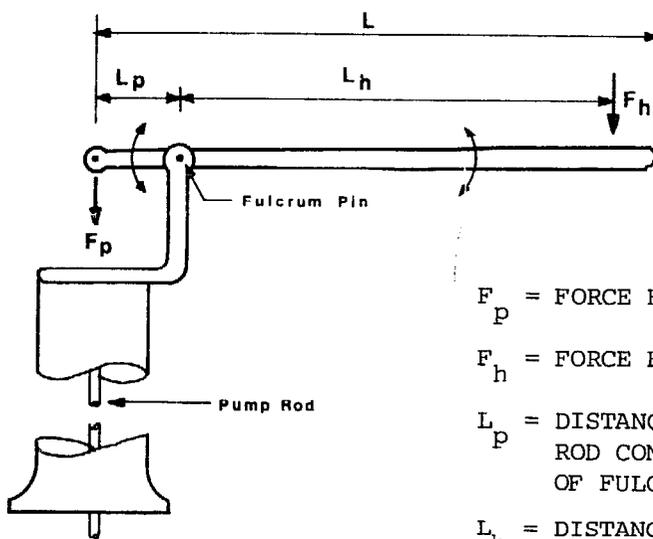
If the distances L_p and L_h were equal and the forces F_p and F_h were equal, the handle would be in balance or "equilibrium" and would not move. If the distance L_h were twice the distance L_p but the force F_h only half the force F_p , then the handle would continue to be balanced.^{**} Indeed any combination in which the product (or "moment" as it is termed in mechanics) of the distance and force on one side of the fulcrum is equal to the product of distance and force on the other side of the fulcrum would be stable. That is, at equilibrium, $F_h L_h = F_p L_p$. The ratio of the handle distance L_h to the pump rod distance L_p is known as the mechanical advantage:

$$\text{Mechanical Advantage} = MA = \frac{L_h}{L_p} \dots\dots\dots(3-5)$$

Note that at equilibrium: $F_h L_h = F_p L_p$

^{*} Most "rules of thumb" fall in this range. No satisfactory ergonomic studies have apparently been made.

^{**} Analogous to the childhood "see-saw" or "teeter-totter".



- F_p = FORCE EXERTED BY PUMP ROD
- F_h = FORCE EXERTED BY HAND
- L_p = DISTANCE FROM CENTRE OF PUMP ROD CONNECTION PIN TO CENTRE OF FULCRUM PIN
- L_h = DISTANCE FROM "CENTRE" OF HAND TO CENTRE OF FULCRUM PIN

$$\text{MECHANICAL ADVANTAGE (MA)} = \frac{L_h}{L_p}$$

$$\text{EQUILIBRIUM FORCE } F_h = \frac{F_p L_p}{L_h} = \frac{F_p}{\text{MA}}$$



FIGURE 3-6 MECHANICAL ADVANTAGE OF PUMP HANDLE AS A LEVER

Rewriting: $F_h = F_p \frac{L_p}{L_h} = \frac{F_p}{\text{MA}} \dots\dots\dots(3-6)$

or $F_p = F_h \text{ MA} \dots\dots\dots(3-7)$

By similar analysis, the mechanical advantage MA for a rotating crankshaft with a crankhandle or wheel (see Figure 3-9) can be shown to be:

$$\text{MA} = \frac{\text{Radius of Handle Rotation}}{\text{Radius of Crankshaft Rotation}} \dots\dots\dots(3-8)$$

The above are equilibrium forces. If F_h exceeds F_h at equilibrium, the long handle end will descend. If F_p exceeds F_p at equilibrium, the pump rod will descend.

Example: Given a pump rod force of 194 lb (88.2 kg). What handle force is needed if the mechanical advantage of the pump handle is 4 to 1.

$$F_{\text{h pa}} = \frac{F_{\text{p}}}{\text{MA}} = \frac{194 \text{ lb}}{4} = 48.5 \text{ lb (22.0 kg)}.$$

The above value may be excessive, especially for hand pumps operated by women and children. Alternatives include extending the handle for greater mechanical advantage or reducing the pump rod force by using a smaller diameter pump cylinder.

If R represents the maximum allowable force on the user end of the handle and MA the mechanical advantage of the handle assembly, then the allowable pump rod force F_{pa} cannot exceed the product of R and MA:

$$F_{\text{pa}} \leq R (\text{MA}) \dots\dots\dots(3-9)$$

Noting that the pump rod force is the sum of the hydraulic force on the plunger (Equation 3-4) and the weight of the pump rod and plunger assembly, the maximum head for a given cylinder diameter can be roughly approximated as follows:

$F_{\text{pa}} = F + UL$ where F is determined as in Equation 3-4,
 U is the weight per unit length of the pump rod, and
 L is the length of pump rod.

Assuming that L is approximately equal to head H:

$$F_{\text{pa}} = \frac{\gamma H \pi D^2}{4} + UH = H \left[\frac{\gamma \pi D^2}{4} + U \right] \leq R (\text{MA})$$

$$H \leq \frac{4 R (\text{MA})}{\gamma \pi D^2 + 4U} \dots\dots\dots(3-10)$$

Table 3-2 solves Equation 3-10 for an average handle force not to exceed 40 lb (18.2 kg), a conventional mechanical advantage of 4 to 1, a 1/2-inch (12.7mm) diameter steel pump rod, and assumes that the pump rod length is approximately equal to the head. The latter assumption is tenable for a pump with its cylinder located just below the water level in the well.

TABLE 3-2

MAXIMUM HEAD FOR COMFORTABLE OPERATION
OF DEEP WELL HAND PUMP

CYLINDER DIAMETER		HEAD (LIFT)	
Inches	Mm	Feet	Meters
2	51	Up to 75	Up to 25
2½	63	Up to 60	Up to 20
3	76	Up to 45	Up to 15
4	102	Up to 30	Up to 10

Note: See text for caveats and assumptions, which include maximum handle force of 40 lb (18.2 kg) and 4 to 1 mechanical advantage.

3.5 ENERGY ANALYSIS

3.5.1 Energy Requirement

In hand pumps the rate of work, or power, is the energy parameter of greatest interest:

$$\text{Power} = \frac{Q H}{e}$$

where Q is the rate of discharge, H is the head, and e the pump's mechanical efficiency. Power is frequently expressed as horsepower (one horsepower or H.P. = 33,000 foot-pounds per minute) or as kilowatts (1,000 watts or 1,000 joules per second). One horsepower is equivalent to 0.746 kilowatt. For Q in U.S. gallons per minute and H in feet, and efficiency expressed as a decimal, power expressed in H.P. is calculated as follows:

$$\text{Power (in H.P.)} = \frac{Q H}{3960 e} \dots\dots\dots(3-11)$$

3.5.2 Human Power

By definition man (or woman or child) is the motive force that drives the hand pump. Just as for, say, electrically driven centrifugal pumps, the characteristics of the hand pump and its motor, man, should be properly matched.

The power available from human muscle depends on the individual, the ambient environment, the conversion efficiency, and the duration of the task.

The power available for long term useful work, for example 8 hours per day, 48 hours per week, by healthy young male laborers is often estimated at 0.08 to 0.10 horsepower (60 to 75 watts). This value must be reduced for individuals in poor health, malnourished, of slight stature, or aged. It also must be reduced for high temperature, high humidity work environments. Where the man and his work are poorly matched - for example pumping from a stooped position - much of the energy expenditure is wasted. Short term power production may be doubled where large muscles can be readily applied - as in pedaling versus arm only movement (Krendel 1960).

The power available during short term work periods is much greater. There are examples of well trained athletes generating up to 2 horsepower for efforts of 5 to 10 seconds. Table 3-3 is adapted from Krendel.

TABLE 3-3
MAN GENERATED POWER

AGE OF MAN	USEFUL POWER BY DURATION OF EFFORT (in H.P.)					
Years	5 min.	10 min.	15 min.	30 min.	60 min.	480 min.
20	0.29	0.28	0.27	0.24	0.21	0.12
35	0.28	0.27	0.24	0.21	0.18	0.10
60	0.24	0.21	0.20	0.17	0.15	0.08

Modified from Krendel (1967).

Most hand pumps used for domestic water supply are operated by many users, each pumping for only a few minutes at a time.* Many operators are women and children rather than man. With virtually no measured data from field tests of hand pumps, an average human horsepower output of about 0.10 H.P. (75 watts) appears reasonable.

Assuming a typical mechanical efficiency by the pump of about 60 percent and power output of 0.10 H.P., Equation 3-11 can be rewritten:

$$Q H = 240 \dots\dots\dots (3-12)$$

for Q in U.S. gallons per minute and H in feet of head.

Equation 3-12 provides a "rough and ready" rule of thumb as to the discharge rate which might be expected for a given head. For example, at a head of 60 feet, the discharge rate, Q, would be about 4 gallons per minute.

3.5.3 Animal Power

Although draft animals constitute a common and vital source of power in developing countries, they are not widely used for pumping water for domestic supplies. (They are widely used for pumping irrigation water from large diameter, open, shallow wells in Africa and Asia). Animal power is poorly suited to direct drive of vertically reciprocating well pumps. Animals are most efficiently used at fixed sites when harnessed to pull rotating circular sweeps or by pushing treadmills with their feet. Both methods require gears and slow moving, large displacement pumps. A second factor in pumping drinking water, as described for human power, is that each family generally pumps its own water. The effort to hook up and unhook a draft animal for only a few minutes pumping is generally justified only in deep wells with rope and bucket (of several gallons displacement) pumping.

A 1,500 to 1,900 lb (700 to 850 kg) horse can work up to 10 hours a day at a rate of 1 horsepower (0.746 kw). For short bursts of 5 to 30 minutes

* Hand pumps for irrigation purposes frequently are operated all day by only one or two persons.

a horse can work at about 4 horsepower (3 kw). Animal horsepower for healthy mature specimens can be estimated for other animals in accordance with the relationship (Brody):

$$\text{animal power} = \text{horsepower} (\text{mass of animal/mass of horse})^{0.73} \dots (3-13)$$

3.5.4 Natural Power

Other nonmechanical prime movers include the natural forces of wind, water, sun, gravity, and geothermal heat. Geothermal heat is of course very site specific and is not widely available. Gravity is of course available everywhere and is the first choice, other things being equal; however the reason for this book is that in many instances available water is below rather than above the site where it is needed. Sun powered pumps are available but not economically feasible now or for many years, if ever, to come. Falling water can be used to drive pumps but this too is very site specific. Hydraulic rams are described in Section 2. Of the natural prime movers wind is the most widely used.

3.5.5 Wind Power

Windpowered pumping may be feasible (Golding; Wagner and Lanoix; et al.)

if:

- (1) Winds of at least 5 miles per hour (8 km/hr) are present at least 60 percent of the time;
- (2) The well can be pumped continuously without excessive drawdown;
- (3) Storage is provided, typically for 3 days' demand (or more) to provide for calm periods without wind;
- (4) A clear sweep of wind to the windmill is provided, i.e., the windmill is placed above surrounding obstructions such as trees or buildings within 400 feet (125 meters); the windmill may be set on a 15 to 20 feet (4.5 to 6 meters) tower; and
- (5) Windmill equipment that can operate relatively unattended for long periods of time, six months or more, is available. The driving mechanism should

be covered and provided with an automatic oiling system. Vanes and sail assemblies should be heavily galvanized or protected by epoxy paint.

Direct pumping of water by a windmill requires matching the characteristics of (1) the local wind regime, (2) the windmill, and (3) the pump. Usually this is best accomplished by the manufacturer based on information provided by the purchaser.

By far the commonest type of wind pump is the slow-running wind wheel driving a piston pump. The pump generally is equipped with a pump rod extending through the pump stand assembly and upper guide with a hole for connection with the pump rod from the windmill. Provision may be made for pumping by hand during becalmed periods.

Modern windmills are designed to insure that they automatically turn into the wind for pumping. They are also equipped with a "pull-out" system to automatically turn the wheel out of excessive winds (30 to 35 mph, 48-56 km/hr) that might damage the windmill. The "sails" or fan blades are also automatically furled to prevent the wheel from "running away" (rotating too fast) in high winds. The windmill will not begin pumping until the wind velocity is about 5 or 6 miles per hour (8 to 9.5 km/hr). The rate of pumping then rises with increasing wind speed to about 15 mph (24 km/hr) after which the wheel begins to turn, automatically, out of wind thereby limiting the rate of pumping at higher wind speeds to that corresponding to a 15 mph wind.

The wind wheels range in diameter from about 6 feet to 20 feet (2 meters to 6 meters). Approximate 1975 prices for windmills purchased in the U.S. (shipping costs not included) are: 6-ft, US \$500; 8-ft, US \$700; 10-ft, US \$1200; 12-ft, US \$2000; and 14-ft, US \$3000. A 22-foot (7 meters) steel tower costs about US \$600 to \$700 from the windmill supplier. Even though windmills may be imported, strong towers can be readily constructed using local materials.

If A represents the area swept by the windmill rotor of diameter D, V the wind velocity, and γ_a the specific weight of the air, then the weight W of air per unit of time that is available to power the windwheel is $W = AV\gamma_w$ and its energy is equal to $\frac{W V^2}{2g}$, g being a constant representing gravitational acceleration. The power P brought to the windwheel by the wind is therefore:

$$P = \frac{W V^2}{2g} = \frac{A \gamma_w V^3}{2g} = \frac{\pi D^2 \gamma_w V^3}{8g}$$

The power used to lift water will be less in proportion to the wind to water mechanical efficiency of the entire windmill water pump unit. Golding estimates that this efficiency will rarely exceed 20 percent.

Combining constants including average values of g and γ_w , the actual pumping (brake H.P.) horsepower can be written as:

$$\text{Net Pumping H.P.} = 0.0000052 D^2 V^3 e \dots\dots\dots(3-14)$$

where D is the wind rotor diameter in feet,
V is the wind velocity in miles per hour, and
e is the wind to water mechanical efficiency.

Similarly:

$$\text{Net Pumping K.W.} = 0.0000020 D^2 V^3 e \dots\dots\dots(3-15)$$

where D is the wind rotor diameter in meters,
V is the wind velocity in km per hour, and
e is the wind to water mechanical efficiency.

The discharge Q for a given windwheel diameter and wind velocity would be inversely proportional to the pumping head. Combining Equations 3-14 and 3-11 (the efficiency term in Eq. 3-11 already appears in Eq. 3-14) yields:

$$\text{H.P.} = \frac{QH}{3960} = 0.0000052 D^2 V^3 e$$

or

$$Q = 0.020 \frac{D^2 V^3 e}{H} \dots\dots\dots(3-16)$$

where Q is discharge in U.S. gallons per minute
 D is wind rotor diameter in feet
 V is wind velocity in miles per hour
 H is pumping head in feet, and
 e is wind to water mechanical efficiency.

Similarly:

$$Q = 0.060 \frac{D^2 V^3 e}{H} \dots\dots\dots(3-17)$$

where Q is discharge in liters per minute
 D is wind rotor diameter in meters
 V is wind velocity in km per hour
 H is pumping head in meters, and
 e is wind to water mechanical efficiency.

Table 3-4 gives some illustrative calculations using Golding's estimated value of e of 20 percent.

Table 3-4 demonstrates the sensitivity of discharge to wind velocity: $Q \sim V^3$. Although the short-term discharge can be estimated readily, the long term discharge and the storage required during periods without wind can be estimated only if the wind regime at the site can be predicted. This includes not only the frequency and velocity of various winds but their duration as well over the entire year.

3.5.6 Mechanical Jacks

Hand powered reciprocating pumps can be readily converted to pumping with electric motors or gasoline engines using mechanical jacks. Good quality geared jacks with long life expectancy and for use with ½-horsepower motors can be purchased for US \$150 to \$200. These are especially useful in pump testing programs.

3.6 HANDLE ASSEMBLY

The handle serves to transmit motion and energy from the hand pump operator to the pump. Although the lever type handle shown in Figure 3-1 is most

TABLE 3-4

WINDMILL PUMPING RATES SHOWING DISCHARGE IN U.S. GALLONS PER MINUTE (LITERS PER MINUTE)

WIND VELOCITY	HEAD = 50 Feet (15 Meters) WINDMILL DIAMETER			HEAD = 100 Feet (30.5 Meters) WINDMILL DIAMETER		
	6 Ft (2M)	8 Ft (2.5M)	10 Ft (3M)	6 Ft (2M)	8 Ft (2.5M)	10 Ft (3M)
Mph (km/hr)						
5 (8.1)	0.4 (1.4)	0.7 (2.7)	1.0 (3.9)	0.2 (0.7)	0.3 (1.3)	0.5 (2.5)
7 (11.3)	1.0 (3.8)	1.8 (6.8)	2.8 (11)	0.5 (1.9)	0.9 (3.4)	1.4 (5.5)
10 (16.1)	3.0 (11)	5.2 (20)	8.2 (31)	1.5 (5.6)	2.6 (9.9)	4.1 (15)
12 (19.3)	5.0 (20)	8.8 (24)	14 (53)	2.5 (9.7)	4.4 (12)	7.0 (26)
14 (22.6)	7.9 (31)	14 (53)	22 (85)	4.0 (15)	7.2 (26)	11 (42)
16 (25.8)	12 (46)	21 (80)	33 (125)	5.9 (23)	11 (40)	16 (62)

Note: Wind to water efficiency assumed to be 20 percent.

Metric units shown in parentheses.

common, other means can be used including wheels and crankshafts, foot treadles, and pump jacks.

3.6.1 Mechanical Advantage

The pump rod force necessary to raise the pump plunger in a reciprocating hand pump can easily exceed the muscular strength of the pump operator. However as shown in Section 3.4.2 and Figure 3-6, the downward handle force necessary to raise the pump rod can be reduced by the mechanical advantage (MA) of the handle in accordance with Equation 3-6.

$$F_h = F_p \frac{L_p}{L_h} = \frac{F_p}{MA} \dots\dots\dots(3-6)$$

- where F_h = force exerted on handle by operator's hand
- F_p = force exerted on handle by pump rod
- L_p = distance from center of pump rod pin to center of fulcrum pin
- L_h = distance from center of fulcrum pin to "center" of operator's hand

and MA = mechanical advantage of handle.

A typical mechanical advantage for a shallow well pump is about 4 to 1. That is a pump rod force can be balanced by a handle force about one quarter as large. In deep wells the mechanical advantage may be larger, even 10 to 1.

The mechanical advantage cannot be increased without limit. As Figure 3-7 illustrates, as the distance L_h from the fulcrum to the hand is increased, the arc ab swept by the end of the handle increases. Too large an arc makes for difficult operation. Decreasing the pump rod to fulcrum distance L_p increases the mechanical advantage but it simultaneously decreases the stroke length S of the pump rod and its attached plunger.

3.6.2 Linkage

Figure 3-7 illustrates the simplest type of handle mechanism: a one piece handle with two connecting pins, one at the pump rod, the other at the fulcrum. This is a common arrangement for shallow well pumps.

Note in Figure 3-7 that the arc cd swept by the pump rod pin defines the vertical distance, S , equivalent to the plunger stroke length, and a horizontal distance, Z . That is, the top of the pump rod moves horizontally as well as vertically. Because the drop pipe (See Figure 3-1) and the pump cylinder are fixed in place, the lower end of the pump rod (attached to the plunger), although free to move vertically is not free to move horizontally. Thus if Z is too large the pump rod will strike the drop pipe (or the pump stand wall, depending on relative dimensions). A second problem is that the horizontal movement of the pump rod makes sealing the top of the pump stand assembly against contamination difficult. A third problem is that the resulting angular tilting of the plunger may cause excessive wearing of the plunger cup seals. A fourth problem, related to the second above, is that the top of the pump must be sealed for force pumps.

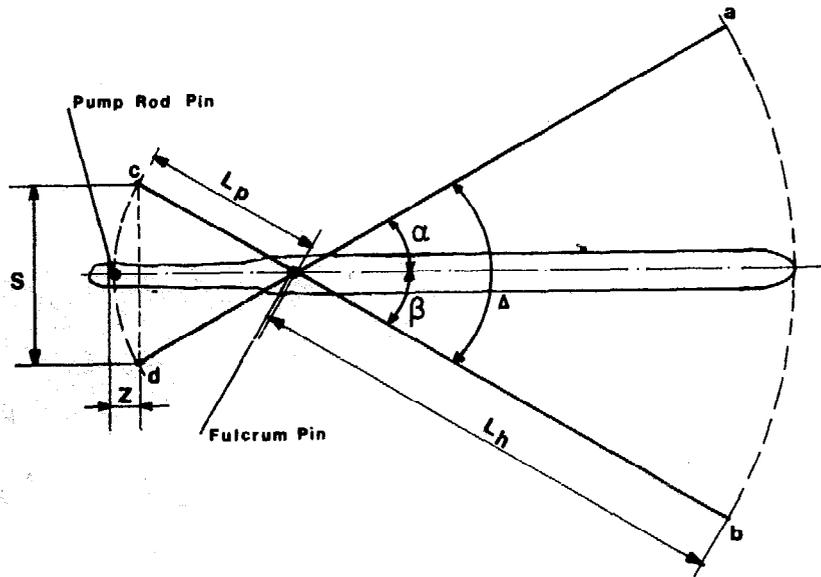


FIGURE 3-7 HANDLE GEOMETRY

Figure 3-8 sums up several common hand pump handle to pump rod linkage mechanisms that are used to insure operation of the pump rod solely in the vertical plane.

Pump A uses two movable and one fixed pin, a rotating fulcrum link, and a stuffing box as a pump rod guide. This system is used in such pumps as the Dempster 23EX and the Godwin HLS and HLD models. This is an economical solution but in deep wells, the stuffing box may wear excessively and bending stresses may be created in the pump rod.

Pump B also uses two movable and one fixed pin and a rotating fulcrum link. Although a stuffing box is used, the pump rod is guided by a cross-head over two guide pillars. Examples include the Wasp and the Beatty pumps. Alignment of the components is critical to avoid binding.

Pump C is a single pillared version of Pump B. The single pillar may also appear on the handle side of the pump rod. The Baker "Monitor" is an example.

Pump D also uses two movable and one fixed pin, but with a fixed fulcrum. The stuffing box is used as a pump rod guide. Examples include EDECO and the NWSA.

Pump E uses only one conventional pin, as the fulcrum. The handle is attached to the pump rod by a short length of flexible motorcycle chain. Gravity, combined with a circular quadrant welded to the end of the handle is used to insure true vertical motion. This pump will work only in wells deep enough and/or at speeds slow enough to allow the downstroke to occur by gravity. ("You can't push a string.") Examples include the Sholapur and Jalna-types found in India.

Pump F uses a two movable, one fixed pin lever with two connecting arms to a pump rod puller pipe installed concentrically over the pump rod. The Uganda and Shinyanga pumps are examples. (See Figures 3-11 and 6-3).

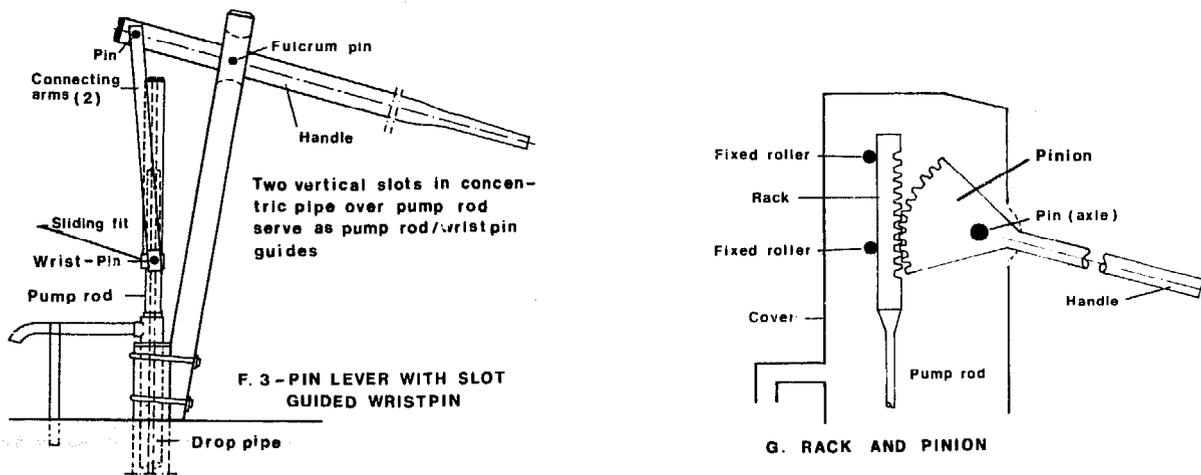
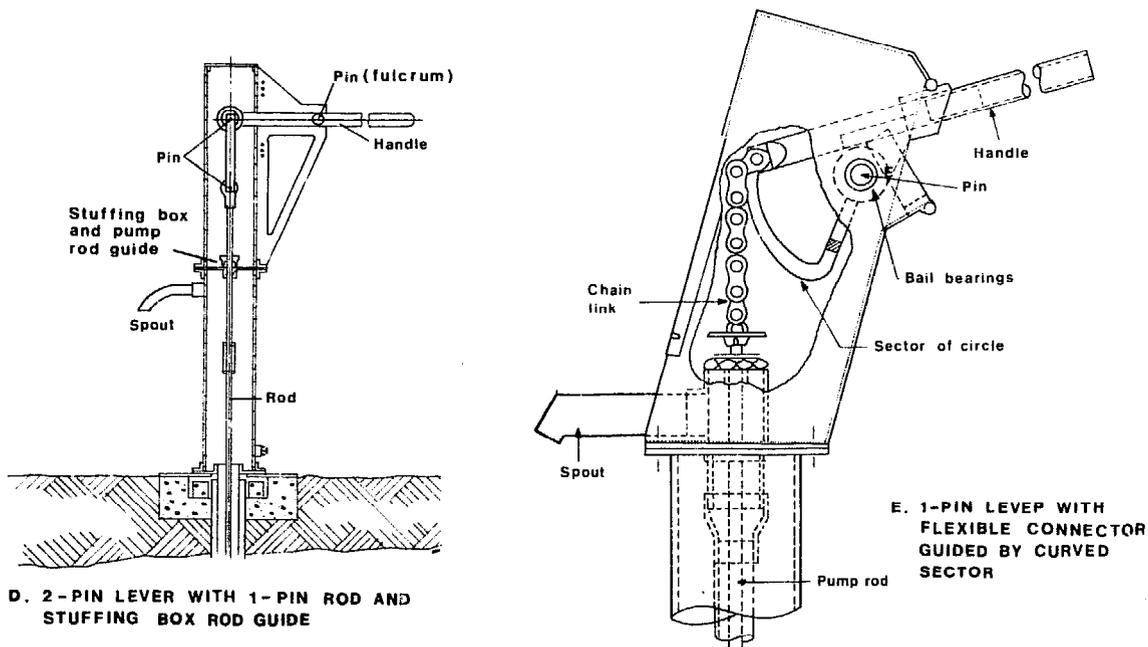
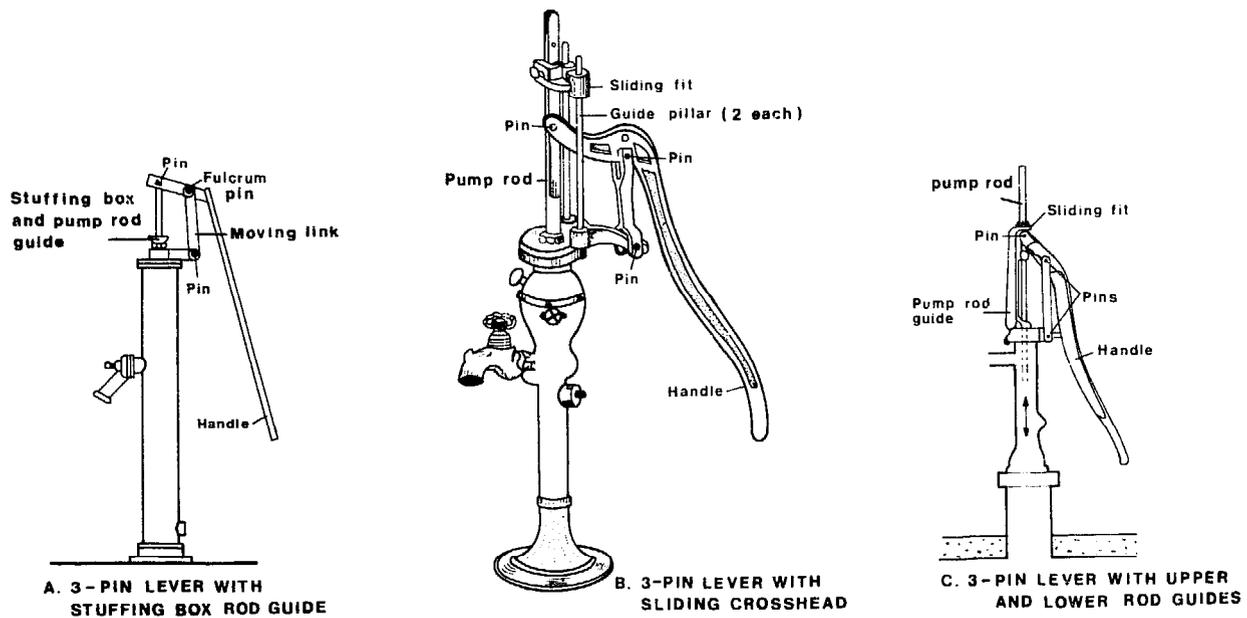
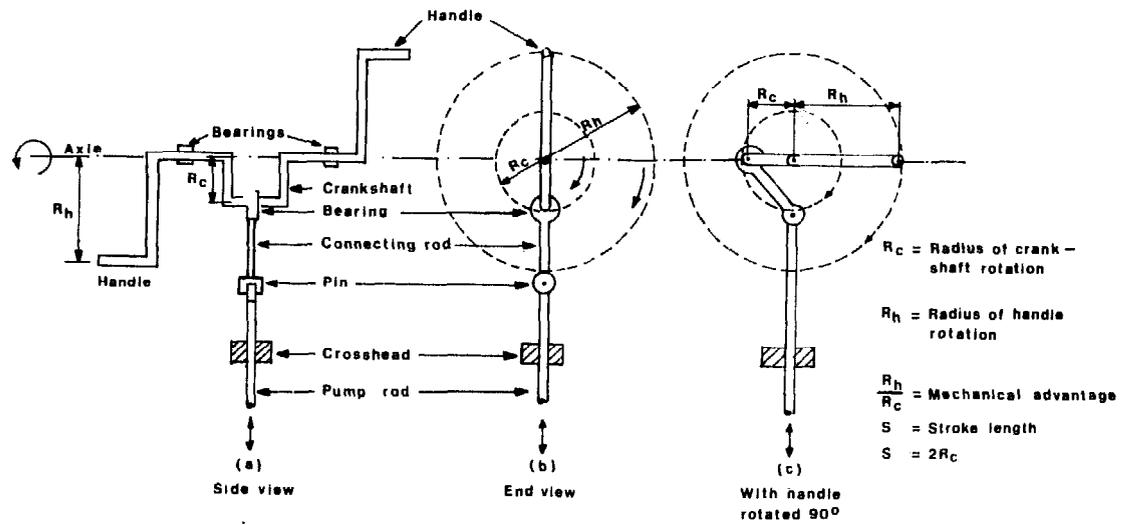


FIGURE 3-8 LEVER AND LINKAGE MECHANISMS FOR VERTICAL OPERATION OF PUMP RODS WITHOUT LATERAL MOVEMENT



TYPICAL IN-LINE SLIDER CRANK MECHANISM

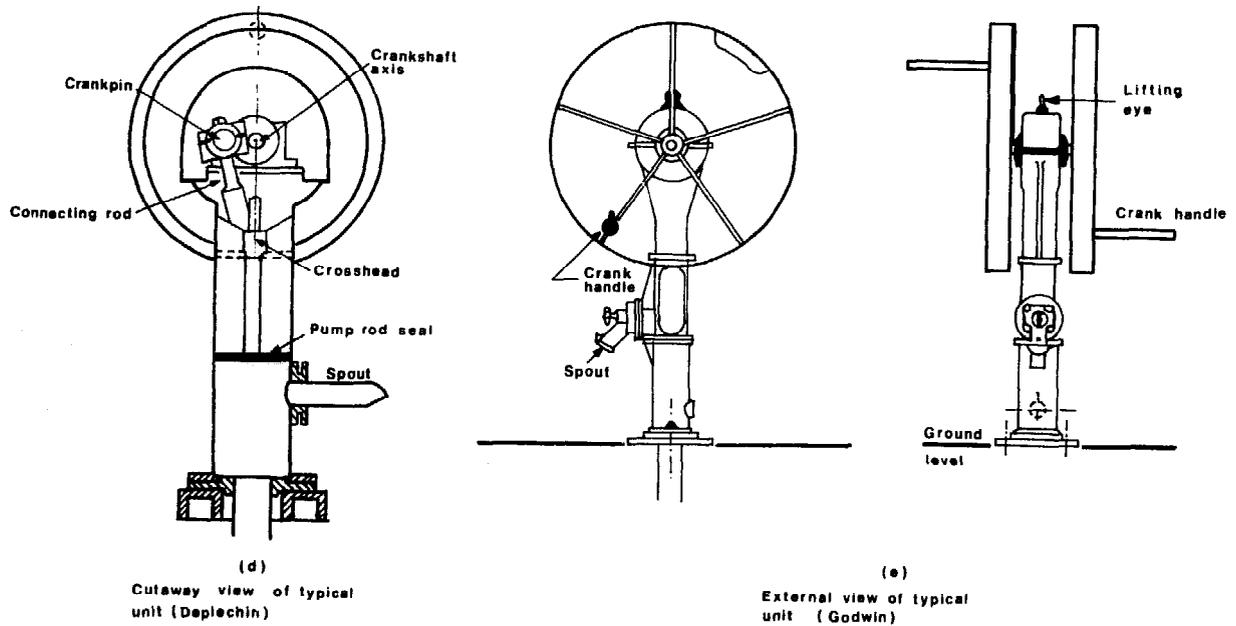


FIGURE 3-9 EXAMPLES OF ROTARY CRANK AND WHEEL OPERATED RECIPROCATING HAND PUMPS

Pump G uses a rack and pinion arrangement. The pinion sector rotates on the fulcrum or axle pin causing the rack to move up and down against two fixed rollers. Examples include the Korat 608 and the Stewart and Lloyd 103D. Rack and pinion pump drives are available in two handled versions in which the rack is "toothed" on opposing sides.

Figure 3-9 illustrates for rotary crank or wheel operated hand pumps how the pump rod motion can be restricted to the vertical plane. For these pumps, the lower end of the rod or link connecting the crankshaft to the pump rod is restricted to the vertical plane by the crosshead while the upper end of the connecting rod is free to follow the rotating crankshaft. Bearings are used at each point of relative motion between components. The mechanism shown, the rotating in line slider crank, is perhaps the most common in use for rotating rather than reciprocating handles.

The mechanisms shown are intended to eliminate lateral movement by the pump rod. In doing so most of them introduce lateral stresses to the top of the pump rod. These stresses are increased with poor alignment, poor lubrication, and poor maintenance. Rotating handles, generally more costly, usually distribute the lateral forces more uniformly with lower maximum stresses. The kinetic energy stored in the wheel usually makes operation easier.

3.6.3 Human Engineering

The height, length, and travel arc of the handle are important to the comfort, convenience, and efficiency of the pump operator. A long handle may have a high mechanical advantage but the operator may not be able to raise or lower it sufficiently to use the full length of the plunger stroke. It may also be cumbersome to work.

For a three foot (0.914 meter) handle with a mechanical advantage of 5 to 1, moved through an arc of 90° (one fourth of a circle) the hand would travel four feet (1.22 meters) and the plunger stroke of the pump would be

about 8 inches (19.3 cm)'. (In Figure 3-7, arc length $ab = 2\pi L_h \left[\frac{\alpha + \beta}{360^\circ} \right]$)

The suitability of these dimensions is largely determined by human factors - anthropometric, ergonomic, and psychological. Field measurements under varying conditions are scanty. Modern time and motion concepts (for example, see Barnes; Brouha; Kauger and Bayha; Maynard; et al.) make possible a few generalizations:

- (1) Dimensions of hand pump handle assemblies should be based on the size of the pump operators; not the mean size but the size of the smaller operators, e.g., women or children. Where more than one hand pump is installed at a single site, their handle heights should be varied.
- (2) Dimensions should avoid severe disturbance of body posture while pumping. Physical efficiency in a stooped position is less than half that of a normal position.
- (3) Within certain limits, heartbeat and respiration show a linear relationship with energy expenditures or performed work. Heartbeat is readily measured through pulse rate. In assessing the efficiency of two pumps (or the same pump with differing handle heights or lengths), their discharge (Q) and head (H) being equal, the pump for which the operator's pulse rate rises least will be the more efficient. A pulse rate rise of about 30 beats per minute above the resting pulse rate is about the optimum limit of performance for long term pumping.
- (4) Optimal muscular efficiency occurs when the force being exerted is about one-half its maximum value and the speed of movement about one-fourth its maximum value (Wilkie).
- (5) For wells with very deep lifts, provision should be made for pumping with both hands and/or by more than one person. Short term work output can be increased by a third to a half using two hands instead of one. Rotating wheel-type handles are easily operated in such a manner.

The importance of handle dimensions and loadings for hand pumps is often disguised by the marvelous adaptive abilities of their human operators. Load too heavy? The operator pumps more slowly. Handle too long? The operator shortens the stroke. Nevertheless judicious selection of handle dimensions can be an important factor in acceptability of the hand pump to its user. Tradition and esthetic appearance may also be important.

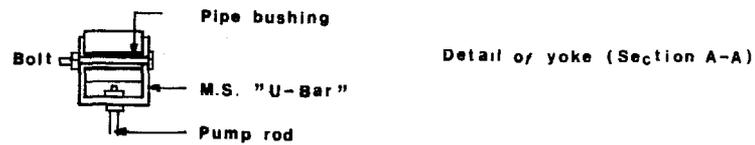
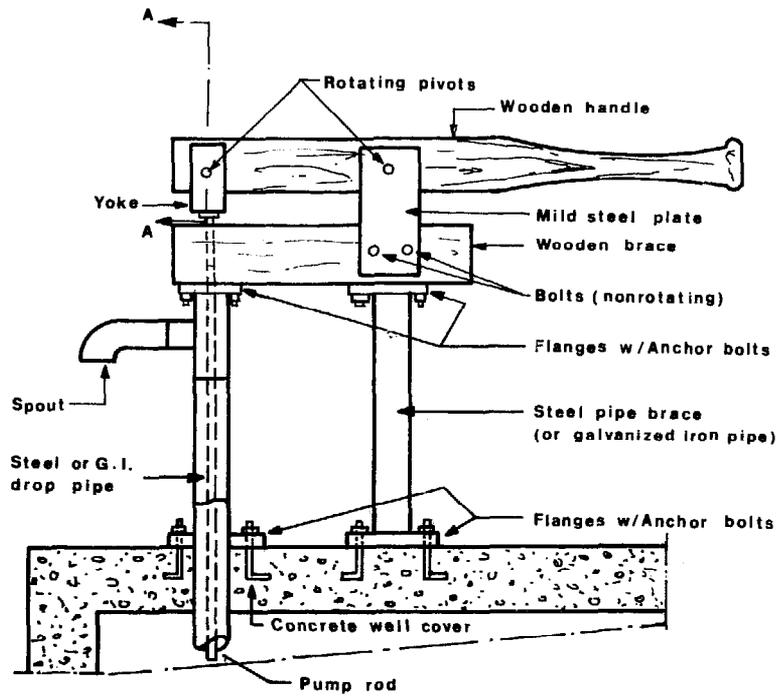


FIGURE 3-10 INDIGENOUS HAND PUMP STAND AND HANDLE DEVELOPED BY CARE/TUNISIA

3.6.4 Structural Loading of the Handle

The structural load exerted on the handle by the pump rod, F_p , is created by the hydraulic and gravitational forces described earlier in Section 3.4. To this must be added the force exerted by the hand of the operator, F_h . These two downward forces, as shown in Figure 3-11, are resisted by the fulcrum. The force on the handle at the fulcrum, $F_f = F_p + F_h$. The handle is structurally speaking, a beam attached to the fulcrum by a pin and loaded at each end. Such a beam may fail from tensile, compressive or shearing stresses. The most frequent failure observed in the field is generally through bending over the fulcrum.

This is a standard structural design problem and formulas and tables are readily available (e.g., see Baumeister). Generally the strongest design for the same cross-sectional area (weight) will be one with an I-shaped cross section with its web strengthened around all pin holes. Design should be conservative; many field failures are the result of shocks or blows in transit, poor quality manufacture including incipient cracks and fractures, and to failure due to brittleness of the material used, especially cast iron.

Many otherwise metal pumps use wooden handles - for example the Uganda pump of East Africa shown in Figure 3-12. CARE and the Tunisian Ministry of Public Health have developed a pump stand assembly with a wooden handle, which is locally assembled for U.S. \$62 (as of 1976). (See Figure 3-10). Both these pumps have good operational records for wells of moderate depth. Wooden handles have several potential advantages: possible cost savings, especially for long-handled deep well pumps; suitability for local repair or replacement; and wear at pivot points may be on the softer handle rather than on more expensive, difficult to replace metal pins.

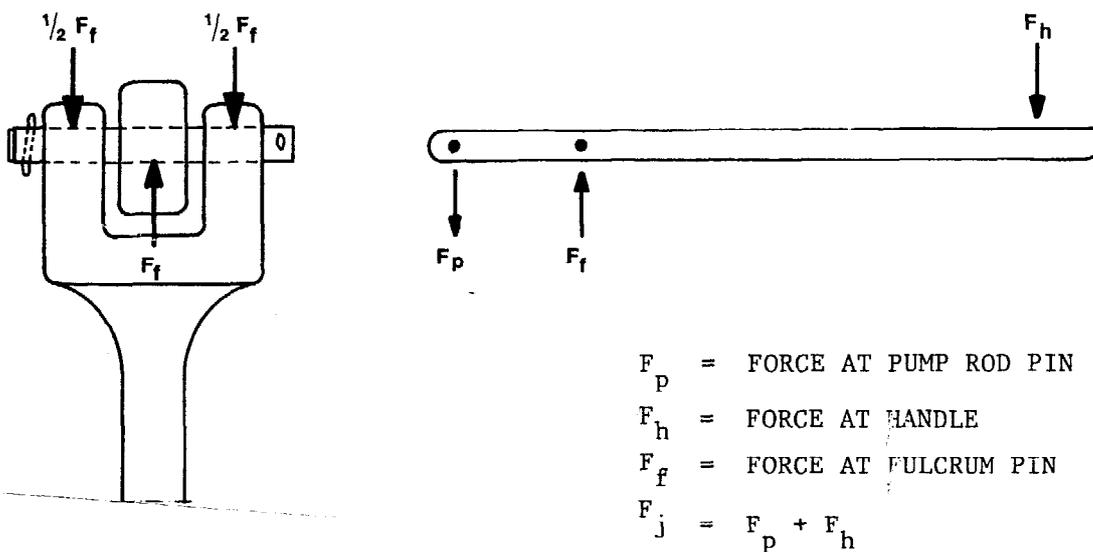


FIGURE 3-11 FORCES AT FULCRUM

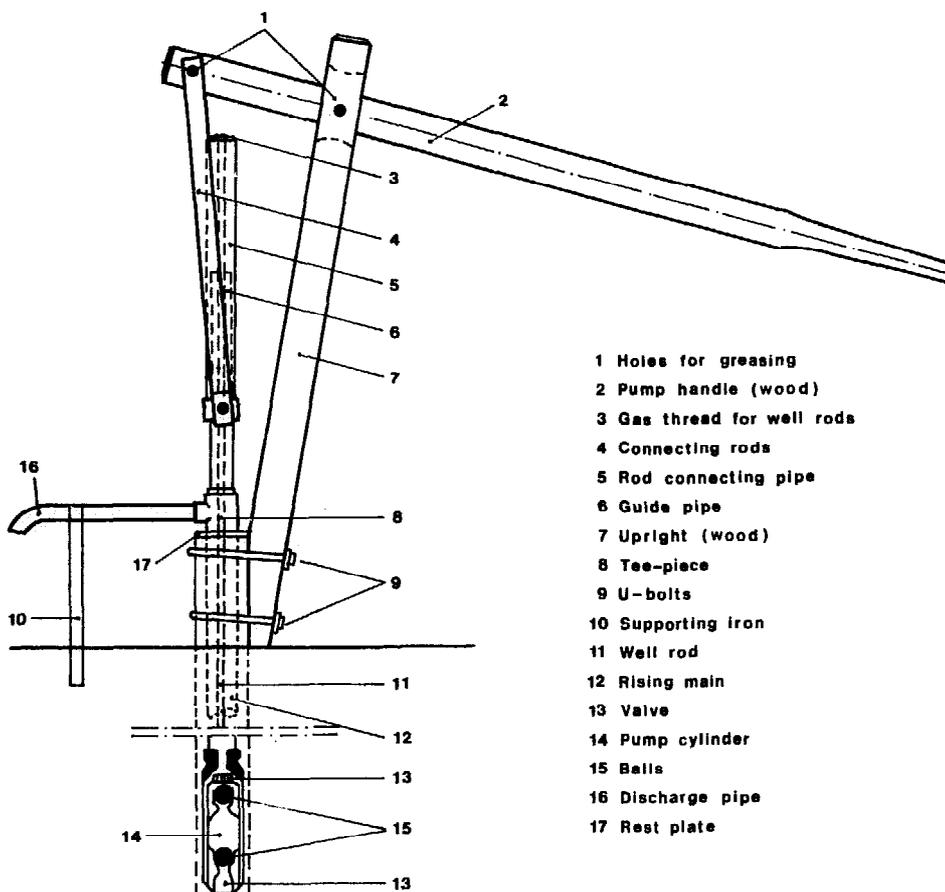


FIGURE 3-12 "KENYA" HAND PUMP (DEEP WELL TYPE)
(Previously "Uganda" Hand Pump)

3.7 CONNECTIONS, PINS AND BEARINGS

Pinned connecting joints are a common source of pump failures due to (1) poor design, (2) poor quality of manufacture, (3) poor maintenance, especially inadequate lubrication, and (4) vandalism and pilferage. Hand pumps have from one to five or more such connections each. (See Figures 3-8 and 3-9).

3.7.1 Bearings

Connector failures due to poor design are most often the result of overstressed pin bearings or journals, that is, bearings that are too small for their imposed loads. The most common (and least expensive) type of bearing used in hand pumps is the plain journal or sleeve bearing illustrated in Figure 3-13. The diameter D and length L of the bearing depend on the magnitude of the radial load F and the allowable bearing pressure P for the combination of materials used in the bearing and journal. Or summarizing for any system of appropriate units, the bearing pressure P for a plain bearing is:

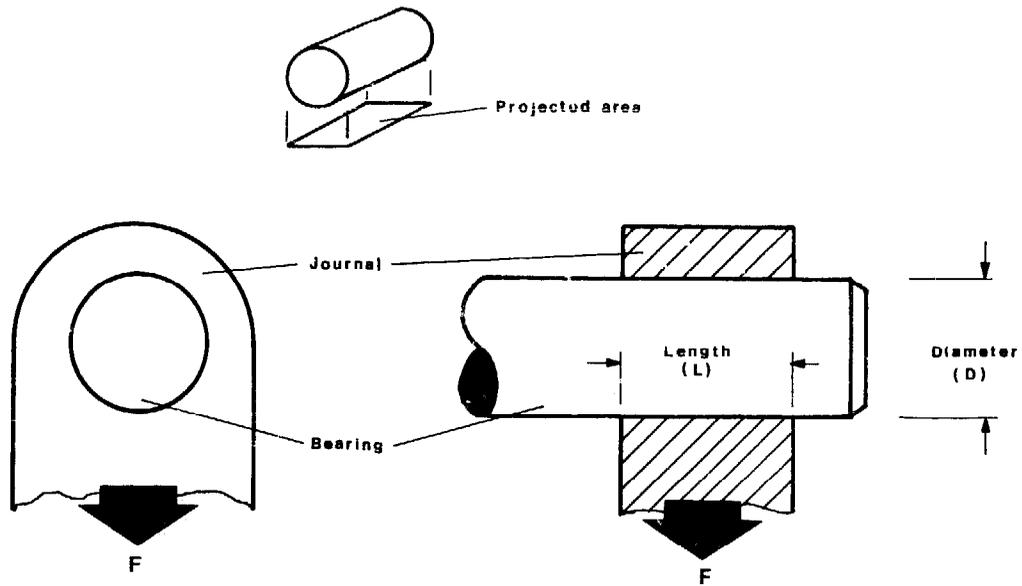
$$P = \frac{F}{LD} \dots\dots\dots(3-18)$$

where P is the bearing pressure
 F is the radial force or load
 L is the length of the bearing
and D is the diameter of the bearing

For steel or cast iron bearings in cast iron journals the bearing pressure should not exceed 100 pounds per square inch, psi (70 kg/cm^2). For steel on hardwood, not more than 30 psi (20 kg/cm^2).

Example: Given a cast iron hand pump with a simple two-pin, single piece handle (similar to Figure 3-6). The force F_p at the pump rod pin is 150 lb (68 kg) and the mechanical advantage of the one-inch x three-inch (25mm x 76mm) cast iron handle is 4 to 1. The allowable bearing pressure is 100 psi (70 kg/cm^2). Find the appropriate dimensions of the two steel bearings in the fulcrum and the two bearings (at pump rod pin and at fulcrum pin) of the pump handle (See Figure 3-10).

BEARING LOADING



F = RADIAL LOAD

P = BEARING PRESSURE

PROJECTED AREA = L D

BEARING PRESSURE = LOAD PER UNIT PROJECTED AREA

OR

$$P = \frac{F}{L D}$$

FIGURE 3-13 CALCULATION OF BEARING PRESSURE FOR PLAIN BEARINGS

Solution: Given pump rod force $F_p = 150$ lb

Handle force $F_h = F_p \div MA = 150/4 = 37.5$ lb

Fulcrum force (handle) $F_f = F_p + F_h = 150 + 37.5 = 187.5$ lb

Fulcrum force (each side of handle) $\frac{1}{2} F_f = 187.5 = 93.8$ lb

$$P = \frac{F}{LD} \quad \text{or} \quad LD = \frac{F}{P}, \quad P \leq 100 \text{ psi for steel on cast iron}$$

$$\text{and } L_p D_p = \frac{F_p}{P} = \frac{150 \text{ lb}}{100 \text{ psi}} = 1.5 \text{ sq in}$$

$$L_f D_f = \frac{F_f}{P} = \frac{187.5 \text{ lb}}{100 \text{ psi}} = 1.88 \text{ sq in}$$

$$L_{\frac{1}{2}f} D_{\frac{1}{2}f} = \frac{\frac{1}{2} F_f}{P} = \frac{93.8}{100} = 0.94 \text{ sq in}$$

The width of the handle is given as 1.00 inch (25mm),

thereby $L_p = L_f = 1.00$ in

$$\text{and } D_p = \frac{L_p D_p}{L_p} = \frac{1.5 \text{ sq in}}{1.00 \text{ sq in}} = 1.5 \text{ in}$$

$$\text{and } D_f = \frac{L_f D_f}{L_f} = \frac{1.88 \text{ sq in}}{1.00 \text{ sq in}} = 1.88 \text{ in}$$

Rounding to standard size pin, $D_f = 2$ in

To minimize number of pin sizes to be stocked, $D_p = 2$ in also, and

$$L_{\frac{1}{2}f} = \frac{L_{\frac{1}{2}f} D_{\frac{1}{2}f}}{D_f} = \frac{0.94 \text{ sq in}}{2 \text{ in}} = 0.47, \text{ say } \frac{1}{2}\text{-inch.}$$

Example: Given the same hand pump, but with all pins of one-inch (25 mm) diameter, what is the maximum bearing pressure?

Solution: From the above problem, the greatest bearing stress will be at the fulcrum pin:

$$P = \frac{F_f}{L_f D_f} = \frac{187.5 \text{ lb}}{(1.00 \text{ in})(1.00 \text{ in})} = 187.5 \text{ psi}$$

Note: (1) The journal holes cut into the handle, if too large, could result in overstressing the handle. Handle stresses at the journal can be reduced by thickening or deepening the handle (typically by adding a boss or fillet) at journals.

(2) For grease-lubricated bearings, long bearings (defined as bearings for which the ratio L/D is greater than one) are generally preferred for their better retention of the lubricant. Redesign of the pump handle as suggested in note (1) would also make this possible.

Design of journal bearings for modern high-speed machinery has a strong scientific basis based on hydrodynamic oil film lubrication between closely fitted - but non-contacting - moving parts. The bearing rests on an oil film, not the journal and the resistance to motion is due to the viscosity of the interposed lubricant, the speed, and the load.

Journal bearings in the great majority of today's hand pumps are not hydrodynamically lubricated but operate with continuous contact between bearing and journal under conditions of marginal or boundary lubrication. Marginal lubrication in hand pump bearings is due to:

(1) Relatively large loose running clearance fits between the bearing shaft and the journal hole. For hand pumps, clearance of 1/32-inch (0.8mm) are often allowed for bearings, ten or more times larger than that needed for boundary lubrication. This recognizes the greater cost of closer fits, tolerances, and allowances and the inability of many hand pump manufacturers to meet more rigid manufacturing standards.

(2) Related to the above is the necessity to be able to assemble and interchange parts and components in the plant and in the field. Examination of Figure 3-10 demonstrates that the centerline axis of three journals must line up at right angles to the pump axis for the pin to fit through the fulcrum. In some designs (which should be discouraged), the fulcrum pin must go through two additional holes in the pump cap - making five holes in all.

(3) The relatively rough surfaces of the journal and/or the bearing which may have surface irregularities higher than the thickness of oil film. The asperities disrupt the oil film and rub on one another, separated by oil films only one or two molecular layers thick. Friction and thereby heat and wear are increased.

(4) The oscillating slow speed of hand pumps is counterproductive to formation of the oil film under the best of conditions.

(5) Inadequate lubrication including not only inadequate frequency but poor choice or quality of lubricant.

Under boundary lubrication, bearing and journal are in partial contact and selection of the two materials can be critical. Table 3-5 lists coefficients of friction for several materials used in hand pumps. The importance of lubrication is readily seen.

With marginal lubrication, materials should be selected to resist wear and to provide a low coefficient of friction. Normally, use of like materials against each other results in excessive wear. Cast iron and steel are exceptions

TABLE 3-5

COEFFICIENTS OF SLIDING FRICTION

MATERIALS	COEFFICIENT OF SLIDING FRICTION	
	Dry	Greasy
Hard steel on hard steel	0.42	0.029
Hard steel on babbitt (ASTM No. 1)	0.33	0.16
Mild steel on mild steel	0.57	0.09
Mild steel on cast iron	0.23	0.133
Brass on cast iron	0.30	--
Bronze on cast iron	0.22	0.077
Cast iron on cast iron	0.15	0.070
Cast iron on oak	0.49	0.075
Leather on cast iron	0.56	0.36 (water)
	--	0.13 (oil)
Laminated plastic on steel	0.35	0.05
Fluted rubber bearing on steel	--	0.05
Hemp or cotton stuffing box packing	--	0.06 to 0.11

After Fuller.

however, particularly if they are of differing hardness.* Other things being equal, harder materials are preferable. Other desirable properties include ability to absorb oil; sufficient plasticity to conform to slight irregularities and to resist scoring; structural strength; corrosion resistance; fatigue resistance; high thermal conductivity, antiseize properties, and of course, low cost. No one journal bearing will ever have all these characteristics, hence the designer must choose materials which best meet the most important requirements: durability; strength; favorable cost.

Bearing materials in addition to steel and cast iron include babbitts, bronzes, and other metal alloys and various nonmetallics such as wood, plastics,

* Brinell hardness for either journal or bearing should be at least 150.

including nylon, flourocarbons (Teflon), and epoxies and epoxy-filled fabrics, rubber, and stone. The metal alloys are used as journal bushings (liners) and generally require close fits, require special tools for field replacement, and are more expensive than steel or cast iron counterparts. (See Table 3-6). With the possible exception of wood, the nonmetallics are not much used in hand pumps. Nylon bushings are available on one widely marketed pump but have a mixed performance record. Many pumps use wooden handles but in most the "journals" have metal pipe liners. Several of these materials are self-lubricating or amenable to use of long-lasting solid lubricants.

Journal bearings must overcome sliding friction. Another category of bearings, termed antifriction bearings, rotate against rolling friction. A common example is the ball bearing used with vehicle shafts. These bearings, usually made of steel, are manufactured by specialist firms. They have relatively low friction, low wear, and are long lived. They are relatively more expensive (see Table 3-6), require close fits and tolerances, require special tools for installation and replacement, and lubrication is mandatory although if properly sealed they will run for months without relubrication. Ball or roller bearings are invariably used in expensive pumps such as shown in Figure 3-9(e).

With the possible exception of wear of the cylinder cup seals, failures of the bearings of the handle and pump stand assembly are the most frequent causes of hand pump operating breakdowns. Yet they are inexpensive relative to other pump components. Improvement of the bearings in existing pump models, even if only to make them bigger, is frequently the single most cost effective improvement that can be made. Closer fits, better lubrication (possibly including oil seals, grease cups, oil wicks and baths, grooved bearings, and other features rarely seen on hand pumps), and flame hardening of cast iron journals (by heating to a cherry red and quenching in water) are promising measures.

TABLE 3-6

COSTS OF SPECIALIZED BEARINGS PURCHASED FROM BEARING MANUFACTURERS

TYPE OF BEARING	DIMENSIONS (Inches)	COST PER EACH (U.S. Dollars)
JOURNAL BEARINGS WITH BUSHINGS		
Oil Impregnated	0.627 ID 0.878 OD 3/4 Long	U.S. \$0.33
Bronze	5/8 ID 7/8 OD 3/4 Long	U.S. \$0.60
Teflon Composition	0.630 ID 0.876 OD 3/4 Long	U.S. \$1.14
Black Nylon	5/8 ID 3/4 OD 3/4 Long	U.S. \$0.14
ANTIFRICTION BEARINGS		
Ball Bearing (Precision)	5/8 ID 1 1/4 OD 1/2 Wide	U.S. \$3.31
Ball Bearing (Unground)	5/8 ID 1 5/8 OD 1/2 Wide	U.S. \$0.86
Needle Bearings	5/8 ID 1 3/16 OD 3/4 Wide	U.S. \$0.92
<p>Note: Prices are in lots of 500 at U.S. factories as of July 1976.</p> <p>Source: R.D. Fannon, Jr. (Personal communication)</p>		

3.7.2 Pins

The all too common practice of using short length of steel reinforcing bars for pins is obviously self-destructive. Pins should be smooth and hard, preferably of austenitic or pearlitic carbon steels. Standard size pins can be obtained with surface treatments to reduce wear. However the pins generally should wear rather than their journals. Pins are more easily replaced than handles, fulcrums, links, and pump rod connectors.

3.7.3 Fasteners

There are two schools of thought in regard to hand pump fasteners - threaded fasteners and pinned fasteners.

Threaded bolts and nuts are often available in standard sizes, often cheaper, and more readily restocked and replaced than pins. However thread quality is often poor and the threaded fasteners can be used for other purposes increasing the risk of pilferage.

Unthreaded pins held in place by heavy cotter pins are less susceptible to pilferage and avoid the problems of poor threads. Spring clip pins, removable only with special tools, can eliminate pilferage and vandalism of fasteners altogether. Pins held in place by threaded setscrews are generally unreliable.

Fasteners, particularly those attached to the pump rod, should not come loose while in use. A locknut can be used to advantage as a safety factor.

Types of locknuts include:

(1) Jam nut - a thin nut used on a threaded male bolt or rod under a full nut.

(2) Slotted nut - a nut with a radial slot to receive a cotter pin which passes through a diametral hole drilled in the bolt or rod.

(3) Free-spinning locknut - a nut that turns freely on a male threaded bolt or rod until it seats against a base surface; further tightening then produces a locking action through a spring or beam action in the nut causing the upper threaded section of the nut to bend inward and grip the bolt under pressure.

(4) Prevailing-torque locknuts - a nut with one of several types of action: deformation of an elastic insert, or upset threads on the nut, etc.

Locknuts can also be used to prevent rotation of the pins in the handle, a feature which may result in wear of the pin rather than the less easily replaced handle assembly. Rotation of pins can be prevented by projections ("ears") or ridges cast on the outside face or boss of one journal.

3.8 PUMP STAND (Standard, Barrell, Head, Hydrant, Pump Body, Column)

3.8.1 Functions

The pump stand has several functions which affect its design:

(1) Through its base it aligns and fixes the pump to the well. The pump stand base, which may or may not be an integral component of the stand, is attached to the well through a threaded connection with the well casing or by anchor bolts with the concrete foundation apron. Threads and anchor bolts must be dimensionally compatible. Thread engagement should be at least 2 inches (5 cm). In either system the well casing should protrude at least 2 inches (5 cm) above the foundation to prevent sullage water from entering the well.

(2) It provides a platform of convenient height for the pump handle assembly and, in particular, for the fulcrum which is often cast integrally with or welded or bolted to the pump stand. Sharp interior corners, notches, grooves, and cracks where the fulcrum meets the pump stand or pump cap may concentrate stresses and result in structural failure of the fulcrum. For pumps with very long handles or with pump stands made of plastic materials, the fulcrum may be separately anchored and not attached to the pump stand.

(3) It provides a platform for suspension of the drop pipe and of the pump rod/cylinder/plunger/valve assemblies. The drop pipe is usually attached to the pump stand by pipe threads. The pump rod and its appendages hang from the handle/pump rod pin. (Wrist pin in rotating handles). All the forces previously described tend to compress and/or tilt the pump stand.

(4) It provides sanitary protection for the well and the water, physically protecting both from external contamination at the top of the well - if properly designed and installed and equipped with a closed cap or top. (Open top "pitcher" pumps are inadequate protection). The stand and its spout (spigot) provide a water conduit from the drop pipe to the user's container.

(5) For many shallow well pumps, the pump stand also serves as the pumping cylinder. Machining, honing, or lining of the interior surface is usually essential to prevent excessive wear. Use of the same pump stand for both shallow well and deep well pumps is possible (an example is the AID/Battelle pump).

3.8.2 Pump Spout (Spigot, Faucet, Hydrant, Outlet)

The spout should be designed to prevent contamination, willful or accidental, of the well and to be dimensionally compatible with the pump users'

containers. Protection against contamination usually takes advantage of gravity - the opening is down, the spout slopes away (or is flat) from the pump stand. Occasionally a screen is inserted in the spout.

The spout discharge must be high enough above the well platform and far enough from the pump stand to provide clearance for the water containers in predominant use locally. Excessive height may make filling containers difficult during high winds. Windy sites may require wing walls around the spout. Use and dimensions of animal carried containers should be noted where appropriate. The spout should be structurally strong enough to support the weight of the largest full container which might be rested on or suspended from it.

Spouts used with force pumps should generally be valved and threaded. Some pump stands for force pumps are equipped with two spout connections.

3.8.3 Other Considerations

The pump stand must be a robust, durable structure capable of withstanding the continuous use and abuse of community life over many years. Most hand pumps are also fully exposed to the weather.* Their design is generally based more on manufacturing constraints than on detailed structural analysis. Pump stand failures are most often due to use of poor quality materials or to poor fabrication or foundry practices.

3.9 PUMP CAP (Cover, Cap, Ring, Top)

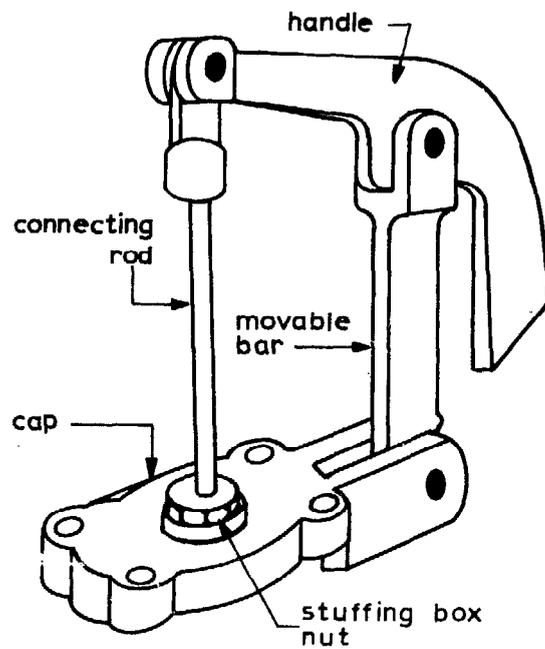
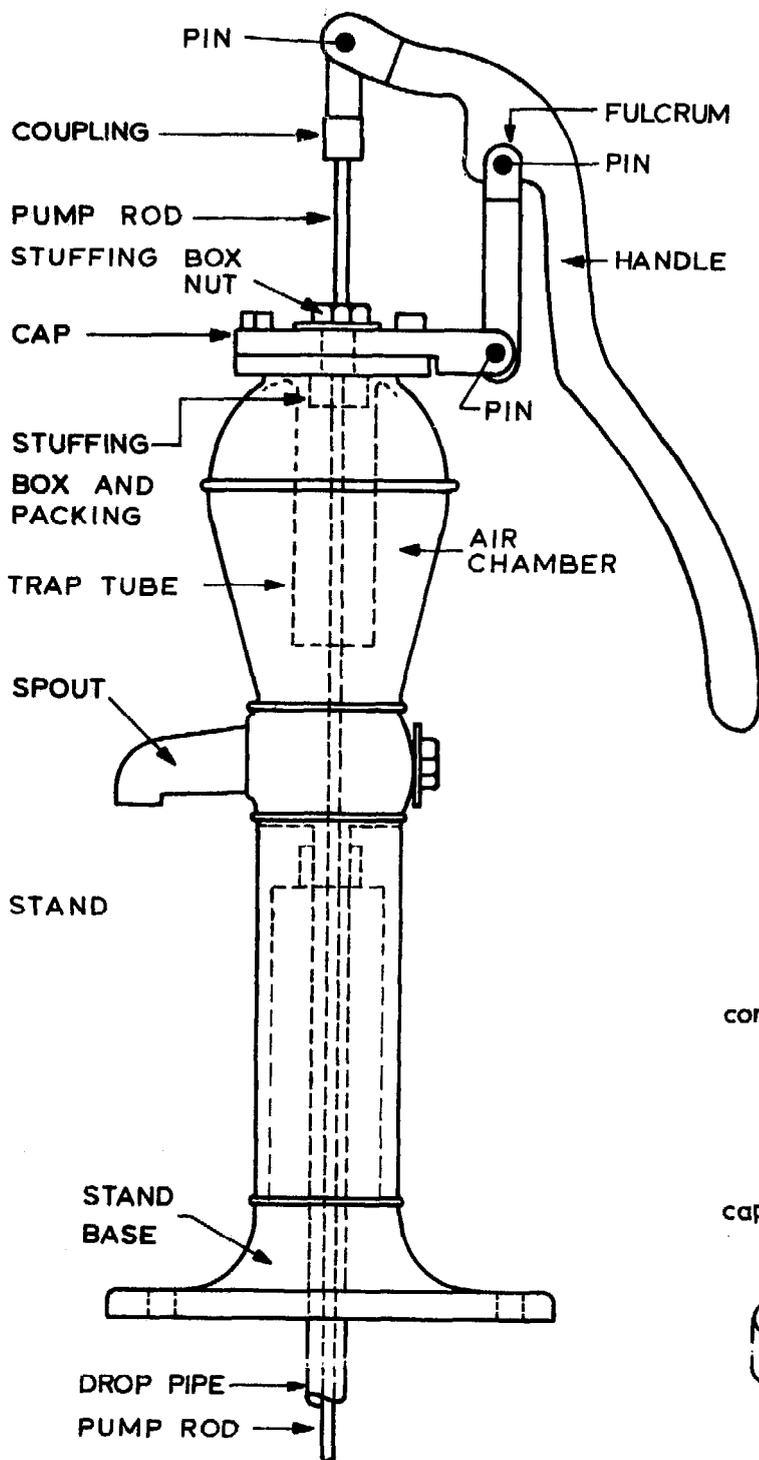
3.9.1 Functions

The pump cap when used (see Figure 3-14) may have any of several functions:

(1) With its stuffing box, the pump cap may seal the top of the pump against potential contamination. Even without the stuffing box or a vertically guided pump rod, the use of a slotted pump cap reduces the open area at the top of the pump. The slot allows lateral movement of the pump rod during pumping.

(2) The same stuffing box seal allows the pump (through extension of the spout) to act as a force pump, that is, to lift the water above the level of the pump stand.

* Provision must be provided for draining the pump stand and drop pipe in freezing climates.



FULCRUM ASSEMBLY

FIGURE 3-14 HAND PUMP WITH STUFFING BOX AND GUIDED PUMP ROD SUITABLE FOR USE AS A FORCE PUMP

(3) The pump cap and its stuffing box or guide bushing are often used as a pump rod guide. In Figure 3-14 this arrangement is used to restrict lateral movement of the pump rod.

(4) The cap generally serves as the seat of the fulcrum link and of pump rod guide pillars.

The cap may be pinned, bolted, or welded to the pump stand. It should be as strong and stable as the pump stand. The contact surfaces may require machining and/or a gasket to avoid cracking the cap when tightening the bolts and to insure water tightness.

3.9.2 Stuffing Box, Nut, Gland, and Packing

The stuffing box serves as a seal to control leakage from the top of the pump stand for force pumps and as a bearing and guide for the pump rod. (See Figure 3-14, also Figures 3-8 and 2-4; Figures 4-5 and 4-6 show replacement of the stuffing box packing).

The visible part of the stuffing box is usually a nut, concentric with the pump rod, which is tightened downward, thereby compressing a flexible packing material around the pump rod. The tightened packing, commonly made of braided hemp or canvas, provides a water seal between the pump rod and the pump stand. A cylindrical ring or washer called the gland or follower may be provided between the nut and the packing.

The packing is lubricated and cooled by water (friction with the moving pump rod develops heat which shortens the life of the packing). Therefore the nut should be tightened only to the point where the escape of water along the pump rod is almost but not completely stopped. Graphite and grease may also be used but slow seepage of water is essential. Graphite should be removed when the pump is in storage; otherwise pitting of the pump rod may result. Pitted and scored pump rods accelerate packing wear.

A trap tube around the stuffing box is shown in Figure 2-4. This creates an air chamber in the top of the pump stand. Compression of the air therein during the pumping stroke is claimed by some manufacturers to result in smoother pump performance. External air chambers are often provided with mechanically powered force pumps.

3.10 PUMP ROD (Connecting Rod, Plunger Rod, Piston Rod, Sucker Rod, Well Rod)

The pump rod connects the handle (or crankshaft) to the plunger assembly. The rod and its connectors (usually threaded) must be strong enough to support the forces earlier described in Section 3-4. During the ascent of the plunger, the rod is then in tension. During plunger descent the pump rod will be in compression if the handle is operated faster than the natural gravitational fall of the rod and plunger. Tensile stresses however generally establish the minimum rod diameter.

The pump rod diameters are usually rounded up to the next standard diameter. Rods in shallow well hand pumps are usually of polished steel or brass if purchased from manufacturers; ordinary mild steel if bought on the local market. Galvanized steel rods with threaded ends are commonly used in deep well hand pumps. Steel pump rods are commonly available in lengths of 10 or 20 feet (3 or 6 meters) and diameters of 7/16 and 1/2-inch (11 and 13 mm). A properly threaded 1/2-inch (13 mm) steel rod should support a force of 400 lb (180 kg).

Wooden pump rods are often used with windmills and with open-top cylinders. Use of wood rather than steel has the advantage of reducing the pump rod load by its buoyancy. Wood also does not crystallize and break at the couplings as does steel rod. The larger cross section, typically 1 1/2-inch (38 mm) octagonal diameter, is stiffer in compression and creates a partial double action pumping effect (pumps on both up and down strokes). The expense of large steel couplings and screws necessary to join wood rods reduces the cost advantage that might be expected. A larger drop pipe is also required.

The principal operating problems with pump rods are disconnections with the handle, the plunger, or between links and corrosion. Disconnections may be reduced by use of lock nuts at couplings (see Section 3.7.3) and by proper threading and thread engagement. Corrosion-resistance is improved by use of galvanized steel or corrosion resistant alloys and may be mandatory in highly acidic or alkaline waters.

3.11 DROP PIPE (Riser, Riser Pipe, Rising Main, Discharge Pipe, Sucker Pipe, Suction Lift Pipe)

The drop pipe supports the cylinder in the well and also serves as the discharge pipe from the cylinder. (See Figure 3-1). Closed top cylinders are removed from the well by pulling up the drop pipe. With open top cylinders the plunger assembly (and in some pumps the "foot" or suction valve) is extracted through the drop pipe using the pump rod to pull it up.

The larger the diameter of the drop pipe, the less loss of friction head through it but the greater the cost. For short and medium length drop pipe the diameter usually selected is approximately half the nominal inside diameter of the cylinder as shown in Table 3-7 below but never less than 1¼-inch (32 mm). For very long drop pipes, particularly with large-diameter pump rods, the diameter should be larger than shown in the Table.

TABLE 3-7

MINIMUM DIAMETER OF DROP PIPE

NOMINAL CYLINDER DIAMETER		NOMINAL DROP PIPE DIAMETER	
Inches	Millimeters	Inches	Millimeters
Less than 3½	Less than 90	1¼	30
3½	90	1½	40
4	100	2	50

Note: (1) Thread type and diameter of tap on cylinder must be coordinated with drop pipe threading.

(2) Drop pipe diameters shown must be increased when using wooden pump rods or steel pump rods with diameter larger than ½-inch (13 mm) or when drop pipe length exceeds 75 feet (25 meters).

For some hand pump configurations the functions of the drop pipe, the cylinder, and the well casing are combined in a single pipe. Figure 6-5 is an example.

3.12 SUCTION PIPE (Also see Drop Pipe)

A suction pipe is any pipe located below the cylinder. Inasmuch as the cylinder for a deep well pump should be installed below drawdown water-level, suction pipes should not be necessary with deep well pumps. With some cylinders or suction valves, a short length of drop pipe may be necessary to mount an intake screen.

Suction pipes for shallow well screens are sized in the same way as for drop pipes. Frequently when a suction pipe is long the pump is difficult to work. The cause may be due to the diameter of the suction pipe being too small or to an obstruction or other restriction partially choking the pipe. The action of the plunger (and handle) may resemble that of a spring under tension. If the flow to the cylinder is not as free as the displacement from it a partial vacuum is created and the plunger will drop immediately to restore equilibrium if the handle is quickly released after its downward push. The handle may simultaneously fly up so fast as to be dangerous.

Both the suction pipe and the drop pipe should be watertight for maximum efficiency. Pump capacity is seriously reduced by leakage. A very small leak, through a "weep hole" in the drop pipe, is sometimes used in freezing climates to protect the pipe during inoperative periods.

3.13 PLUNGER ASSEMBLY (Plunger, Piston, Bucket, Lift Bucket, Sucker)

The plunger assembly lifts the water to the pump spout during its upward stroke and supports the discharge check valve. (See Figure 3-15). It should be designed for strength, to guide the valve as it opens and closes, for ready replacement of cup seals, and to provide at least as much cross-sectional

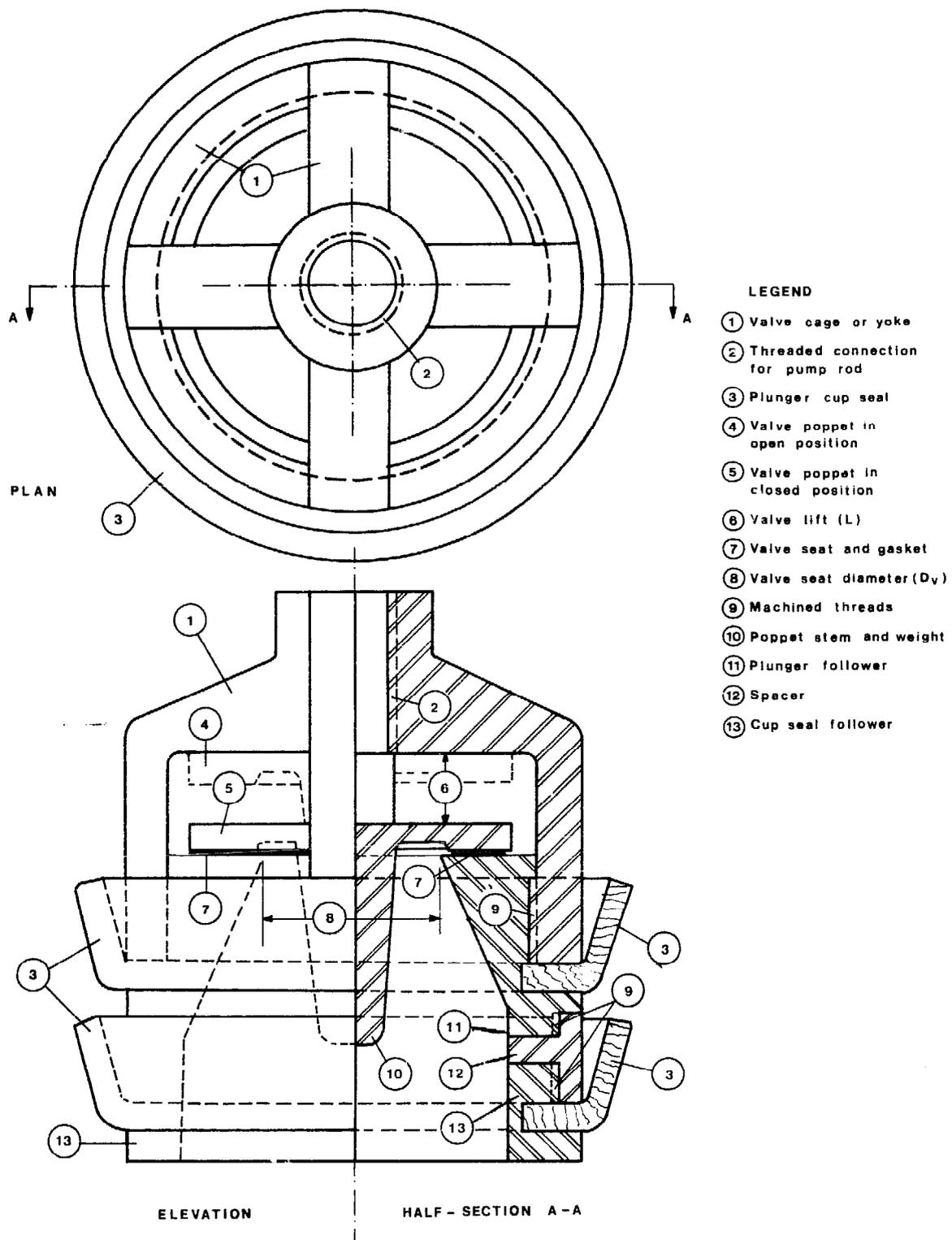


FIGURE 3-15 DETAIL OF PLUNGER ASSEMBLY

hydraulic flow area as the drop pipe. It typically consists of a yoke or cage connection to the pump rod, discharge check valve, and cup seal(s) and cup seal follower(s) and spacer(s). Cup seals and valves are discussed in Sections 3.14 and 3.15.

In hand pumps the terms "plunger" and "piston" are used interchangeably. Piston may be the more strictly appropriate term, yet plunger is much more widely used for hand pumps.

3.14 CUP SEALS (Cups, Buckets, Plunger Cups, Piston Cups, Leathers, Packing Cups, Packing Leathers)

Cup seals have one major function, prevention of backflow (slip) between the plunger and the cylinder walls during pumping (the ascending stroke in single acting pumps). Leather or another flexible material is folded or cupped over the plunger face. (See Figure 3-15). As the plunger ascends the lip of the cup is pressed against the cylinder wall to form a seal. The inward movement of the lip during plunger descent reduces friction and wear. Repeated sliding friction between the cups and the cylinder wall eventually wears away the cups and they must be periodically replaced.

Cup seals should be non-toxic; have long life; have a low friction coefficient; resist mildew, fungi, and other biological attack; be readily available; be flexible enough to fill cylinder wall irregularities including ovality yet be rigid enough to avoid being turned inside out by the reversal of stress direction when the plunger begins its ascent; be resistant to cyclic wetting and drying; and be low in cost.

No one cup seal fully meets all the criteria. Leather has been the material of choice for centuries and is still the standard. Leather is relatively cheap and available worldwide. Its life as cup seals is greatly extended by proper selection of hide (preferably from butts or backs, hair side out); proper shaving, scouring, tanning, and molding; and use of additives (impregnation with molten wax).

Polyvinyl chloride (PVC) cups are now being used in several shallow well programs. Their principal advantage appears to be longer service life. They cannot be used with PVC cylinders. Other possible materials include rubber, neoprene, and epoxy or elastomer filled fabrics.

The most important means of reducing friction and thereby, wear, is the use of smooth-walled cylinders or cylinder linings, discussed further in Section 3.16. Friction can also be reduced by careful control of the cup seal diameter. For leather cups the maximum outside diameter of the cup seal, before installation should be about 1/16-inch (1.6 mm) less than the nominal inside diameter of the cylinder; PVC cups should fit with slightly less clearance. The cup follower(s) and spacer(s) should be tight against the cups but not so tight as to cause distortion. The water pressure on the cup during the pumping stroke will bend the lip outward and insure perimeter contact with the cylinder wall.

Accelerated cup seal wear is one of the reasons for guided pump rods for deep well hand pumps. Frink and Fannon (1967), based on extensive testing, report that "... there was more than twice the wear in cups from (deep well) pumps with unguided rod than in cups from pumps with guided rod" (p. 10).

A common practice is to use multiple cups in wells deeper than 100 ft (30 meters) adding a new cup every 50 to 100 feet (15 to 30 meters). The added head increases the slip (back flow) rate which multiple cups counteract by creation of a labyrinth type seal.

3.15 * VALVES (Many different names, see text)

3.15.1 Function and Nomenclature

Reciprocating hand pumps generally contain two valves within the cylinder; one valve in the plunger assembly; the other in the bottom or suction end of

* Force pumps may have check, gate, globe or other valves on the spout or other discharge piping. These are not included in this discussion.

the cylinder. The plunger valve is also known as the discharge, outlet, or bucket valve. The suction valve is often called the foot valve, less often the intake or inlet valve. Both the plunger valve and the suction valve are check valves, that is, valves restricting flow to one direction, in the case of wells, vertically up.

The plunger check valve closes during its upward movement with the plunger to discharge the water above it and opens during its downward movement to refill, replacing the water discharged during the previous pumping cycle. The suction check valve opens during the upward movement of the plunger and closes during its downward movement. (See Figure 2-2 for an explanation of the basic principle of operation). The suction check valve also maintains the pump in primed condition thereby eliminating the labor of repriming to restart pumping; the potential hazards of repriming with contaminated water; and keeping leather cup seals, valve flappers and seats, and cylinder gaskets from drying out. (Cyclic wetting and drying of leather shortens its useful life).

Valves are also named by their mechanism or disc for opening and closing. The following valves can be used as either the plunger or the suction check valve (several are illustrated in Figures 3-15 and 3-16):

(1) Flapper valve: a valve in which a flexible, hinged, horizontal disc, generally made of leather, opens and closes over the valve opening. This is the oldest and least expensive pump valve also and is still widely used as a suction check valve in shallow well pumps. Its major disadvantage is the need for relatively frequent replacement of the leather flappers. Reinforced neoprene is a promising flapper material in this regard.

(2) Butterfly flapper valve: a flapper valve diametrically hinged in two parts across two or more valve openings or concentrically hinged in four parts across four or more valve openings. Its advantages are faster opening and closing and greater flow through area for the same lift.

(3) Clack valve: another name for flapper valves.

(4) Poppet valve ("T"): a rising and falling horizontal metal disc covers the valve opening and is guided by a vertical stem or spindle concentric with its center. A section through the disc and stem - usually formed in one piece - forms a "T". This and the winged poppet valve below are the two most common metallic valves.

(5) Poppet valve ("winged"): a poppet valve in which the stem has an "x"-shaped horizontal cross section; the maximum diameter of the "x" may

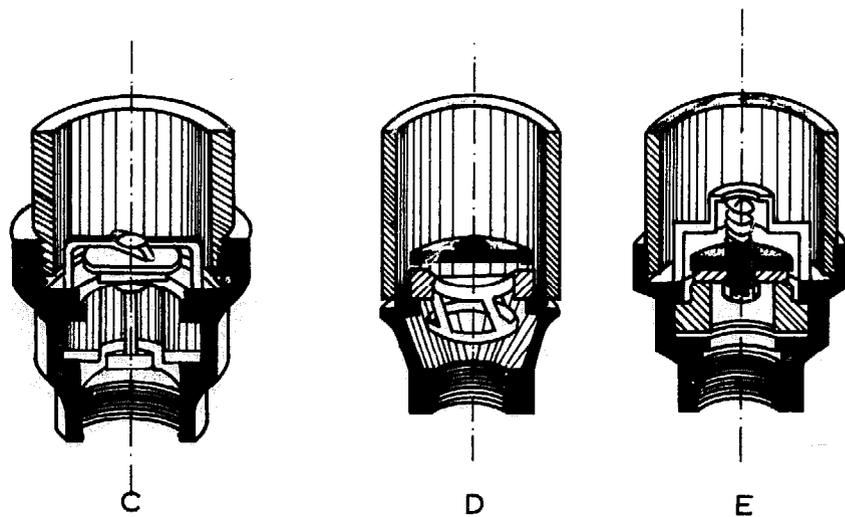
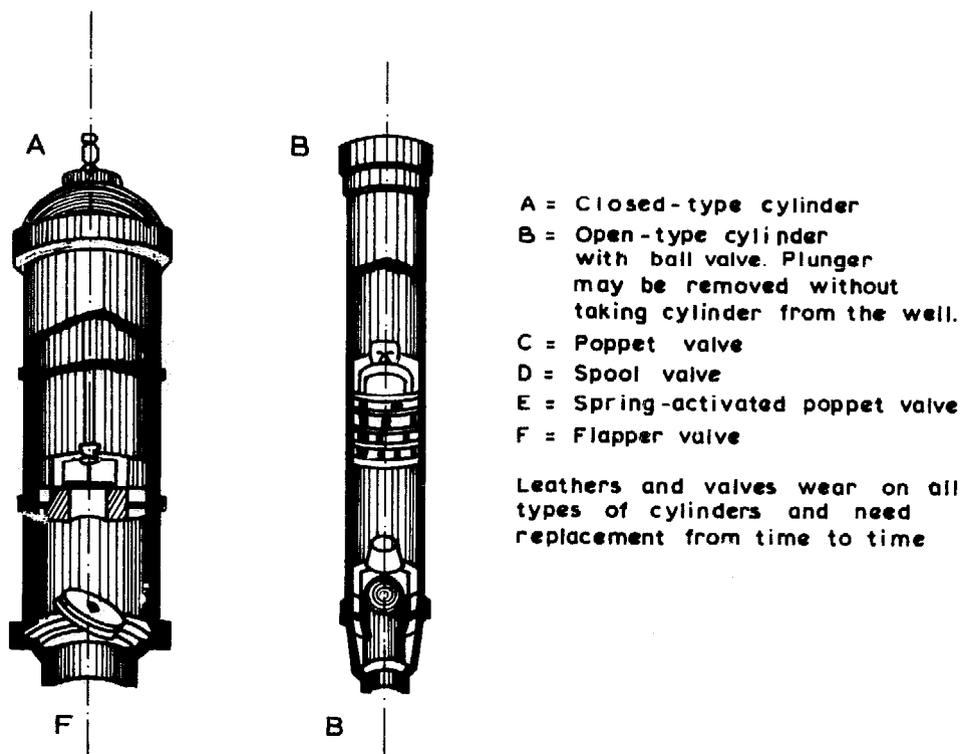


Figure 3-16 PUMP CYLINDERS AND PUMP CYLINDER VALVES

After: Henderson and Roberts

approach the diameter of the valve opening. The four "wings" formed by the stem are sometimes curved to promote rotation of the disc by the upward flow of the water. Rotation may make for more even wear and seating of the disc and its seat.

(6) Spear valve: a winged poppet valve with exaggerated vertical dimensions of the winged stem. The wings narrow to a rounded point below the disc. The valve seat is sloped to mate with the slope of the wings.

(7) Spool valve: a horizontal disc valve in which the center stem guide is replaced by a concentric vertical wall near the perimeter of the disc. It may be designed to rotate. (See Figure 3-16).

(8) Ball valves: rather than a disc, the valve opening is closed by a ball made of metal or of other material of appropriate specific gravity. The ball is usually guided by a ribbed cage. These valves are sometimes recommended for use with deeper wells.

3.15.2 Valve Seats

The perimetric area of the valve opening contacted by the moving flapper, poppet disc, or ball is termed the valve seat. The contact should be watertight, especially for the suction check valve which must hold water for hours overnight if the pump is to maintain its prime.

Several measures may be taken to insure a good seal: careful machining of the valve seat; careful machining of the contact area of metal poppets or balls - leather flappers cannot be machined but are self-sealing; and/or provision of flexible gaskets on one of both of the mating parts. Also use of beveled edges rather than flat seats, and of valve weights, may make seating more positive. Spring actuated closure as used in fast running mechanically powered pumps is another option, but has not found favor with hand pumps.

3.15.3 Valve Openings

Valve openings should be large to minimize friction head losses. Valves should close quickly to minimize slip (backflow). Other things being equal small valves close more quickly. Thus the design of the valve is a tradeoff between head losses and water losses. Further the valve opening is restricted by the cylinder diameter and by space needs for cup seals, followers, spacers, yokes, cages, stems, spindles, and the plunger rod. Prediction of valve performance has many uncertainties.

Despite, or because of, these uncertainties, several rules of thumb have been found to be useful. The horizontal cross sectional area of the opening through the valve seat, D_v , should be equivalent to 40 to 50 percent of the horizontal cross sectional area of the cylinder opening, D . That is:

$$\frac{\pi D_v^2}{4} = (1/2) \left(\frac{\pi D^2}{4} \right)$$

or $D_v = 0.7 D \dots\dots\dots(3-19)$

where D_v is the diameter of the valve seat opening
and D is the cylinder diameter.

Vertical flow through the open valve seat will be diverted to horizontal flow by the poppet disc, ball, or flapper now lifted above the valve seat by the flowing water. This flow must pass through an imaginary vertical cylinder of diameter D_v and height L equivalent to the full lift of the disc. The horizontal flow-through area is equivalent to that of the walls of the imaginary cylinder. As a rule of thumb this area should be equal to the flow-through area of the valve seat, that is:

$$L \pi D_v = \frac{\pi D_v^2}{4}$$

or $L = 1/4 D_v \dots\dots\dots(3-20)$

where D_v is the diameter of the valve seat opening
and L is the height of the poppet lift.

The lifted flapper valve is hinged on one end. Therefore its imaginary cylinder is truncated. If L is the maximum lift of the unhinged end, then following the same rule:

$$\frac{L}{2} \pi D_v = \frac{\pi D_v^2}{4}$$

or $L = 1/2 D_v \dots\dots\dots(3-21)$

where D_v is the diameter of the valve seat opening
and L is the maximum height of the flapper lift.

A bump block can be placed on top of the flapper hinge to limit its lift to the calculated value thereby minimizing unnecessary flexure and wear. (For an example see the "New No. 6 Pump").

3.15.4 Strainer

Strainers when necessary are placed below the suction check-valve. They protect the pump against suspended matter in the water which might cause excessive wear or clogging. The flow through area of the strainer should be at least three times that of the drop pipe.

3.15.5 Materials

The majority of valve bodies are made of cast iron or brass. Wood was used for many centuries. Several plastics show promise but their use is largely experimental (as of 1976). Ferrous compounds should not be used with highly acidic or alkaline waters.

Leather is the most widely used flapper material. It should be of a quality equal to that described for cup seals. Flappers, cup seals, and cylinder cap gaskets are also known jointly as "pump leathers". Synthetic materials show promise for all three uses. (See Section 6).

3.16 CYLINDERS

3.16.1 Function

The cylinder is a pipe or tube which houses the plunger assembly and the suction (foot) check valve. The water seal formed by the moving contact between the cylinder well and the plunger cup seal(s) creates the partial vacuum which makes suction lift possible (see Section 2.2).

3.16.2 Sizing

The cylinder length is a function of the stroke length which is typically 5 to 10 inches (125 to 250 mm) for hand pumps, up to several times longer for windmill pumps. Additional length is required for caps and for the plunger and suction valve assemblies, for tolerances in measurement of drop pipe

and pump rod lengths, and to prevent operator abuses such as driving the plunger into the suction valve with excessive handle lift. Cylinders which wear rapidly are sometimes constructed double length allowing the plunger depth to be reset and pumping to be continued without pulling and replacing the cylinder. Standard cylinder lengths available range from about 10 to 42 inches (0.25 to 1.10 meters).

Cylinder diameter generally decreases with increased pumping head as described in Section 3.4 and Table 3-2. Typical standard diameters range from about 3 to 4 inches (70 to 100 mm) for shallow wells down to 2 inches (50 mm) or less for deeper wells. Standard cylinders are available in diameters as small as 1 11/16-inches (40 mm) which will fit into a 2 inch (50 mm) diameter well.

3.16.3 Cylinder Location and Type

Cylinders may be located in one of three places depending on suction lift and type of pump or well construction:

(1) **Pump stand location:** for shallow wells with suction lifts not exceeding those outlined in Table 3-1, the cylinder may be an integral part of or a liner inserted in the pump stand. (The "New No. 6" pump shown in Figure 5-6 is an example). Pumps with cylinders located in the pump stand frequently have difficulty holding their priming water. Also, repeated wetting and drying of pump leathers shortens their useful life and increases maintenance requirements. However this configuration of pump stand and cylinder is the lowest in initial cost and its components are the most readily accessible for maintenance.

(2) **Drop pipe location:** for deep wells the cylinder must be located in the well, preferably below the water table. In conventional practice the cylinder is suspended from the drop pipe as in Figure 3-1. Cylinders for use with drop pipes are commercially available in two basic types as shown in Figure 3-16:

Closed-type cylinder: this type of cylinder is provided with a cap or top which is threaded to receive the normal drop pipe. Note that in order to replace or repair the valves or the plunger cup seals the pump rod and the drop pipe must be pulled from the well.

Open-type cylinder: this type of cylinder is provided with a cap or ring that is threaded to receive a drop pipe of large enough diameter to allow the pump rod and plunger assembly to be pulled up the well through the drop pipe. Disassembly of the drop pipe is not required. This cylinder and its drop pipe are more costly than the equivalent

closed-type cylinder installation. The advantage of the open-type cylinder is the greater ease of withdrawal and replacement of pump leathers.

(3) Well casing location: in wells cased with smooth pipe (see Section 3.16.4) of appropriate diameter, the pipe casing itself can serve as the well cylinder. (For an example see Figure 6-4). In some wells a short length of brass or brass-lined steel pipe may be inserted in the well casing to serve as the cylinder. In this type of installation the well casing also serves as the drop pipe. This technique was common during the heyday of wooden pumps (for example, see Agricola) and holds promise today with development of new well casing pipe materials, especially pipe of polyvinyl chloride (PVC).

The drop pipe can similarly be simultaneously used as the cylinder. Drop pipes are usually mandatory for hand pumps atop dug wells due to their large diameter.

3.16.4 Cylinder Wall Smoothness

Surface smoothness of finish of the cylinder wall is the key factor in the life expectancy of plunger cup seals.* This is a basic reason for use of brass or brass-lined cylinders rather than cast iron cylinders despite the lower cost of the latter.** Good quality brass cylinders have a centerline average smoothness of 4 to 8 microinches (0.1 to 0.2 micrometers) compared to good quality machined cast iron cylinders 50 to 200 microinches (1.3 to 5.1 μm). Rusted cylinder bores may have a "smoothness" of 1000 microinches (25 μm) or more.

Plain steel pipe has an inside surface finish of 140 to 180 microinches (3.5 to 4.5 μm); comparable to that of iron cylinders but does not perform nearly as well as iron. One hypothesis is that although the average smoothness is about the same, steel pipe has more "peak" deviations, cast iron more "valley" deviations, and the harder, sharper peaks in steel pipe tend to tear and abrade the cups more rapidly. The cups also hone down imperfections in iron much faster than in steel cylinders.

PVC plastic cylinders have a smoothness of about 4 to 10 microinches (0.1 to 0.3 μm). Tests indicate that leather cup wear in PVC cylinders is comparable to that of brass cylinders. Being relatively soft, PVC is more

* This common field observation is conclusively supported by comprehensive investigations at Battelle Columbus Laboratories (see Frink and Fannon; Fannon; and Fannon and Varga).

** Brass is also more resistant to corrosion in acidic water.

subject to scoring by silt and other solid impurities in the water and by the plunger when cups are worn out or faulty. PVC cylinders should not be used with PVC cup seals. Wear of PVC cylinder walls is currently (1976) the subject of an intensive testing program. With a few exceptions field performance has been satisfactory and PVC cylinders are now commercially available from at least one manufacturer.*

Porcelain-, epoxy-, and urethane-coated steel pipe are other possible cylinder linings.

In summary brass is the industry standard, cast iron is used when low cost is paramount, and PVC is not widely used as yet but has much potential.

3.17 COST COMPARISON OF ALTERNATIVE HAND PUMPS

Only the larger hand pump programs can afford to design and develop new hand pumps. Other programs must necessarily select from hand pumps already on the market; for larger orders some design modifications of current pumps may be possible. In either event hand pumps are compared and selected on the basis of relative total cost, capital costs of purchase and installation plus costs of operation and maintenance.

Inasmuch as all pumps do not have the same service life expectancy, capital costs must be placed on a common basis - usually discounted to equivalent uniform annual cost; making possible the addition of annual operation and maintenance (O & M) costs to obtain comparative total costs on an annual basis.

The following much simplified two pump example is illustrative and could be extended to a larger number of pump alternatives. A discount rate of 10 percent is assumed.

Given: Two pumps, A and B, which meet the necessary requirements for discharge, head, power, handle force, user acceptability, sanitation, etc.

* Equipped with all-brass plunger and check valves and 2 leather cup seals, this manufacturer's 1976 catalog prices for closed-type PVC cylinders are about 13 to 19 percent cheaper than his equivalent brass cylinders.

	<u>Pump A</u>	<u>Pump B</u>
Capital Cost, P	\$300	\$600
Service Life, n	5 years	10 years
Operation and Maintenance Cost Per Year, M	\$120	\$100

Find: Which is the "cheaper" pump?

Solution: Annual capital cost R of a present single payment of P dollars over n years at compound annual interest i:

$$R = P \times \text{Capital Recovery Factor} = P \times \frac{i(1+i)^n}{1(1+i)^n - 1} \dots\dots\dots(3-22)$$

For Pump A

$$P_a = \$300, i = 0.10, \text{ and } n = 5$$

and $R_a = \$300 \times \text{CRF} = \300×0.26380 ,

$$R_a = \$79$$

For Pump B

$$P_b = \$600, i = 0.10, \text{ and } n = 10$$

and $R_b = \$600 \times \text{CRF} = \600×0.16275

$$R_b = \$98$$

$$\text{Total Annual Costs } C = \text{Annual Capital Cost } R + \text{Annual O \& M Cost } M$$

For Pump A

$$C_a = R_a + M_a$$

$$C_a = \$79 + \$120 = \$199, \text{ say}$$

$$C_a = \$200$$

For Pump B

$$C_b = R_b + M_b$$

$$C_b = \$98 + \$100 = \$198, \text{ say}$$

$$C_b = \$200$$

Answer: On an annual basis, the pumps are equal in cost.

An objection might be raised that Pump B will give service for 10 years whereas Pump A will last only 5 years. The different service lives are reflected in the use of the 5-year capital recovery factor, 0.26380 for Pump A and the 10-year capital recovery factor, 0.16275 for Pump B. The estimate of a 10-year life for Pump B implied that a service of at least this long would be required. Although the annual costs for Pump A are for 5-years only the service must be continued thereafter. Presumably, although not necessarily, the annual costs of continuing service after 5 years, if Pump A is selected

will be about the same.*

Suppose a Pump C was available at a purchase and installation cost of \$600 but with a service life of 15 years. Discounted at 10 percent, its annual cost would be about \$79, the same as the annual cost for Pump A - even though its initial capital cost was \$600/\$300 or twice that of Pump A. The useful life expectancy of various hand pump models is difficult to predict with much accuracy and varies with the conditions of service and with levels of maintenance.** Nevertheless, as the example shows, catalog unit price or even bid or tendered unit price should not be the sole criterion in comparing hand pumps. Also price and cost are not necessarily identical.

Data on hand pump maintenance costs are sparse. These costs are difficult to predict a priori and depend primarily on local circumstances. They are invariably under-estimated; estimates based on historical data sometimes fail to recognize that the data represent costs of inadequate maintenance programs. Any program with estimated annual maintenance costs less than \$50 per hand pump is suspect. Some deep well programs may require \$150 or more per pump.

Other cost considerations include:

(1) Cost of well development: the cost of the hand pump should be related to the cost, yield, and reliability of the well.

(2) Conditions of service: stress and wear on a hand pump is directly proportional to the number of people it serves and to the depth from which the water must be raised. Many people (see Figure 3-17) and deep water tables mean greater stresses and justify greater costs per hand pump; for example brass rather than cast iron cylinders.

* A reinvestment of \$300 in Pump A after 5 years would have a present value, discounted at 10 percent, of $(\$300)(\text{Present Worth Factor}) = (\$300)(1 + i)^{-n} = (\$300)(0.6209) = \186 . Added to the \$300 payment now (year 0) and multiplied by the 10-year Capital Recovery Factor, $P_a = (\$300 + \$186)(0.16275) = \$79$ as before.

** It could be argued that with perfect maintenance including long term replacement of all parts, hand pumps could last forever. However the costs of installing new hand pumps piece by piece would show up in the O & M account and it is the capital cost plus O & M cost that is the ruling criterion.

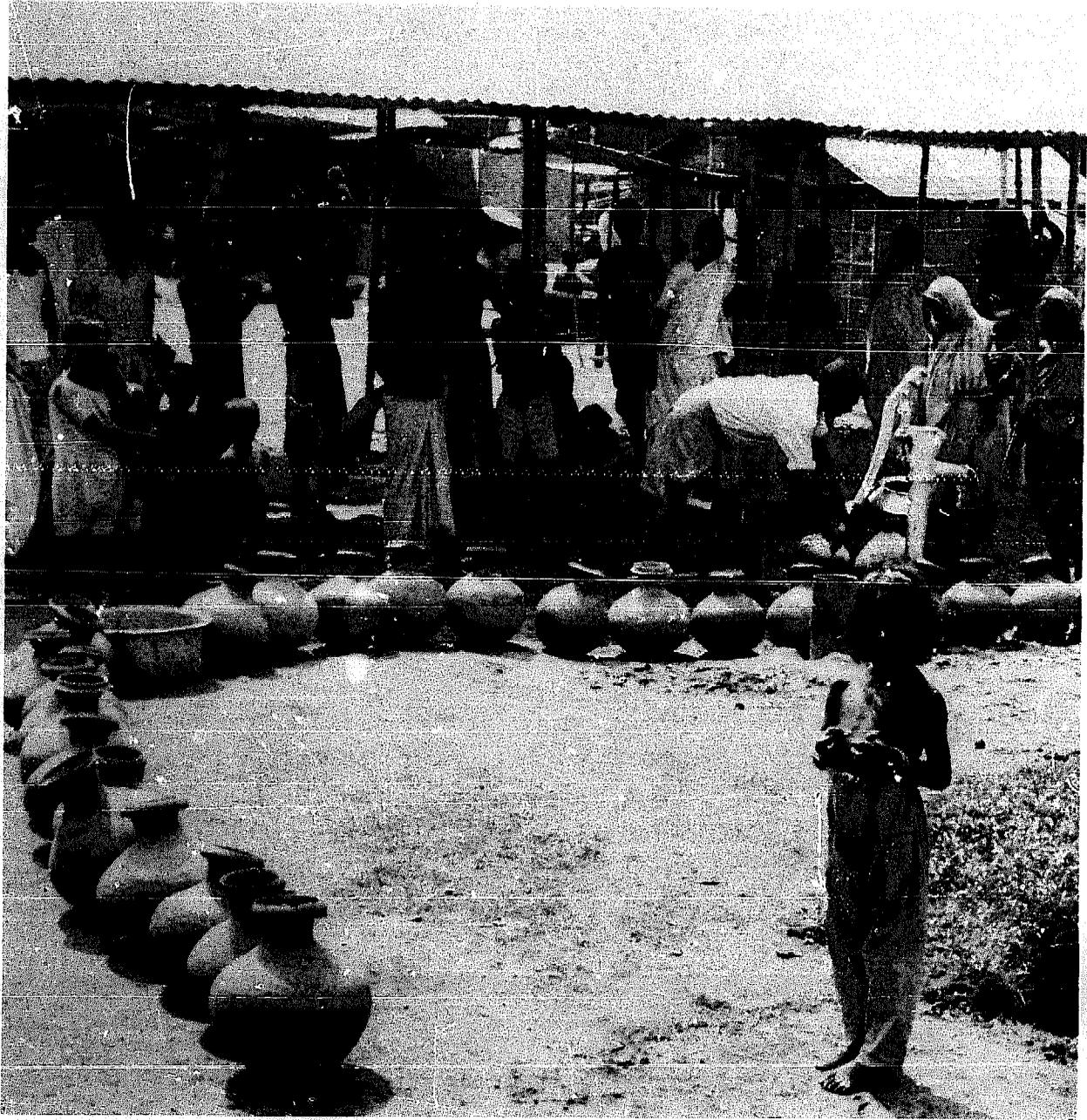


Photo: Courtesy of R.D. Fannon, Jr.

FIGURE 3-17 HEAVY USE OF HAND PUMPS IN DEVELOPING COUNTRIES

In some parts of the world, over 1,000 people may draw their drinking water from a single hand pump. Many hand pump models in use were originally designed for single family farmyard use and are inadequate for the wear resulting from conditions of use in developing countries.

(3) Reliability: where the population is solely dependent on hand pumps for water, additional investment in hand pumps is merited, either per each or in duplicate installations (e.g., two or more hand pumps per well). A cheap pump is no bargain when it is not working.

(4) Local versus imported hand pumps: hard currency costs may require weighting in comparing costs.

(5) Distribution of payments: social objectives may weight selection toward high maintenance/low capital cost hand pumps in order to distribute income within the area served rather than transfer payments to the capital or abroad.

3.18 HAND PUMP SPECIFICATIONS

The following notes provide a check list for preparation of general hand pump specifications. For particular installations, data requirements are necessarily more specific, for example the exact depth of the cylinder setting.

3.18.1 General

The specifications should be oriented towards a limited number of hand pump models based on pre-qualification, preferably through field testing or proven experience under local conditions, supplemented by component by component review of the design. Proliferation of hand pump models in a single program can lead to difficult maintenance problems - inventories, spares, purchasing, lubricants, training, et al.

Use of a single hand pump model would be the ultimate in standardization but should be avoided inasmuch as few pumps are fully suited to all installations and dependence on a single supplier is hazardous to price competition and to factory service.

3.18.2 Performance Requirements

The performance requirements of hand pumps within the program should be identified, tabulated, and categorized. An illustrative example is shown in Table 3-8.

TABLE 3-8

NUMBER CATEGORIZATION OF HAND PUMPS BY PERFORMANCE REQUIRED
(EXAMPLE)

PUMPING HEAD	POPULATION SERVED PER PUMP					TOTAL	
	50	100	300	500	1000		
Feet (Meters)	V	W	X	Y	Z		
15 (5)	A	5	20	250	6	1	282
50 (15)	B	8	160	27	2	1	198
100 (30)	C	40	23	3	2	4	72
150 (45)	D	0	12	6	4	0	22
200 (60)	E	0	5	2	0	0	7
TOTAL		53	220	288	14	6	581

Analysis of Table 3-8 indicates a need for about 282 good quality, durable shallow well pumps (row A) with special maintenance attention for 7 of them (row A; columns Y and Z, that is, blocks AY and AZ).

A moderately-priced deep well hand pump can probably handle blocks BV, BW, BX, CV and CW, about 258 pumps. Blocks CV and CW will require pumps with smaller cylinder diameters.

The remaining 41 pumps will require a heavy duty deep well pump, possibly with a rotary wheel handle and antifriction bearings.

Thus only three hand pump models can effectively and economically serve the varied needs shown in the example of Table 3-8.

With the needed inventory now established, the ergonomic (strength, power, etc.) and anthropometric (height, reach, etc.) requirements can be matched with the appropriate ranges of cylinder diameters, mechanical advantage, handle dimensions, stroke lengths, and pumping speed as described earlier in Section 3. This information should then be summarized and specified for each

pump as an allowable range of discharge (Q) for a stated pumping head (H), pumping speed (N), and stroke length (S). Maximum slip and minimum mechanical efficiency can be specified if a means of verification is available. Slip and efficiency are measures of pump quality.

3.18.3 Dimensional Requirements

The dimensions and threading of pump rods, drop pipes, cylinders and cylinder caps should all be standardized and interchangeable even between pump models. (They can also be bid separately from the top of the well pump stand assembly). These dimensions must be compatible with the wells to be used.

The minimum bearing sizes can be calculated for each pump. The number of different pin sizes should be limited and a unified threading system used. A standard cotter pin should be adopted. For small orders the manufacturer's standard bearings and pins may have to be accepted.

Fits, tolerances, and allowances should be established. Guidance is available from standard sources (Baumeister; Camm and Collins; LeGrand; Obeng, et al.; and Rothbart); however local manufacture may require interim compromise.

3.18.4 Material Requirements

The construction material for each component should be specified. Allowable alternate materials if any should be specified. Any special treatment such as hardening or galvanizing should be described. These should be cross referenced to widely accepted commercial standards and practices.

3.18.5 Special Requirements

Other requirements to be specified include:

- (1) Type of cylinder - open or closed, liners or inserts.
- (2) Types of valves.
- (3) Spout requirements for thread and valve, if any.
- (4) Stuffing box requirements.

(5) Spares required.

(6) Lubricants required.

3.18.6 International Specification

No international standard hand pump specification is extant. No widely accepted standard or "protocol" for evaluation or comparison of hand pumps presently (1976) exists. Such a protocol is now under development. Widely accepted standards for mechanically powered pumps may offer some guidance. (See for example Hydraulic Institute, 1975).

4. ADMINISTRATION OF A HAND PUMP PROGRAM

Administering a hand pump program is much like administering any rural water supply program with many common elements:

Institutional development

Legal authority

Consumer relations including community motivation and support

Health education

Personnel management and development including training

Financial planning and fiscal control including budgeting, billing, collection, and accounting

Supply management including purchasing, inventory control, and motor vehicle and equipment control

Engineering including planning, design, supervision of construction and well drilling, mapping, location of sources, etc.

Water quality surveillance

Maintenance organization and management

Record keeping

Emergency planning

Many of these subjects are covered in some detail in standard works, such as World Health Organization (WHO) Monograph Series Nos. 42, 49, and 63 and the Technical Series published by the Pan American Health Organization's Department of Environmental Engineering and Science. Some administrative aspects of particular relevance to hand pump programs are outlined below. Field maintenance of hand pumps, perhaps the critical factor in their successful use, is treated in some detail.

4.1 ORGANIZATION

4.1.1 Local Organization

An effective pump system program is not simply a technological object but a conglomerate of technology, institutions and people - individuals who

must plan, design, manufacture, finance, purchase, install, operate, maintain, oversee and use the pumps. In addition to a centralized agency, organizations should be developed at a village level in the form of a committee or some other entity that is usual in the country. The importance of a local committee is that it represents the village, directly involves the leaders and most important people in the day to day operation and administration of the system, and hopefully, educates and motivates the users of the hand pumps. Health educators, public communication media, and schools should also be used for this purpose.

When practiced, the concept of charging for the water, even if only a token amount, is important if it makes the villagers feel they have a personal share in the system and it also provides some funds for minor repair and maintenance. This must be balanced against the costs and difficulties of a collection system and usually requires a full time pump attendant. Not every village has a monetary economy. Public rules and regulations help set the conditions and limits of use and user responsibilities.

4.1.2 Central Organization

The great number of small hand pump systems requires a central organization for planning, funding, engineering, purchasing, construction, training, supervision and control. Such an organization can obtain the benefits of economies of scale, bulk purchasing, standardization, and qualified staff.

The central organization is also responsible for administering the national program and policy; sets the technical standards and controls the execution of the program; is responsible for obtaining community participation; and insuring health education of the committees and the village, emphasizing the benefits of safe water and correct operation and maintenance. The central organization also assists the local committees in establishing systems of charges (where practiced) and procedures for operation. It

should have central and regional stores of spare parts, and materials, tools, and heavy equipment for common use in special repairs.

Technical support could include assistance to solve problems and training at a community level. Local level financial support could include provision of funds, spare parts, tools, transport, and initiation of a community water supply fund. This fund could be incremented by revenues from charges for use of the hand pump.

4.2 PLANNING AND ENGINEERING

A continuing activity in a hand pump program, by a central agency, is assessment and planning including such elements as:

- (1) Inventory, identification, and mapping of the areas and populations served and to be served, including health and economic status.
- (2) Establishment of criteria for priorities and levels of service; when and whether open wells or springs, hand pumps, public fountains, yard hydrants, or piped systems.
- (3) Evaluation of resources needed and available - money, manpower, skills, equipment, materials, transport, communications, community support, local manufacturing capability and capacity, political organization, etc.
- (4) Assessment of public wants and needs.
- (5) Inventory, identification, and evaluation of water resources available - groundwater and surface water, quantity and quality.
- (6) Coordination with other agencies, e.g., well drilling, housing, agricultural, and health authorities.
- (7) Continuing estimation and evaluation of personnel and training needs.
- (8) Establishment and continuing review of design standards and specifications, manuals, unit costs, and system performance, including that of hand pumps, local and imported.

4.3 INSTALLATION

4.3.1 Site Selection

Considerations in selecting a site include:

- (1) The quantity and quality of water available. The source must be evaluated

on the basis of an assured supply year around, including dry seasons, and under conditions of use which may effect the source reliability, for example, drawdown not only in the well used for the hand pump but as influenced by nearby wells.

The principal quality concern is the bacteriological safety of the supply, particularly its freedom from contamination by human excreta. Because water treatment plants and chlorination are problematic in these rural supplies, protected ground water sources, where available, are generally purer (and less expensive). That is, naturally pure or "innocent" waters are preferred to treated or "repentent" waters. In addition to wells, sources may include infiltration galleries, cisterns, canals, and treated water reservoirs. Figure 4-1 is illustrative.

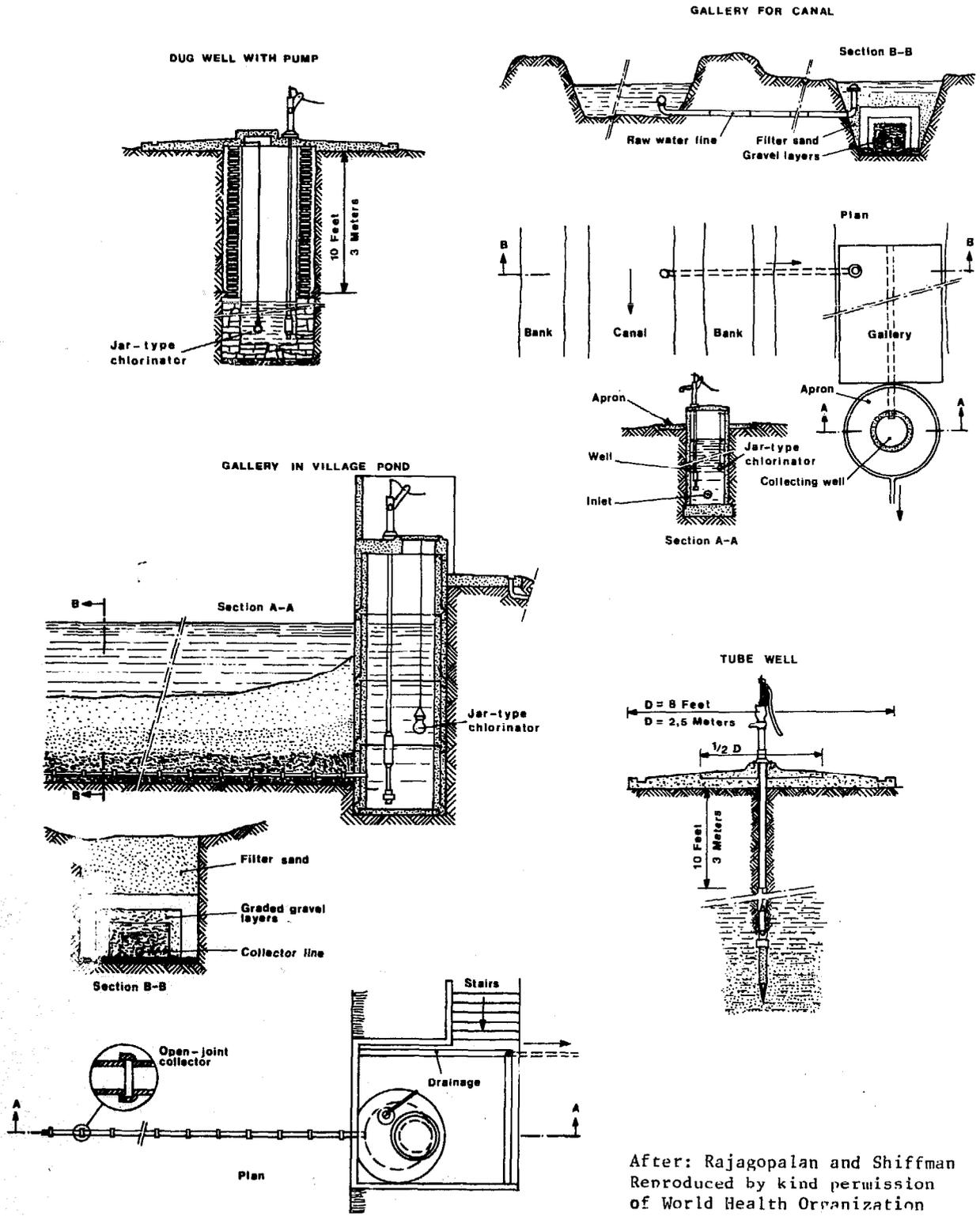
While bacteriological quality is paramount, other quality parameters may be important, for example, some groundwaters have excessive concentrations of chlorides, arsenic, or fluorides. Taste, odor, or turbidity may influence acceptance of the new source by consumers whose previously existing source is contaminated. See Figure 4-2.

- (2) Protection of the pump and water from hazards to health. The site should be free from existing and potential contamination by human or animal excreta; should be above flood level; and distant from drains, sewers, sullage waters, privies, and septic tanks. Selection of the site should include a sanitary survey of the source and its surrounding environment. Procedures have been outlined elsewhere (McJunkin, WHO, 1976).
- (3) Convenience to the user population. The ultimate success of the installation will depend on user acceptance. Thus site selection should consider also such factors as community readiness or preparation for the pump, proximity to users, ethnic or caste differences among users, and exposure to vandalism or pilferage. An extensive number of users per pump with long waiting lines or long distances to walk may discourage users particularly if alternative sources, perhaps irrigation canals, even with unsafe water, (Figure 4-2 is illustrative), are nearby. Where use is heavy, provision of two or more pumps (and wells) should be considered. This also provides a standby pump in event of one breaking down.
- (4) Access to users and for maintenance. Public pumps should be on public right of way* and accessible to pump maintenance and, where applicable, well drilling crews and vehicles. The vertical clearance above the well should allow the pump to be pulled from the well.

4.3.2 Protection of Health

In addition to proper site selection, wells and tanks must be sealed against contamination from surface waters. Figure 4-1 illustrates use of

* But protected from vehicles. Also use of hand pumps as "hitching posts" for livestock should be discouraged.



After: Rajagopalan and Shiffman
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FIGURE 4-1 HAND PUMP INSTALLATION IN WELLS
 AND INFILTRATION GALLERIES



Photo: Courtesy of CROP

FIGURE 4-2 AN ALTERNATIVE SOURCE OF WATER

aprons and seals. When possible wells and pumps should be disinfected prior to initial use or if contamination is suspected. Disinfection during use is also recommended if at all feasible and mandatory during epidemics of waterborne diseases such as cholera.

Drainage for wasted or spilled water should be provided, including soakaways or other means for prevention of puddles or pools, conducive to breeding of mosquitos and other vectors. Figure 4-3 shows poor practice.



FIGURE 4-3 HAND PUMP WITH INADEQUATE DRAINAGE

Maintenance of suction (foot) valves is essential to protection of health. These valves, when working properly, eliminate the need for priming the pumps from the top - a frequent source of contamination.

4.3.3 Sanitary Installation Guidelines

The pump equipment for either power-driven or manual systems should be constructed and installed to prevent the entrance of contamination or objectionable material either into the well or into the water that is being pumped. The following factors should be considered.

- (1) The pump head or enclosure should be designed to prevent pollution of the water by lubricants or other maintenance materials used during operation of the equipment. Pollution from hand contact, dust, rain, birds, flies, rodents or animals, and similar sources should be prevented from reaching the water chamber of the pump or the source of supply. The spout should be fully covered, open downward, and prevent solid objects from readily reaching the well.
- (2) The pump base or enclosure should be built so that a sanitary well seal can be installed within the well cover or casing.
- (3) When possible, the cylinder should be placed near or below the static water level in the well so that priming will not be necessary. This setting also keeps the pump leathers from alternate wetting and drying and increases their life and efficiency. The foot valve is less likely to leak with the resultant advantage of elimination of the need for priming. Additionally, the lower the suction head below the cylinder, the less likely is "pounding" to occur. Pounding (cavitation) shortens the life of the pump.
- (4) A pump drainage within the well, in freezing climate, should be possible for protection from frost.
- (5) The sides of the well should be sealed watertight for 10 feet (3 meters) below ground level.
- (6) Manhole covers on top of the well should be elevated, be larger than the manhole, and drain away from the well.
- (7) Livestock watering troughs should be located away from the well, preferably 30 feet (10 meters) or more.
- (8) The well site should be designed so that overall necessary maintenance and repair, including overhead clearance for removing the drop pipe and other accessories is made relatively simple.

For over the well installation the pump should be placed on a raised, impervious, concrete base, not less than 8 feet (2.5 meters) in diameter, and at least 4 inches (10 cm) thick. The top of the base should slope to

allow for the drainage of any water that may collect on it.

The pump heads on most force pumps are designed with a stuffing box surrounding the pump rod. This design provides reasonable protection against contamination. Ordinary lift pumps with slotted pump head tops are open to contamination and should be avoided if possible. The pump spout should be closed and directed downward.

The pump base should be designed to (1) provide a means of supporting the pump on the well cover or casing top; and (2) to protect the well opening or casing top from the entrance of contaminated water or other harmful or objectionable material. The base should be solid, one-piece, cast integrally with or threaded to the pump column or stand. It should be of sufficient diameter and depth to permit a 6-inch (152 mm) well casing to extend at least one inch (25 mm) above the surface upon which the pump base is to rest. The use of a flanged sleeve imbedded in the concrete well cover or a flange threaded or clamped on the top of the casing to form a support for the pump base is recommended. Suitable gaskets should be used to insure tight closure.

The protective closing of the pump head, together with the pollution hazard incident to pump priming, makes it essential that the pump cylinders be so installed that priming will not be necessary.

4.3.4 Records and Evaluation

The records of wells such as diameter and depth; screen slot size, length, and setting; aquifer log, quality and yield of water; year of sinking etc. should be recorded for each well for evaluation, maintenance, and planning. Similarly hand pump make and model; cylinder diameter and setting; date of installation; number of users; etc. should also be recorded and accessible.

4.4 MAINTENANCE

4.4.1 Background

The high rate of abandoned or defective hand pumps* is not simply a reflection of poor quality pumps but also of inadequate maintenance and repair. Many authorities contend that maintenance is the critical element of hand pump programs. The possible causes of poor maintenance may provide some insight into improvement of maintenance.

- (1) Poor quality of hand pump design and manufacture. Documented in other sections, to a considerable extent this condition is also the result of many years of trimming weight, bearing sizes, etc. in seeking low bids (tenders) in the absence of definitive specifications. Much hand pump procurement has an inherent bias towards low initial capital cost and ignores life cycle costs.
- (2) The technology in use makes frequent lubrication mandatory. Iron and steel journals and bearings, poor fits and large clearances, lack of lubricant reservoirs, exposure to weather, etc.
- (3) Underestimates or lack of appreciation of the structural and bearing loadings in deep well pumps.
- (4) Large variety of hand pumps in use with accompanying need for many different spares. Little parts interchangeability, sometimes even between the same models of the same manufacturer. Even for fasteners, e.g., bolts and nuts.
- (5) Lack of feedback from maintenance to engineering and procurement personnel. Little analysis, for example, of the most common failures. Inadequate record keeping.
- (6) Poor maintenance skills, lack of training, inadequate tools, (for example, few village maintenance men have a clevis for pulling up pump rod, drop pipe, and cylinder), lack of transport, and lack of supervision are characteristic of many programs.
- (7) Invisibility of maintenance and lack of urgency. Users return to their pre-hand pump source. Maintenance supervisors are far removed from scene or need.
- (8) Lack of glamor or peer status. "Deferred maintenance" is often first action in a budget crisis. Maintenance rarely the path to promotion or financial reward.
- (9) Lack of appreciation of preventive maintenance. Maintenance too often seen as repair function.

* Thirty to eighty percent of pumps out of operation at one time in a hand pump program is a not uncommon experience.

4.4.2 Levels of Responsibility

Most hand pump maintenance programs can be characterized as a one level or a two level system. The one level system is one where all maintenance is the responsibility of the central organization. In the two level organization, maintenance is shared with local villages or communities.

Central maintenance systems:

The central organization in both systems usually installs the pump. The well may be its task or that of another central agency. For dug wells the village may provide labor under central agency supervision. The central agency usually handles major repairs or replacement of the pump in both systems. It maintains stores of parts and lubricants and provides transport, warehousing, and training. When the central agency provides routine maintenance, it often uses a roving maintenance man or team who may or may not have a vehicle and who services from 20 to 200 pumps (the numbers varying with circumstances) on a repetitive basis.

Joint central and local systems:

In this system the local community, or a resident employed by the central agency, assumes responsibility for all lubrication and minor repairs, for example, replacement of shallow well cup seals ("leathers").

Where villagers deal only with the basic maintenance tasks requiring frequent attention, then the back-up service could visit the pump at regular intervals (e.g., every three months) for a thorough servicing. This system is found in parts of India.

In some programs certain villagers may be given a thorough training in pump maintenance and virtually all responsibility left in their hands. These approaches are being tried in Kenya and in Tanzania. Each village is required to nominate a person before the well is sunk who will go to the district office for two weeks to learn about shallow well construction

and maintenance, particularly of the pump. He will then be responsible for the well once it is sunk, and will carry a small stock of leather components and other spare parts in his house. If a major breakdown occurs he will go back to the district water office and either get the parts needed to do the repairs himself, or else get the district water engineer's fitters to do the job. (Pacey).

Village "self-reliance" systems:

Some people have argued that if a pump could be designed capable of being made by a village craftsman using simple tools and off-the-shelf local materials, then the maker of the pump would always be on hand to repair it when necessary and the village would be entirely self-sufficient in its pump requirements.

This argument is supported by the observation that many low-lift irrigation pumps of "traditional" design are built and maintained by village craftsmen. These pumps are not much used for community water supplies even in their own milieu. Other designs, more suitable to drinking water supplies, have been proposed, built, and used with varying success. Most have been unsuccessful in intensive community use, and functionally or structurally inadequate, especially for deep well application; lacking durability and too expensive * or otherwise unacceptable to local users or markets.*

Maintenance "free" systems:

When hand pumps are installed subject to unusually strenuous and isolated conditions, and their failure is of vital impact to their users, very expensive, nearly maintenance-free hand pumps may be used. These use fly wheels, crank shafts with antifriction bearings, pressure lubrication, etc., and have been successfully used for long periods with only annual maintenance. Their expense however limits their use severely.

* When produced in small lots. Both production and maintenance apparently need a "critical mass" which may need an initial subsidy to attain. Needless to say, the local craftsman is invariably underfinanced.

4.4.3 Development, Welfare, and Economics

Community water supplies are promoted by many as vehicles of social education and community development. Acceptance of responsibility for maintenance may be a milestone on this path. Yet, if local maintenance is inadequate, it may become a millstone grinding down the hopes of the populace and their sponsors for an adequate and safe drinking water supply, that is, improving their welfare. This tension is increased by the necessity for economic efficiency in providing water with severely limited available resources. Pacey (1976) develops this issue in detail in an excellent review of fundamental premises of hand pump programs.

4.4.4 Common Failures

Both pump design or selection and maintenance should be oriented towards reducing the risk of pump breakdowns and other trouble. Experience in a variety of countries suggests certain hand pump components as the most frequent points of failure and requiring maintenance emphasis. In the operating head these are the hinge pins on which the handle pivots; breakages of the handle; and wear, loss, or breakage of nuts and bolts and other parts. Lack of lubrication and clumsy use (banging the handle against the stops) frequently cause trouble.

Another common cause of pump breakdowns is wear of the leather cup seals in the cylinder - in many countries the most common problem. This problem is reduced by using smoother walled brass or plastic cylinders instead of cast iron ones, or by using high quality leather. Synthetic materials for replacement of leather show much promise. Polyvinyl chloride (PVC) cup seals may even hone (make smoother) the cylinder wall.

Another significant cause of pump failures is trouble with valves in the cylinder. Ball valves are normally simple and trouble-free, but the pounding of the steel ball may deform the metal seat. Poppet valves with rubber cushioning have some times been more effective in the long term for

this reason, but they may erode over time. Flap valves are probably the most easily repaired but require more frequent attention.

One other common problem with hand pumps is breakage of pump rods or pump rod couplings and trouble with rod bushings, glands, and stuffing boxes.

Common operating problems and their causes and repair are summarized in Table 4-1.

During the early life and the old age of a hand pump program with a large number of installations, failures will occur at a higher rate than average; many pumps will suffer from "infant mortality", enter a relatively trouble-free stage, and then "die of old age". (Morrow).

4.4.5 Periodic Inspection, Lubrication, and Repair

Although wise pump design or selection avoids many difficulties, regular maintenance is the key to successful pump operation. Table 4-2 and Figure 4-4 describe the maintenance needed on simpler hand pumps. They refer specifically to the Dempster model 23F, to the Craelius pump, and to comparable pumps made in India (WASP, Kirti, and Kaveri) and in Britain (Godwin and Lee, Howl). Table 4-2 is based on advice obtained from manufacturers, and on the maintenance schedule recommended by SATA in Cameroon. Where other makes of pumps are used, Table 4-2 should be amended in the light of the manufacturers' instructions and local experience.

Village pumps are often used very intensively; Table 4-2 recommends a correspondingly high level of maintenance. Frequency of maintenance can be adjusted for lightly used pumps. Pumps maintained on this basis should rarely break down.

Some projects have provided selected villagers with stamped and addressed postcards which they can use to summon an emergency repair team when necessary. This or some other arrangement for dealing quickly with breakdowns will always be necessary. These cards may carry a picture of

the pump on which the sender can indicate the defective part. Not only does this alert the repair team to the appropriate part(s) and tools but the cumulative card file gives an overall record of breakdowns by component and signals possible change in pump design or maintenance practices.

4.4.6 Manufacturer's Instructions

The manufacturer's instructions for assembly, installation, and lubrication and maintenance should be followed closely. The pump should be examined thoroughly and all adjustments made prior to installation.

4.4.7 Training

Training programs related to pump maintenance should emphasize installation, operation, and maintenance. The latter is of vital importance. Manufacturers' and agency booklets on installation, operation, and maintenance of the particular pumps in use should be supported by actual on-site training. Figure 4-5 shows one page from a Laotian booklet on hand pump maintenance. Figure 4-6A and 4-6B is another example.

Trainees should be instructed in how hand pumps work, the more common causes of failure, and their correction. Training should not be confined to lectures; trainees should be physically involved. On the job training during original pump installation is an excellent means of training.

Samples of hand pump(s) used locally, with tools to dismantle and reassemble them, should be available for training. A collection of broken or worn parts is also useful for demonstration purposes.

TABLE 4-1

COMMON HAND PUMP TROUBLES AND REMEDIES

TROUBLE	LIKELY CAUSE	REMEDY
1. Pump handle works easily but no water delivered.	A. No Water at the source. Well dry.	Rehabilitate well, or develop a new source or sources of water.
	or	
	B. Level of water has dropped below suction distance of pump.	Can be checked with vacuum gauge or with weighted string. Reduce pumping rate or lower pump cylinder.
	or	
	C. Pump has lost its priming.	Prime the pump. If the pump repeatedly loses its priming it may be periodically pumping the well dry, the suction line may be leaking, or the suction valve or discharge check valve may be leaking. Repair line or valve. Also check 1-A and 1-B.
	or	
	D. The cylinder cup seals ("leathers") may be worn out	Renew the cylinder cup seals ("leathers").
or		
E. The valves or valve seats may be worn or corroded.	Renew valves and repair or renew seats.	
or		
F. With a deep-well plunger pump the plunger rod may be broken.	This trouble would be indicated by the pump running freer and probably quieter. Turn the pump over by hand and note if there is resistance on the up-stroke. Broken rods must be renewed and this usually means pulling the drop pipe and cylinder out of the well.	
or		
G. Shutoff valve may be closed (force pump).	Open valve	
or		

Continued

TROUBLE

LIKELY CAUSE

REMEDY

<p>1. Pump handle works easily but no water delivered (continued)</p>	<p>H. Hole in suction pipe.</p> <p style="text-align: center;">or</p> <p>I. The suction pipe may be plugged with scale or iron bacteria growth or sediment.</p> <p style="text-align: center;">or</p> <p>J. The pump cylinder may be cracked.</p> <p style="text-align: center;">or</p> <p>K. Leak at base of cylinder.</p> <p style="text-align: center;">or</p> <p>L. One or more check valves held open by trash or scale.</p>	<p>Renew suction pipe. Cylinder may be lowered below water level in well.</p> <p>Can be checked with vacuum gauge. Remove suction pipe and clean or renew.</p> <p>Renew the cylinder.</p> <p>Renew cylinder gasket.</p> <p>Remove valves and inspect for trouble. With deep-well plunger pumps this may mean pulling the pump cylinder or plunger and valves out of the well.</p>
<p>2. Pump runs but delivers only a small amount of water.</p>	<p>A. Plunger leathers badly worn (plunger and piston pumps).</p> <p style="text-align: center;">or</p> <p>B. Well not yielding enough water.</p> <p style="text-align: center;">or</p> <p>C. Cracked cylinder (plunger or piston pump).</p> <p style="text-align: center;">or</p> <p>D. Check valve(s) leaking.</p> <p style="text-align: center;">or</p>	<p>Renew leathers.</p> <p>Decrease demands or establish new sources of water.</p> <p>Renew cylinder.</p> <p>Repair valve(s).</p>

Continued

TROUBLE	LIKELY CAUSE	REMEDY
<p>2. Pump runs but delivers only a small amount of water. (continued)</p>	<p>E. Screen or suction valve may be obstructed.</p> <p style="text-align: center;">or</p> <p>F. Suction pipes are too small.</p> <p style="text-align: center;">or</p> <p>G. Suction valve(s) may be out of order.</p> <p style="text-align: center;">or</p> <p>H. Cracked drop pipe or coupling.</p>	<p>Remove and clean.</p> <p>Can be checked with vacuum gauge. Install pipe with larger diameter, or for deep well pump, lower pump cylinder below water level in well.</p> <p>Repair valve(s).</p> <p>Renew drop pipe or coupling.</p>
<p>3. Pump needs too many strokes to start.</p>	<p>A. Pump has lost its priming.</p> <p style="text-align: center;">or</p> <p>B. The cylinder cup seals ("leathers") may be worn out.</p>	<p>Prime the pump. If the pump repeatedly loses its priming, it may be periodically pumping the well dry, or the suction line or the suction valve may be leaking. Repair or renew line or valve.</p> <p>Renew the cylinder cup seals.</p>
<p>4. Handle springs up after down stroke.</p>	<p>A. Suction pipe plugged up below pump cylinder.</p> <p style="text-align: center;">or</p> <p>B. Plunger check valve fails to open or to close.</p> <p style="text-align: center;">or</p>	<p>Remove pump and clean out suction pipe. If well has filled with dirt up to suction pipe, the well should be cleaned out or the pipe cut off.</p> <p>Repair check valve.</p>

TROUBLE

LIKELY CAUSE

REMEDY

TROUBLE	LIKELY CAUSE	REMEDY
4. Handle springs up after down stroke (continued)	C. Suction pipe too small. or D. Water too far below pump (suction pipe too long).	Replace with larger suction pipe. Place cylinder nearer water.
5. Leaks at stuffing box	A. Packing worn out or loose. or B. Plunger rod badly scored.	Renew or tighten packing. Leave packing nut loose enough to allow a slow drip of water. The water serves as a lubricant. Renew plunger rod.
6. Pump is noisy	A. Bearings or other working parts of the pump are loose. or B. Pump is loose on mountings. or C. With deep-well plunger pumps having a steel plunger rod the rod may be slapping against the drop line.	Tighten or renew parts. Righten mountings. Use a wooden rod or install guides for rod or straighten drop pipe if crooked.

TABLE 4-2 SCHEDULE FOR MAINTENANCE OF SIMPLE HAND PUMPS

- daily
1. lock and unlock the pump at hours agreed by the village.
 2. clean the well-head.
- weekly
1. thorough clean-up of pump, well-head and surroundings.
 2. oil or grease all hinge pins, bearings, and sliding parts, after checking that no rust has developed on them.
 3. record any comments from users about irregularities in working (tightness of parts, leaks from stuffing box, fall-off in water raised). Correct these when possible.
- monthly
1. if necessary, adjust the stuffing box or gland (this does not apply to the Craelius pump). Usually this is done by tightening the packing nut. This should not be too tight - there should be a slight leak when the adjustment is correct.
 2. check that all nuts and bolts are tight, and check that there is no evidence of loose connections on the pump rods.
 3. check for symptoms of wear at the leathers, noting any comments from users about any falling off in the water raised. If the pump fails to raise water when worked slowly (e.g., at 10 strokes per minute), replace the leathers.
 4. carry out all weekly maintenance tasks.
- annually
1. paint all exposed parts to prevent development of rust.
 2. repair any cracked concrete in the well-head and surrounds.
 3. check wear at handle bearings and replace parts as necessary. On the Craelius pump, worn bushes can be replaced by short sections of pipe of suitable diameter.
 4. check plunger valve and foot valve; replace if found leaking.
 5. check the pump rod and replace any defective lengths or connectors.
 6. replace packing at the stuffing box or gland (does not apply to the Craelius pump).
 7. carry out all monthly maintenance tasks.

After Pacey (1976)

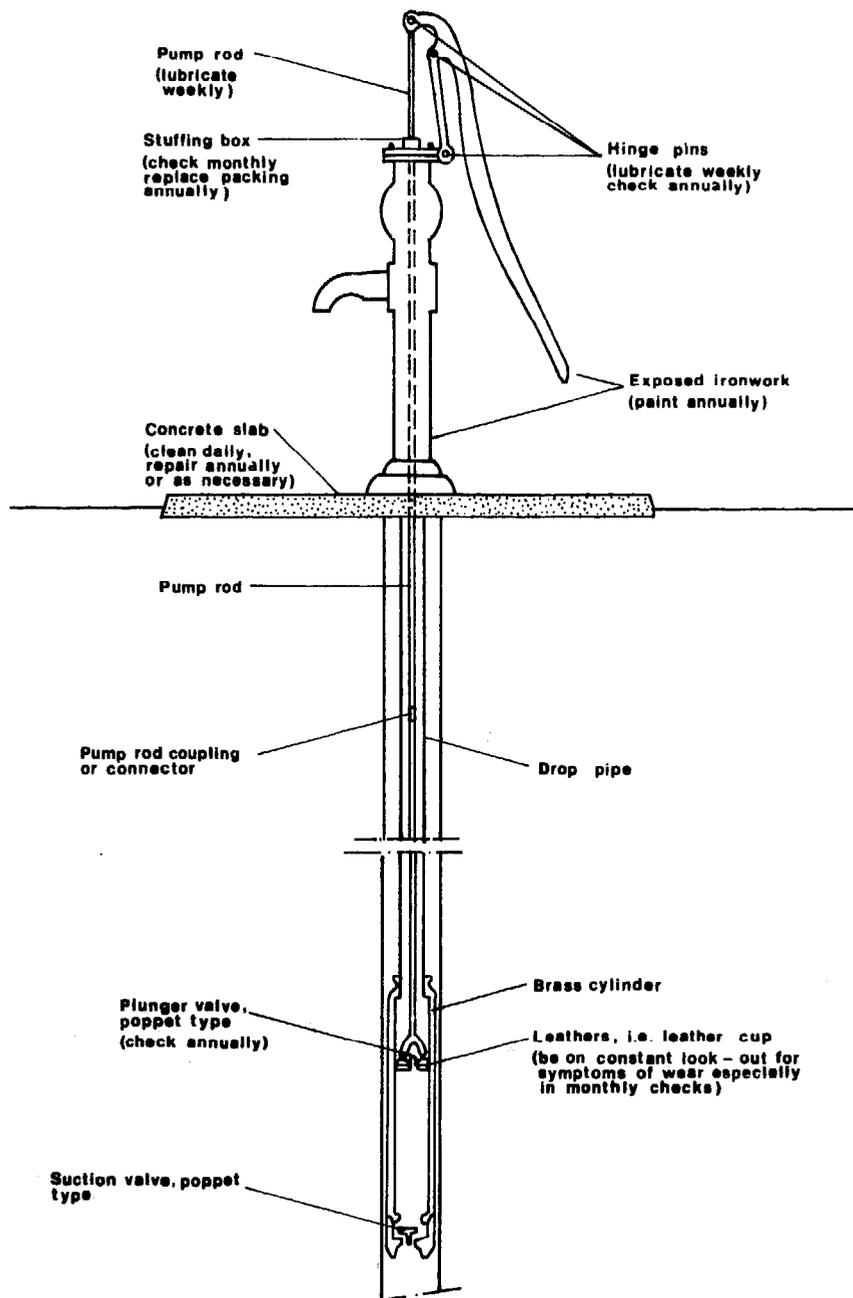
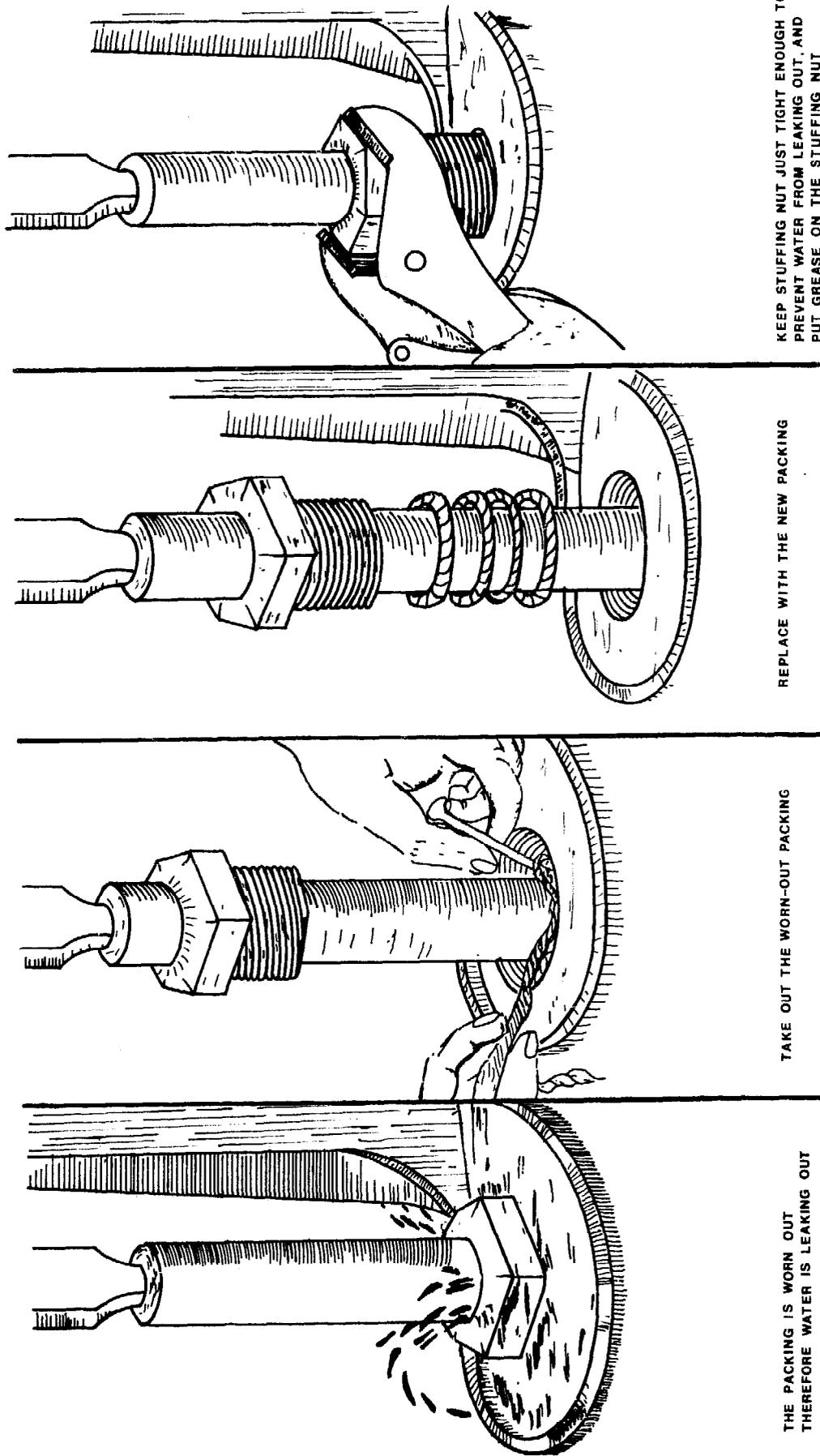


FIGURE 4-4 MAINTENANCE NEEDS OF HAND PUMP COMPONENTS
 (after Pacey, 1976)

HOW TO REPLACE WORN - OUT PACKING



THE PACKING IS WORN OUT
THEREFORE WATER IS LEAKING OUT

TAKE OUT THE WORN-OUT PACKING

REPLACE WITH THE NEW PACKING

KEEP STUFFING NUT JUST TIGHT ENOUGH TO
PREVENT WATER FROM LEAKING OUT, AND
PUT GREASE ON THE STUFFING NUT

FIGURE 4-5 PAGE FROM LAOTIAN HAND PUMP MAINTENANCE MANUAL FOR FIELD USE
(original in Laotian and English)

FIGURE 4-6a CARE AND MAINTENANCE OF THE HAND PUMP
(OPEN CYLINDER - SPOUT DISCHARGE)

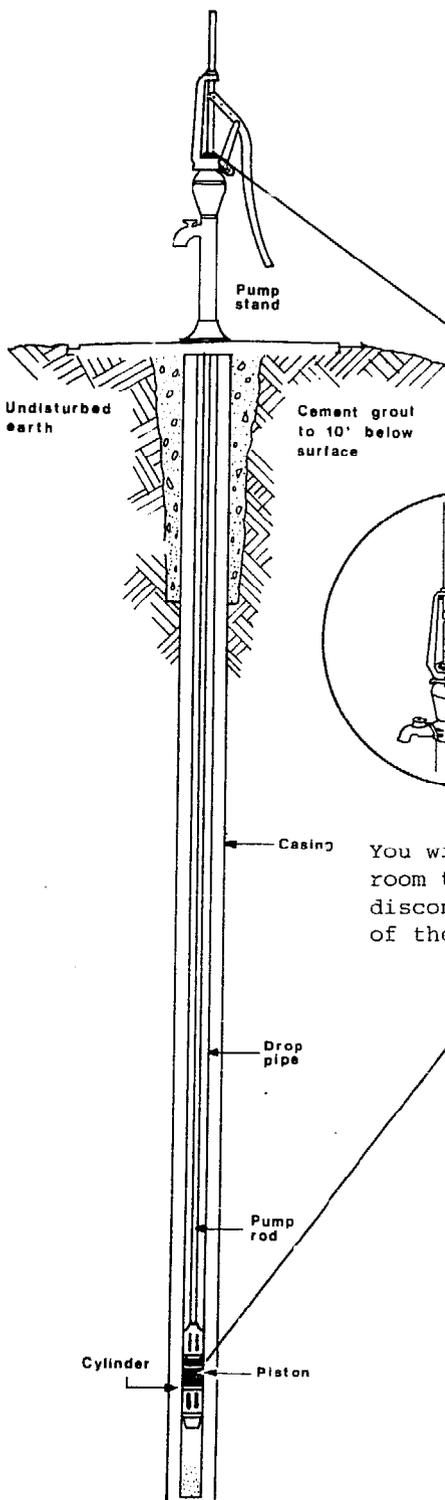
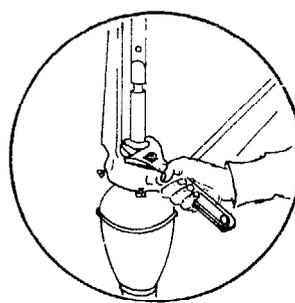
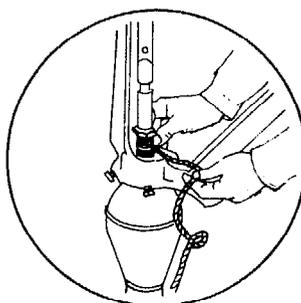
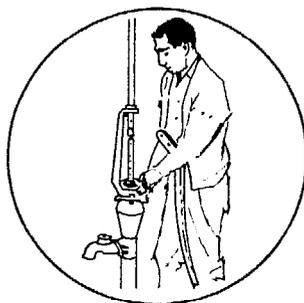
Keep the ground sloped around the pump slab so rain water will drain away from the well. It is a good idea to have a windbreak or shed around the pump, especially where the weather gets cold.

Be sure nothing happens that might break the pump. For example, do not tie horses to the pump or let children play with the pump.

Two things which you must do once in a while to keep your pump work working good.

① FIX THE STUFFING BOX

If the water leaks from the top of the pump, you should tighten the nut at the top of the box or put in a new packing.



You will have more room to work if you disconnect the top of the pump handle.

Unscrew and slide the packing nut up. Wrap packing around the shaft then tighten the packing nut.

② REPLACE LEATHER CUP SEALS IN CYLINDER

If the pump does not lift water from the well as it should, then you may need to replace the leather cup seals in the cylinder. The back of this sheet tells how to do this.

FACTS ABOUT YOUR PUMP AND WELL

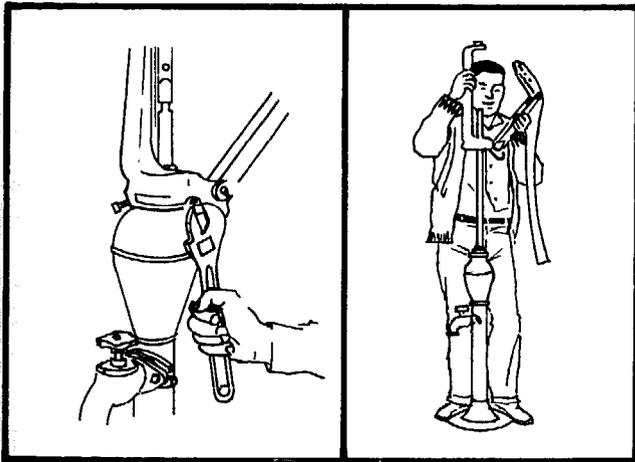
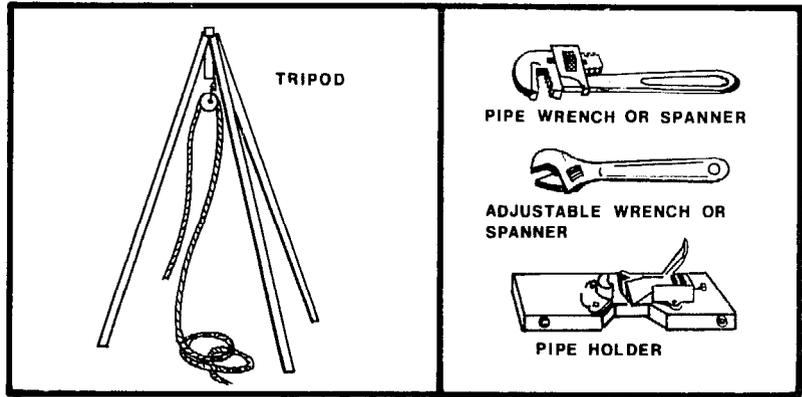
Your pump is a _____, MODEL _____.
YOUR WELL IS _____ feet deep. To replace the cylinder leather cup seals you must remove _____ feet of pump rod and _____ feet of drop pipe. The cylinder has _____ cup leathers that are _____ inches across. There are _____ leather valves that are _____ inches across.

* Adapted from a pamphlet of the United States Public Health Service

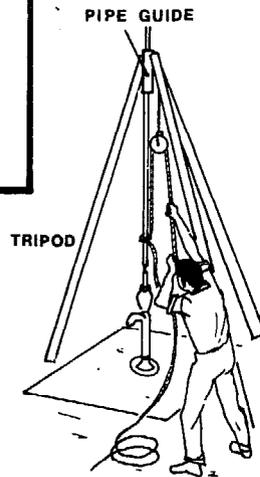
FIGURE 4-6b TO REPLACE CUP SEALS IN CYLINDERS REQUIRING REMOVAL OF PUMP ROD

Replacement of the leather cup seals in the piston means that you must pull the sucker rod from the well. The tools needed to do this are shown at the right.

These tools are located at



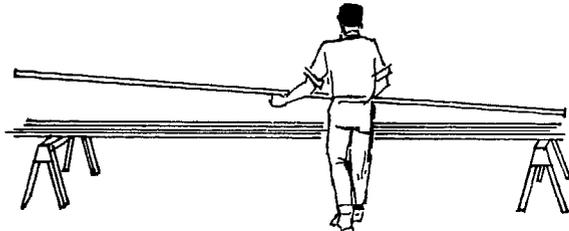
Remove the top part of the pump stand by loosening the three bolts on the flange and lift the top part of pump as shown in the picture to the left.



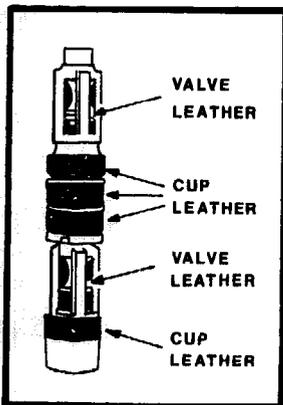
With the Tripod hoist, lift the pump rod.

Be very careful. Do not let the pump rod slip back into the well.

The clove hitch is a good knot to use on this kind of a job.

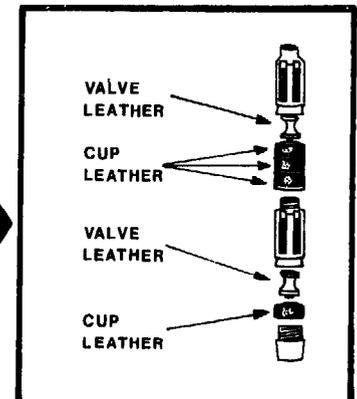


As the sections are removed, place them on saw horses or boxes so they will not become dirty.



This is the way the pump piston will look as it comes from the cylinder, however, your pump may have more or fewer leathers.

Be sure and take a good look at the piston before you take it apart, for after you replace the leathers the piston must be put back together exactly the way it was before. This picture shows the different parts of the piston. Notice that the edge or rim of the cup leathers will be up, towards the top of the well.



5. RESEARCH AND DEVELOPMENT ON HAND PUMPS

5.1 HISTORICAL

The origin of hand pumps is lost in antiquity.* The mass produced, iron-bodied, hand operated reciprocating pump came into being during the middle of the 19th century. This was an age of empiricism rather than derivation from first principles. New ideas were born in the field or the shop, not on the drawing board. Those that had merit survived, thousands (including many in patent offices) perished. Present designs have evolved over generations with hundreds of modifications made by users or small entrepreneurs but rarely as part of a major agency program and rarely reported in technical literature.

In the late 1800's agricultural development of the North American plains, made possible according to some historians by "barbed wire and windmill driven hand pumps", was in full flower. The simultaneous development of agricultural colleges and research stations led to the first scientific testing and evaluation of hand pumps, work of a quality comparable to that of today. (The work of Hood, published in 1898, is an excellent example.) Contemporaneously across the Atlantic a German professor, Dr. Julius Weisbach,** was deriving the fundamental equations for performance of reciprocating hand pumps.

With increasing mechanization and electrification, the market for hand pumps (and for research) in the industrialized countries dwindled away and lay dormant for over 50 years until reawakened by international assistance programs for rural water supplies. However, relative to the investments made and needed in rural water supply development, the funds allocated to hand pump research and development have been very small.

* Vitruvius (1st century B.C.) attributes invention of the reciprocating pump to Ctesibius (circa 275 B.C.). Even if so, some other types predate the reciprocating pump.

** Better known for the Darcy-Weisbach flow equation.

5.2 AID/BATTELLE HAND PUMP DEVELOPMENT

In 1966 the United States Agency for International Development (AID) contracted with the Battelle Memorial Institute-Columbus Laboratories to develop a dependable hand pump suitable for use in rural water supplies in developing countries. Basic specifications for such a pump were established:

- (1) Low production costs.
- (2) Long life under severe conditions.
- (3) Ready maintenance with simple tools and unskilled labor.
- (4) Ready conversion for shallow or deep well installations with only minor changes.
- (5) Ready manufacture by established firms within developing countries with a minimum of capital investment.
- (6) Ready operation by small people, including women and children.
- (7) Design features to discourage pilfering and vandalism.

The program to develop an improved domestic water pump was conducted by Battelle for AID in three steps:

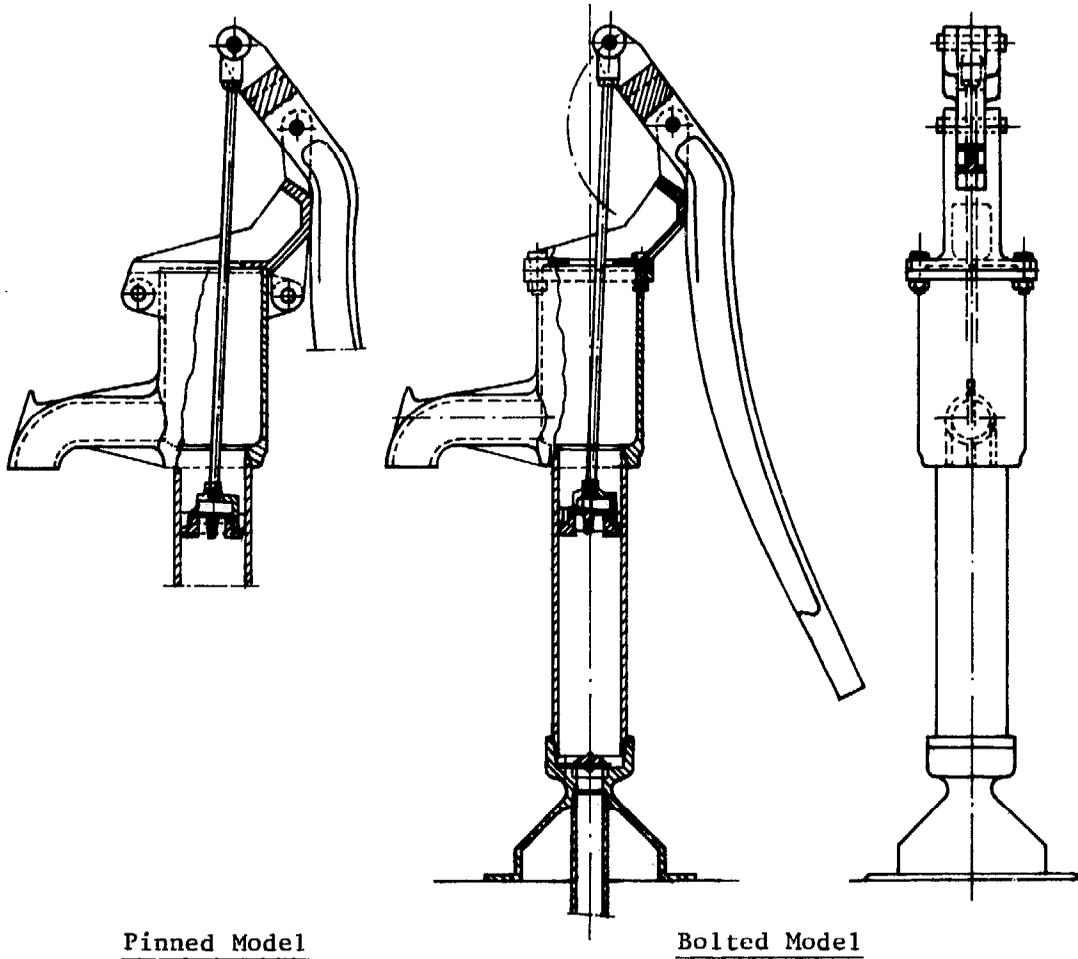
- (1) Examination of existing conditions.
- (2) Pump development and laboratory evaluation.
- (3) Field evaluation programs.

5.2.1 Examination of Existing Conditions.

In its survey of developing countries Battelle found the following conditions and practices:

- (1) Lack of pumps and inadequate facilities to make them.
- (2) Some areas had pumps given them, but many different kinds with little or no maintenance and inadequate replacement of parts.
- (3) Lack of community spirit toward community water supply systems even to the extent of vandalism.
- (4) Reluctance of government officials to act as positively or as effectively as they could.
- (5) Inadequate pump design, both those made in the country and those being imported:
 - (a) cylinders too rough,
 - (b) plunger cups improperly sized (generally too large),
 - (c) highly stressed fulcrums and handles, frequently made worse by poor alignment and tolerance,
 - (d) bearing surfaces too small,
 - (e) valve seats poorly cast and machined, and
 - (f) fasteners (bolts and nuts) poorly made.
- (6) Inadequate storage facilities - many of the parts so deteriorated as to be unusable.
- (7) Hand pumps unable to withstand rigorous usage without adequate maintenance.

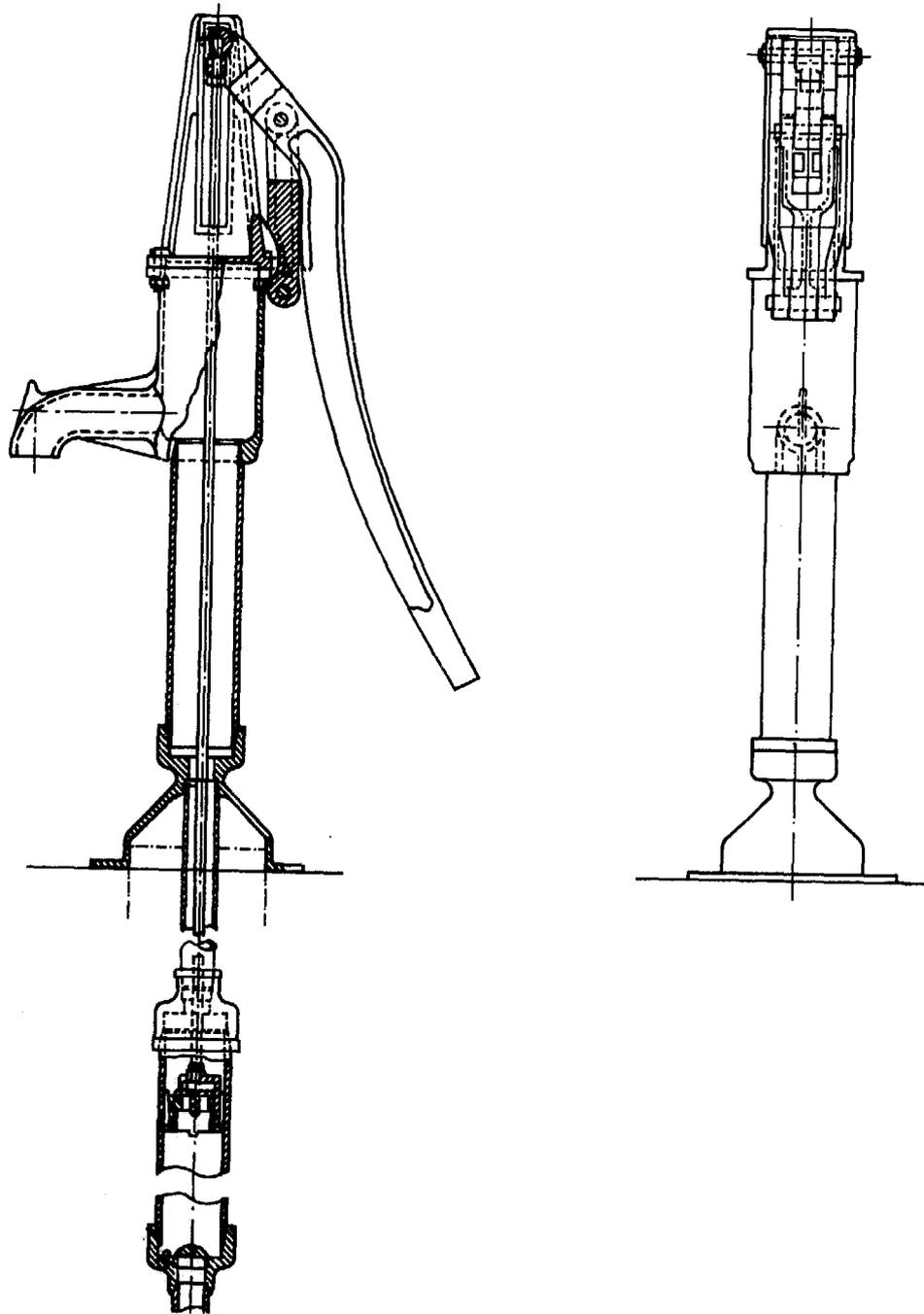
FIGURE 5-1a BATTELLE PUMPS - SHALLOW WELL CONFIGURATION



Pinned Model

Bolted Model

FIGURE 5-1b BATTELLE PUMP - DEEP WELL CONFIGURATION



5.2.2 Pump Development and Evaluation

Deep well and shallow well pump configurations were developed incorporating design improvements for many of the deficiencies noted. Prototype pumps were manufactured and subjected to rigorous laboratory testing. Battelle's findings and conclusions relevant to pump design included the following:

- (1) 5/8-inch diameter x 1½-inch long bearing surfaces are minimum, and under extreme conditions, a larger size should be considered. If at all possible, the cast iron bearing journals or "holes" should be hardened. If the skill and materials are locally available, bearing inserts might be considered.
- (2) Non-rotating pinned assemblies may be satisfactory if use is not extensive and acceptable nuts and bolts not available. However, bolted assemblies are preferred because machining is somewhat easier and will provide a more acceptable unit for continuous use.
- (3) A pump rod extension with single upper guide bearing does not provide satisfactory life under vigorous deep well pumping. (In its deep well design, Battelle substituted a sliding block design, which does not require a pump rod extension.)
- (4) Because of rising material costs, material shortages, and difficulties in transportation, hand pumps should be as light as possible without jeopardizing pump function or long life.
- (5) No particular valve type has been proven better than another; however, whatever valve is preferred, fabrication must be done with care for satisfactory operation.
- (6) The chemistry of the iron and the coke used for casting must be within an acceptable range to facilitate casting and make an acceptable product. Phosphorous content is especially critical.
- (7) Installation of the complete pump must be accomplished in an acceptable manner using the prescribed components for satisfactory operation.
- (8) The secret of long cup life is the smoothness of the cylinder wall in which the plunger operates; a centerline average (CLA) smoothness* of 8 to 12 microinches (approximately that of extruded brass cylinder walls) or less.
- (9) Use of epoxy coated iron cylinders and of polyvinyl chloride (PVC) plastic pipe cylinders or cylinder linings shows promise.
- (10) Good quality, undyed, wax impregnated leather is recommended for making plunger cups.
- (11) Other "pump leather" options that should be considered are "Corfam" for making plunger cups, nylon fabric covered with Neoprene for making flapper valves, and the use of plastic pipe for constructing tube wells, for fabricating well screens, or for use as suction pipe.
- (12) Valve seats must be smoothly finished and without blemish to assure pumps maintaining their prime, a constant source of irritation.
- (13) All unprotected (uncoated) iron surfaces such as iron cylinders, valve seats, bearings, and threaded parts must be coated with an oil or grease during storage.
- (14) Bearing surfaces should be made with as close tolerances as possible for longer operating life.
- (15) No cylinder sizes over 3-inches (approximately 75 millimeters) in diameter should be used, based on Battelle's observation that leather cups tend to fail structurally rather than wear out in 3½-inch shallow well pumps.

*The smaller the CLA smoothness, the smoother the surface. A microinch is equivalent to one millionth part (10^{-6}) of an inch or 0.25 microns.

5.2.3 Field Evaluation

Although prototype models of the Battelle pump were subjected to rigorously controlled laboratory tests, unfortunately, no large scale field tests of the Battelle pump have been undertaken despite efforts by Battelle and AID to organize on-site evaluation projects in cooperation with local rural water supply programs.

Some four Battelle deep well pumps were installed under Thailand's Accelerated Rural Development program. Based on somewhat limited reporting, Battelle concluded:

- (1) that PVC deep well cylinders are economic and effective and
- (2) that the pump castings, as designed, can be made in small "rural" foundries and acceptably machined.

Battelle also concluded that its initial design of the pump rod extension and pump cap rod guide resulted in excessive wear. Battelle has redesigned this assembly, replacing it with a unique but yet untested sliding block design.

Although 100 Battelle deep well pumps were cast by a foundry in Nigeria, few seem to be in service, partly due to high prices and partly due to "difficulty in pumping water". The latter was probably due to local use of improper drop pipe (under-sized) and pump rod and pump rod couplings (over-sized) and to use of 3-inch (76 millimeters) diameter cylinders at depths of 180 feet (55 meters). UNICEF is attempting to send several of these pumps to Ouagadougou for testing by the Comité Interafricain d'Etudes Hydrauliques (CIEH).

Some Battelle shallow well pumps were also tested in the UNICEF-assisted pump development program in Bangladesh. Local scarcity of iron and coke necessitated a lighter weight pump. The pump program in Bangladesh is now (1976) underway and, although the pump currently in production resembles the old pump, a number of the Battelle pump features have been incorporated in the Bangladesh design.* The new design Battelle deep well pump has been sent to Bangladesh for evaluation, but no information is yet available.

* See Discussion of UNICEF/BANGLADESH "New No. 6 Hand Pump" on following pages.

5.2.4 Manufacture of Hand Pumps

Metallurgical quality, foundry and machine shop practice, inspection procedures, and alternate materials were also analyzed and evaluated by Battelle. Requirements for pig iron and coke were developed by Battelle. Their 1972 report on this subject is the definitive published work.

5.2.5 Documentation

The Battelle studies are well documented. See Frink and Fannon (1967), Fannon and Frink (1970), Fannon and Varga (1972) and Fannon (1975). The last report is available from the Office of Health, Technical Assistance Bureau, Agency for International Development, Washington D.C. 25203, U.S.A.; sums up previous work; and contains complete working drawings of deep and shallow well pumps with both pinned and bolted connections. Figure 5-1 shows views of the general assemblies.

5.2.6 Assessment of AID/Battelle Pump Research Program

Although the AID/Battelle pumps have not been used widely or in large numbers, the research program had great value in clearly defining the relationship between cylinder wall smoothness and wear of plunger cup seals; in establishing metallurgical and manufacturing requirements for cast iron pumps; in its findings on bearing design and valve development; and in its testing and evaluation of alternate cylinder materials and cylinder wall coatings; and of alternative replacement materials for leather cup seals and valve flaps. It has influenced all subsequent major hand pump programs.

AID has recently (1976) contracted with the Georgia Institute of Technology for further field testing and evaluation of the AID/Battelle pump.

5.3 STUDY OF EXISTING HAND PUMPS FOR SHALLOW TUBE WELLS NEAR CALCUTTA

This was basically a study of maintenance requirements of shallow well suction pumps of local manufacture (5 companies) used in rural areas near Calcutta. The study was undertaken by the All India Institute of Hygiene

and Public Health with support from the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF). (See Majumder and Sen Gupta.)

The pumps studied were of conventional reciprocating design with lever type handles, poppet discharge and flapper suction valves, and 3½-inch (approx. 90 mm) cylinders integral with the pump body. Each pump served about 125 people and had a lift of 10 to 15 feet (3 to 5 meters).

5.3.1 Findings

Two sets of pumps - 14 in one set, 15 in the other - were installed and observed for two years and for nine months, respectively. The first set, installed as received from the factory, required "attendance" about 1.5 times per year (on the average) for each pump. The most frequent major replacements needed in the first set of 14 were of the leather cups and valves. There were also numerous replacements necessitated by poor threading of piston rods, flapper weight screws, bolts, and nuts. Great variation in frequency of repair was noted between different pumps including those of the same manufacturer.

Before installation of the second set of 15 they were "improved" by machining, cutting threads, boring holes, improving tolerances, and equipped with polythene cups and valves and with nuts and washers of the "best quality available in the market". During a nine month period, these 15 pumps required only 2 attendances in total.

A review of maintenance records for one year for 412 similar pumps of standard factory finish, already in place, tallied the following replacements: pump bodies, 10; leather cups, 390; leather valves, 348; piston rods, 82; handles, 50; and bolts and nuts, 1101. There were 2296 component replacements in all and 724 days of "attendance" were required.

5.3.2 Recommendations

Recommendations included:

- (1) Phosphorous content of cast iron should be less than 0.15 to 0.20 percent to prevent hard, brittle pump bodies subject to breakage and difficult to machine with resulting rougher cylinder walls and poorer tolerances.

- (2) Plunger rods should be made from mild steel rounds. Rods made from flat steel strips had poor threads. When heated for rounding, the thread broke away quickly. Threads can be cut to full depth in rounds but only to 40 percent depth in flats.
- (3) Bolts and nuts holding leather valve weights should be galvanized.
- (4) Bright steel pins with two washers and cotter pins at both ends should be used in lieu of bolts and nuts in the handle assembly. Occasional lubrication will extend hole and pin life.
- (5) Tolerances should be minimized at all pinned connections not only to prevent excessive wear at those points but to reduce wear and damage of other parts that may result from poor alignment and wobbling.
- (6) Leather is the best bucket and flapper valve material for cylinder bores of the quality available in Calcutta. Average life of leather cup seals is about 200 days. Principal cause of flapper valve failure is cyclic wetting and drying with resultant loss of elasticity; failure occurs at the contact point with the weight.
- (7) Proper storage of pumps and components is a major problem. Proper painting, protection of machined portions against rust, and protection of leather against mildew are necessary.
- (8) Standardization is needed.
- (9) Maintenance is the key to operation.

5.4 WHO/UNICEF/INDIA 0268 STUDY AND DEVELOPMENT OF DEEP WELL HAND PUMPS (THE BANGALORE PUMP)

The objectives of this project were to develop an improved deep well hand pump, suitable for community use, and to find ways and means of reducing the cost of the pump. This included a study of indigenously manufactured reciprocating deep well hand pumps in India. The Government of Karnataka (through the agency of the Department of Minor Irrigation & Public Health Engineering), the World Health Organization (WHO), and The United Nations Children's Fund (UNICEF) collaborated in the project. The project began in March 1973 and ended in December 1974. (See WHO/SEARO, 1976).

Project elements included:

- (1) Field survey of user characteristics in order to determine basic design criteria.
- (2) Workshop study of available indigenous and imported pumps to identify strong and weak points in design and manufacture.
- (3) Search for substitute materials suitable for pump construction.
- (4) Design, manufacture and testing of a prototype cylinder.
- (5) Design, manufacture and testing of a prototype pump head.

5.4.1 User Studies

This program was unique in that it included anthropometric and ergonomic measurements of the dimensions, motions and work of the population of

20 users per pump using 100 hand pumps. This work is briefly summarized in Table 5-1. The heterogenous make-up of the user population should be noted.

TABLE 5-1
FIELD OBSERVATIONS ON USERS OF DEEP WELL HAND PUMPS
IN KARNATAKA STATE, INDIA

Description or Parameter	Characteristic or statistic	Measurement or Calculation	Unit
User Classification	Women	57.4	Percent
	Children (age undefined)	34.8	Percent
	Men	7.8	Percent
Users per pump per day	Mean	Uncalculated	Users/Pump/Day
	Median	665	Users/Pump/Day
	Mode	665	Users/Pump/Day
	Range	240-1340	Users/Pump/Day
Height of Users	Mean	151.2	Centimeters
	Median	152.6	Centimeters
	Mode	152.7	Centimeters
	Range	92.6-187.5	Centimeters
Stroke Frequency	2½-Inch Pump	Mean	64
	3 -Inch Pump	Mean	58
	4 -Inch Pump	Mean	48
Stroke Length	2½-Inch Pump	Mode	11.8
	3 -Inch Pump	Mode	11.8
	4 -Inch Pump	Mode	8.2
Pump Discharge	2½-Inch Pump	Mean	26.9
	3 -Inch Pump	Mean	30.0
	4 -Inch Pump	Mean	34.8

1 Centimeter : 0.4 inch (approximately)

1 Litre/minute: 0.26 U.S. gallon per minute

The photographs shown in Figure 5-2 illustrate the importance of proper positioning of hand pump handles. (Photos courtesy of V.J. Emmanuel).

5.4.2 Derived Design Criteria

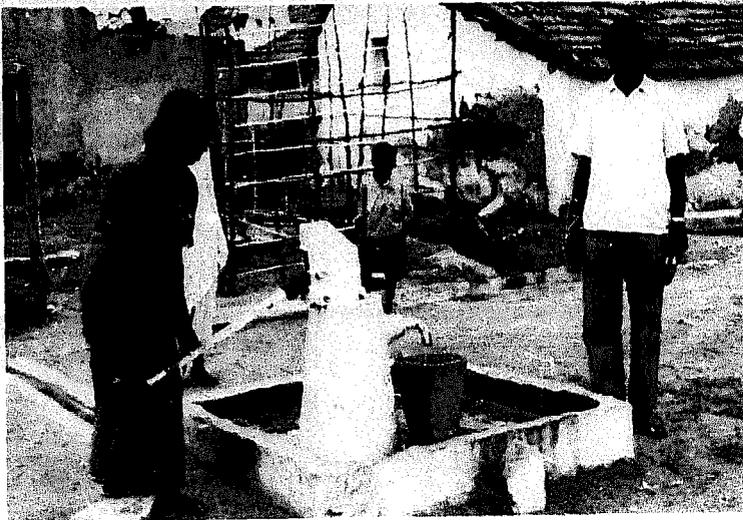
Based on the field survey, the height of pump selected was 1.00 meter (3.28 feet), exclusive of the height of the foundation, which should be limited to 100 millimeters (4 inches) above platform level. The cylinder diameter chosen was 2½-inch (68 mm). A stroke length of 144 mm (4.5 inches) was selected; stroke frequency used in calculations was 50 strokes (presumably double strokes) per minute.

5.4.3 Workshop Study

This part of the study was an analysis of design and manufacturing defects of commercially available pumps including the "Patel", "Mahasagar", "Economy", "Senco", "Wasp", "Cauvery", "Jalvad" (all preceding made in India), Dempster (U.S.), and "Mono" (U.K.). All but the "Jalvad" and the "Mono" have conventional pump head assemblies.

In pumps with conventional pump heads, all moving parts were found to be poorly matched. Tolerances and fits were "excessive", allowing the handles and fulcrum links to rock sideways. Figure 5-3 is illustrative. Guide pillars were not truly vertical, pivot pins and bearings were not truly horizontal, set screws frequently worked loose, foundation bolts were too small, and several pumps had defective threaded connections with casing or drop pipes. The "Jalvad" head (discussed in a later section) construction was subject to corrosion and the chain link connecting the pump rod and the pivot point was often mis-aligned.

Dimensional tolerance control of cylinder components was judged to be poor. Leather "buckets" (cup seals) were of poor quality, swelling when wet, stiffening when dry, and generally failing to hold their shape. Holes were often eccentric.



This pump handle is too low for operating comfort



This pump is too low for this user. He compensates by bending.



This girl operates pump comfortably, using almost entirely body weight. Resting position of handle, however is too high

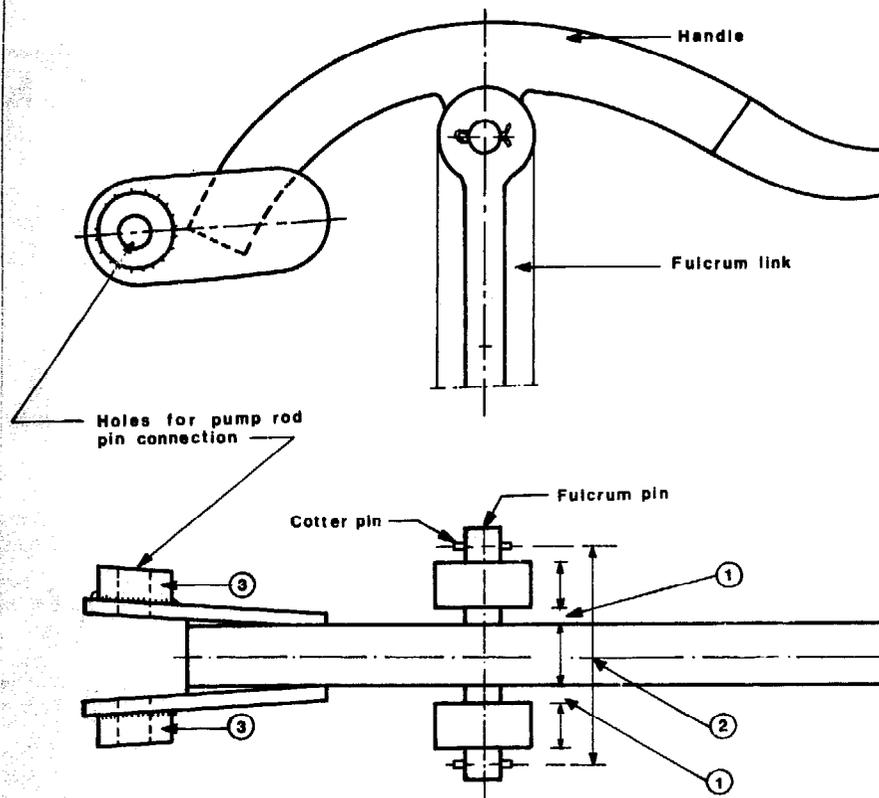


The low position of the handle allows "stiff-arm" operation

(Photos courtesy of V.J. Emmanuel)

FIGURE 5-2 PUMP HANDLE HEIGHTS FOR OPERATING (DIS)COMFORT

FIGURE 5-3 EXAMPLES OF COMMON DEFECTS
IN HANDLE FULCRUM LINK ASSEMBLY



DEFECTS:

- 1 Excessive tolerance between fulcrum link & handle
- 2 Distance between cotter pins too great
- 3 Misaligned bushes

Some examples of defects found are shown in Figure 5-4. (Photos courtesy V.J. Emmanuel).

5.4.4 Design of Bangalore Pump

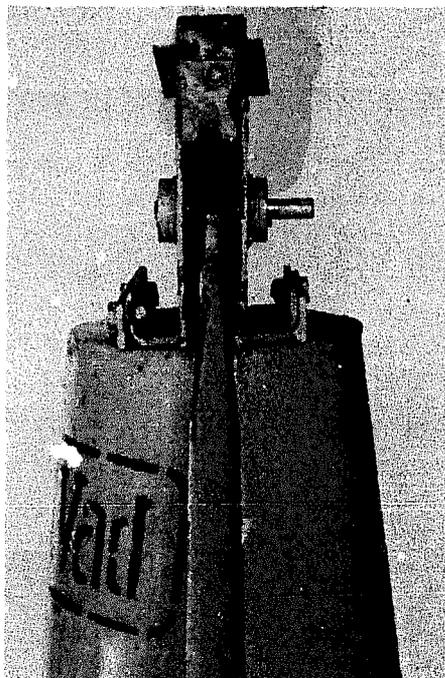
The deep well hand pump design developed in this program differs from conventional pumps in several respects:

- (1) The handle to pump rod linkage uses only one pivot (as in the "Mission" Jalna and Sholapur pumps), made possible by a roller-chain linkage, the chain riding over a quadrant placed tangentially to the pump rod, at the load bearing end of the handle. (The operating principle is derivative of that shown in Figure 5-10, "The Sholapur Pump").
- (2) The pump head currently (1976) planned will utilize a welded steel body.
- (3) The pivot currently (1976) planned will utilize ball bearings.
- (4) Imported nylon balls are used in the plunger and foot valves.
- (5) Cup seals are made of acrylo nitrile rubber (Neoprene) with a 0.2 mm clearance fit with the cylinder wall.

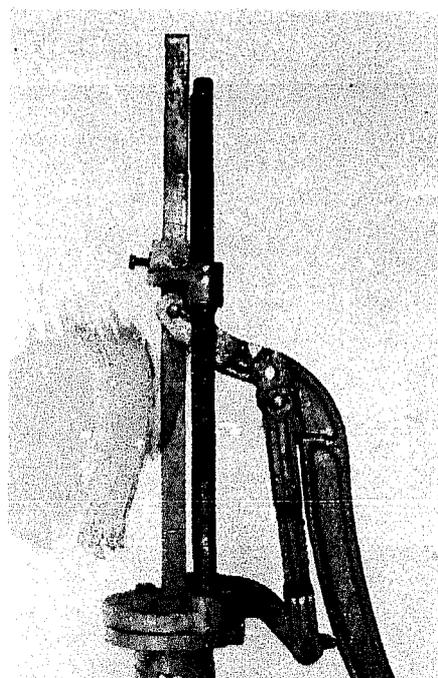
FIGURE 5-4 MANUFACTURING AND DESIGN DEFECTS IN INDIA

MANUFACTURED DEEP-WELL HAND PUMPS

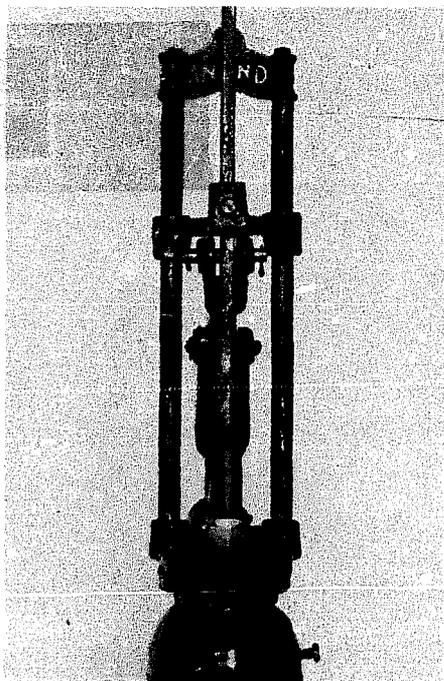
(Photos courtesy of V.J. Emmanuel)



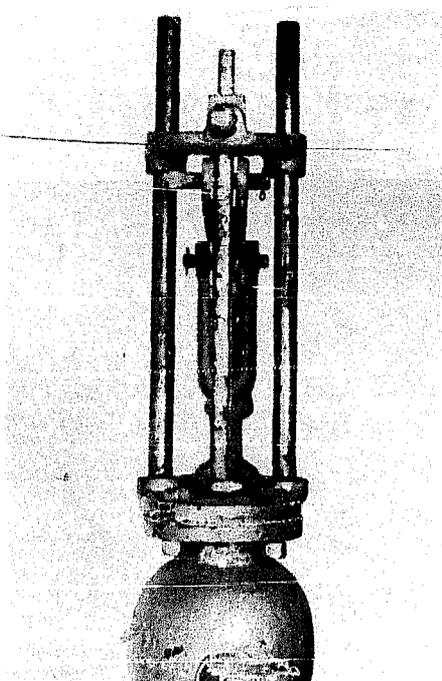
(a) Pivot pin not horizontal
(Alignment of bearings defective).



(a) Piston rod not vertical.
(b) Guide friction high in upper position.



(a) Guide pillars not truly vertical
(b) Too high tolerance between handle fork and piston rod
(c) Pin bushes of handle fork poorly aligned
(d) Handle fork - piston rod pin not horizontal.



(a) Too high tolerance between forks and pivot points
(b) Pivot points not horizontal
(c) Slide not moving horizontally.

- (6) All other valve and plunger components are made of rubber, nylon, neoprene, or glass or cotton fibre fabric impregnated with epoxy resin.
- (7) The cylinder consists of a standard galvanized iron pipe body with a "liner" or "sleeve" tube made of cotton fabric impregnated with an epoxy resin. The liners are manufactured in India by Hylam Bakelite of Bombay for other commercial uses in several lengths, diameters, and wall thicknesses under the trade name "Hylam TF 2211". A roughness specification of 250 microinches is proposed for the inside finish of the liner. Figure 5-5 illustrates the cylinder.

5.4.5 Testing of Bangalore Pump

A prototype cylinder and pump head were made and tested. The prototype cylinder was connected to a conventional pump head, driven by an electric motor for 1,000 hours at 40 to 48 strokes per minute against an unstated head. Stroke length was 4.5 inches. Discharge ranged from about 21 to 25 litres per minute. The test represented the equivalent of "four months of actual field use". Cylinder wear was observed to be less than 0.001 inch. After some initial wear (0.6 mm and 0.9 mm), the two cup seals (buckets or washers) showed no wear for at least the last 534 hours of testing.

The prototype pump head tested differs radically from that now (1976) planned. The prototype employed a wire cable as a "rod" connecting the handle and the plunger. The pivot bearings of the original prototype were of the sintered bronze, oil retaining type.

The cast iron pump head has been newly designed using fabricated steel construction. This model is referred to as the "Deep Well Hand Pump, India-Mark II)".

5.4.6 Cost of Bangalore Pump

Estimated costs for large scale production of the Bangalore pump 3-inch cylinder range from Rupees 80 (US \$9) to Rs 250 (US \$28).^{*} The aforementioned "Sholapur" pump uses a 3-inch brass cylinder which sells for about Rs 250 (US \$ 28).^{*}

The design of the currently developed pump head differs so greatly from the prototype tested that its costs are no longer relevant. A Sholapur pump head, which the Bangalore pump closely resembles, currently (1976) sells for about Rs 500-600 (US \$ 50).

^{*} Amsterdam exchange rate of US \$11.30 per Rs 100 on 12 July 1976.

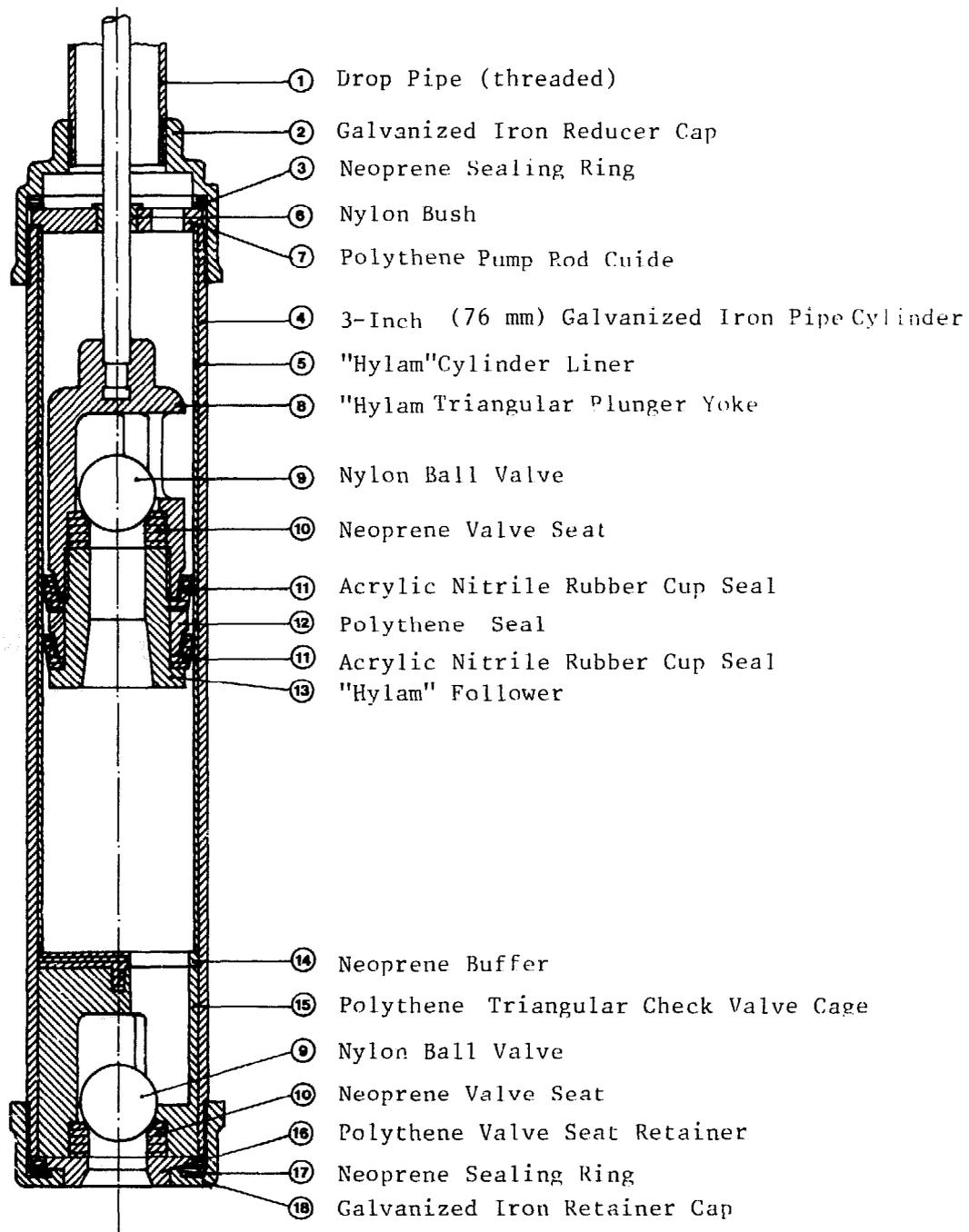


FIGURE 5-5 BANGALORE PUMP CYLINDER

Reproduced from
 WHO Report SEA/Env. San./168
 SEARO, 1976

5.5 UNICEF/BANGLADESH SHALLOW WELL HAND PUMP DEVELOPMENT

For some years UNICEF has assisted the Department of Public Health Engineering (DPHE) in Bangladesh in perhaps the world's largest single hand pump program. Within a relatively short timespan over 400,000 new hand pumps will be manufactured and installed. The program has stimulated considerable experimentation, prototype testing, and many design modifications in shallow well hand pumps for at least two reasons: (1) the sheer size of the program provided an excellent opportunity for large scale improvements and economies in pump design, and (2) the maintenance problems of the existing technology, if continued, would have required so much of the program's resources as to have threatened its viability. The improvements made have evolved over several years through several generations of modifications based on field observations.

5.5.1 "New No. 6 Pump"

The newly developed model, with over 300,000 planned for installation by 1979, is known as the "New No. 6" hand pump. See Figure 5-6. The new pump represents a cross between the Battelle pump and the old Maya No. 6 pump. The new name is part of the effort to insure local acceptance. (No. 6 designates a $3\frac{1}{2}$ -inch cylinder diameter, about 90 mm).

The major improvements on the traditional No. 6 are:

- (1) Increased bearing surfaces on cast iron moving parts and pivot pins.
- (2) Use of round, smooth mild steel pins held by cotter pins, rather than nuts and bolts at pivot points.
- (3) A piston rod with reinforced bearing areas and jam nut at plunger end.
- (4) Polyvinyl chloride (PVC) cup seal or bucket instead of leather bucket.
- (5) More stable configuration of four nuts and bolts located at "heel" and "toe" points of headcover (2,4,8, and 10 o'clock positions relative to the fulcrum at 6 o'clock), rather than the three points on the old design.
- (6) Standardized size ($2\frac{1}{2}$ -inch x $\frac{1}{2}$ -inch) for all nuts and bolts instead of three or four sizes on previous pumps. Lock washers have been added to nuts and bolts (approximately 65 mm x 13 mm).
- (7) A stronger handle with higher mechanical advantage and an 8-inch (20 cm) stroke length. The cross section of the handle was changed from an "I" to a "T".

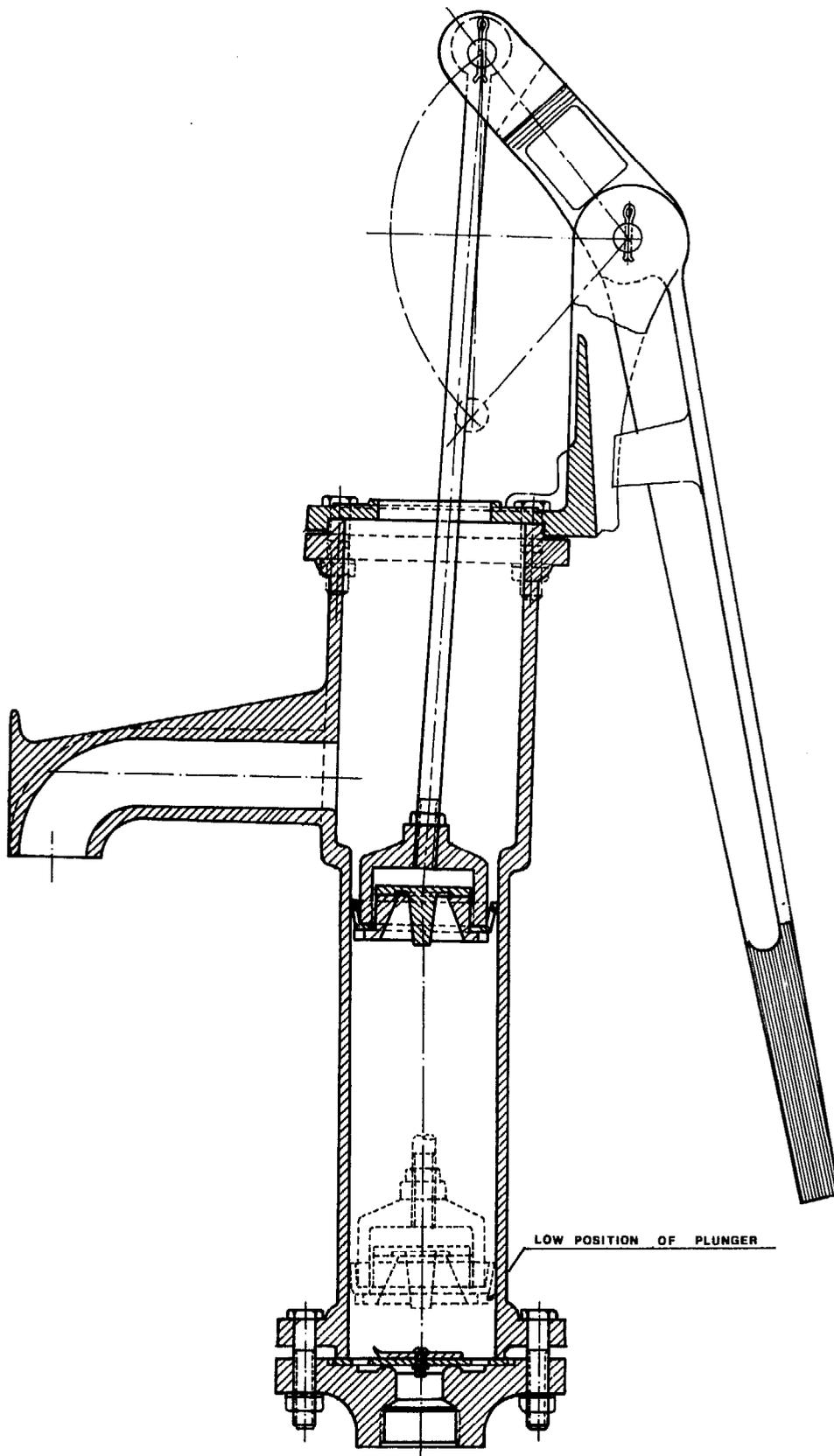


FIGURE 5-6 NEW NO. 6 HAND PUMP (BANGLADESH)

The design of the pump was strongly influenced by the severe shortage of pig iron and the casting technology available in Bangladesh. For example the "New No. 6" is about 20 lbs (9 kg) or 15 percent lighter than the Battelle shallow well pump configuration. This savings was achieved partly through redesign of the base plate of the pump stand for Bangladesh standard installation (threaded connections to well casing), and foregoing pump stand interchangeability with deep well pumps.

5.5.2 Polyvinyl Chloride (PVC) Cup Seals

The polyvinyl chloride (PVC) cup seals used in Bangladesh have been found to have 2-3 times longer lifespan and greater uniformity than the traditional leather buckets available. In Bangladesh, they are less expensive than leather cups.* Because cup seal wear was the leading reason for pump shutdown (estimated at 25 to 30 percent at one time), the PVC cups have made a major contribution to improved maintenance. Over time the water-lubricated PVC cups may be honing (making smoother) the iron cylinder walls.

5.5.3 Polyvinyl Chloride (PVC) Cylinders and Liners

Beginning in 1969, PVC liners with leather cup seals were tested in Bangladesh in shallow well hand pumps, none of which are still in service. Most were removed during the civil war in 1971-72, because only 3½-inch (89 mm) diameter cup seals were available and these were too large to fit in the PVC liner. In 1975 a few remaining liners were examined and all showed severe wear on one side of the 1/8-inch (3 mm) thick wall, presumably because of the oscillation of the piston rod of the No. 6 shallow well pump. Later tests with ½-inch (6 mm) wall thickness PVC pipe begun in 1975 showed mixed results: one sample showed rapid wear, 1/8-inch (3 mm) increase in diameter in one month; another is still in operation after two years with negligible wear, but has been gouged, presumably from foreign objects introduced from above. With the success of the PVC cups the liner program was discontinued because of the

* PVC about \$0.12 each, leather about \$0.25.

difficulty of mixing PVC and leather cups for maintenance of existing and new cups.

U.S. manufactured "Dempster" PVC deep well cylinders have been tested one year in Bangladesh with good results. UNICEF is now fitting 500 deep wells with the cylinders.

5.5.4 Polyvinyl Chloride (PVC) Well Casing

PVC pipe is being used for well casings in Bangladesh. Because PVC pipe has a low tolerance for stress reversals, threading cast iron hand pumps directly to PVC well casings is inadvisable. Thus in Bangladesh a 20-foot (6 meter) length of steel pipe is used to join the hand pump and the PVC casing. To further prevent rotation between the steel and plastic pipes, (1) a horizontal steel bar is welded to the steel pipe at its midsection and (2) a concrete platform incorporating the steel pipe and bar is provided for the hand pump.

5.5.5 Field Based Program

The hand pump development program in Bangladesh has demonstrated the benefits of having an operational base at field level with experienced personnel in constant attendance. The UNICEF/DPHE program has tested prototypes under field conditions; obtained, analyzed, and responded to feedback from both field tests and regular operation, and fitted an inexpensive (less than US \$20), locally manufactured, improved hand pump technology to local conditions.

More detailed information may be found in the various papers of Hussain, Phillips, and Shawcross.

FIGURE 5-7

TWO HAND PUMPS USED IN WEST AFRICA



"ABI"

"Africa"



5.6 COMITE INTER-AFRICAIN D'ETUDES HYDRAULIQUES (CIEH) STUDIES IN UPPER VOLTA INCLUDING THE HYDRO-POMPE VERGNET

The Inter-African Committee on Hydraulic Studies (CIEH), an international organization headquartered in Ouagadougou, under a 1973 agreement with WHO and with assistance from UNICEF, is studying the use of small hand pumps for water supply in West Africa. The study comprises inventory and testing of pumps manufactured in Africa, including "ABI", Bodin "Majestic", Briau "Africa", and Craelius "Uganda", and imported pumps including Dempster "23F Ex" (US), Briau "Royale" (France), and Godwin "WIH 51" and "54" (UK). (See figure 5-7).

An important part of these studies is the field testing of a newly developed pump, the French-made (by Mengin) "Hydro-Pompe Vergnet". Several prototypes of these pumps, provided by WHO and UNICEF, are being tested in Ouagadougou and in the village of Koupela, about 140 kms east.

5.6.1 The "Hydro-Pompe Vergnet" (Description)

This pump has a novel operating mode. A flexible diaphragmatic hose (cylinder) is located inside a rigid cylinder immersed in the well. Using a hydraulic pilot system operated by a foot pedal, at ground level, the flexible hose is alternatively stretched, and left to contract, thereby pumping water from the rigid cylinder to the surface. Its operation is best explained stepwise in conjunction with Figure 5-8. Beginning with the pump primed* and the foot pedal in the high position:

- (1) The operator steps on the pedal, forcing the piston down into the cylinder.
- (2) The water in the piston cylinder is forced from the cylinder, through the pilot pipe or hose, and into the diaphragmatic hose with flexible, spring-like walls.
- (3) The increasing water pressure in the flexible hose stretches its walls, thereby expanding its volume.
- (4) The increased volume of the smaller cylinder increases the pressure of the water within the larger, rigid cylinder surrounding the smaller cylinder.
- (5) The rising pressure within the rigid cylinder closes the suction valve and opens the delivery (discharge) valve.

* Rigid cylinder around flexible hose primed; the pilot system is filled with water upon installation.

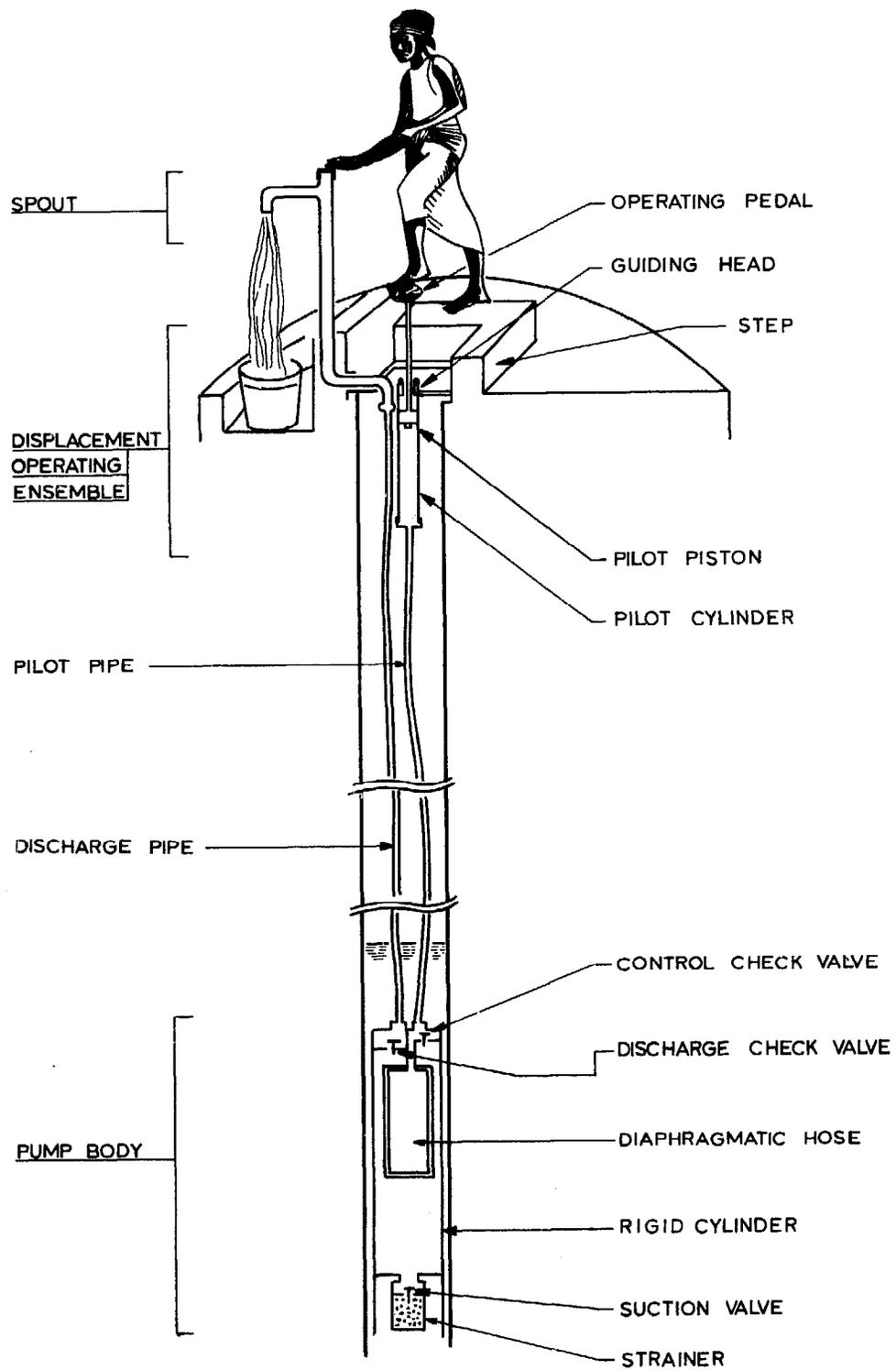


FIGURE 5- 8

HYDRO - POMPE VERGNET
SCHEMATIC ARRANGEMENT

Courtesy: Ets. Pierre Mengin,
Montargis, France

- (6) The water within the rigid cylinder is forced to the surface through the discharge valve and discharge pipe or hose as the smaller cylinder expands.
- (7) The operator lifts his foot, relieving pressure within the pilot system.
- (8) The flexible, springlike cylinder contracts to its initial position, forcing water up the pilot hose and pushing the pedal back to its high position.
- (9) The contraction of the flexible cylinder reduces the pressure of the water within the rigid cylinder.
- (10) The falling pressure within the rigid cylinder closes the delivery valve and opens the suction valve, refilling the rigid cylinder.
- (11) The operator again steps on the pedal and the cycle begins anew.

The diaphragmatic hose as well as the pilot cylinder and pipe are filled with water from the surface upon installation in the well. The pilot system being completely closed, apart from a refilling valve, there should be no potential for contamination of the pumped water.

5.6.2 Observations

In spite of careful development work and many laboratory tests (including testing of the flexible diaphragmatic hose for over 2 million cycles, without failure), some modifications of the "Vergnet" pump's original design proved necessary in view of difficulties experienced under field conditions. The PVC used for the rigid cylinder was found to develop cracks due to the continuous pressure variations, and was replaced by stainless steel. Leather cup seals used in the pilot cylinder did wear very quickly; a marked improvement was achieved by the introduction of piston rings with leather or urethane seals.

In wells less than 30 meters deep, light-weight flexible piping can be employed in the "Vergnet" pump assembly facilitating its installation and maintenance. Pipes and pumping unit are readily pulled from the well. Normally, two men should be able to do this by hand so eliminating the need for tripods or scaffolding. The use of light-weight materials also should save on transport costs.

In reciprocating hand pumps the short life of cup seals is a major maintenance problem, especially for deep well pumps where the pump rod, discharge pipe and cylinder have to be pulled up in order to replace the seals. In the "Vergnet" pump all rubbing parts are readily accessible at the surface.



Photos: Courtesy of L.A. Orihuela

FIGURE 5-9 HYDRO PUMP "VERGNET"

From top right, counterclockwise: (1) pump in operation, (2) control pedal, driving piston and cylinder, mounting plate, and attached flexible control and delivery hoses after removal from well, (3) replacing leather cap and piston, and (4) lifting the pumping cylinder from the well. This cylinder contains the elastic expansion chamber and the three valves (suction, delivery, and repriming).

Another group of maintenance problems in conventional hand pumps is associated with handles, pump rods, and handle/pump rod linkages - components which are non-existent in the "Vergnet" pump.

Because the "Vergnet" pump is foot-operated, it can be pumped with more power and less fatigue than the conventional lever operated pumps. The linear movement of the foot pedal eliminates all rotating components.

The "Vergnet" pump requires a well casing of 4-inch (100 mm) or more. It can be used as a lift pump or lift-and-force pump, but not as a suction pump; its pumping cylinder must be immersed.

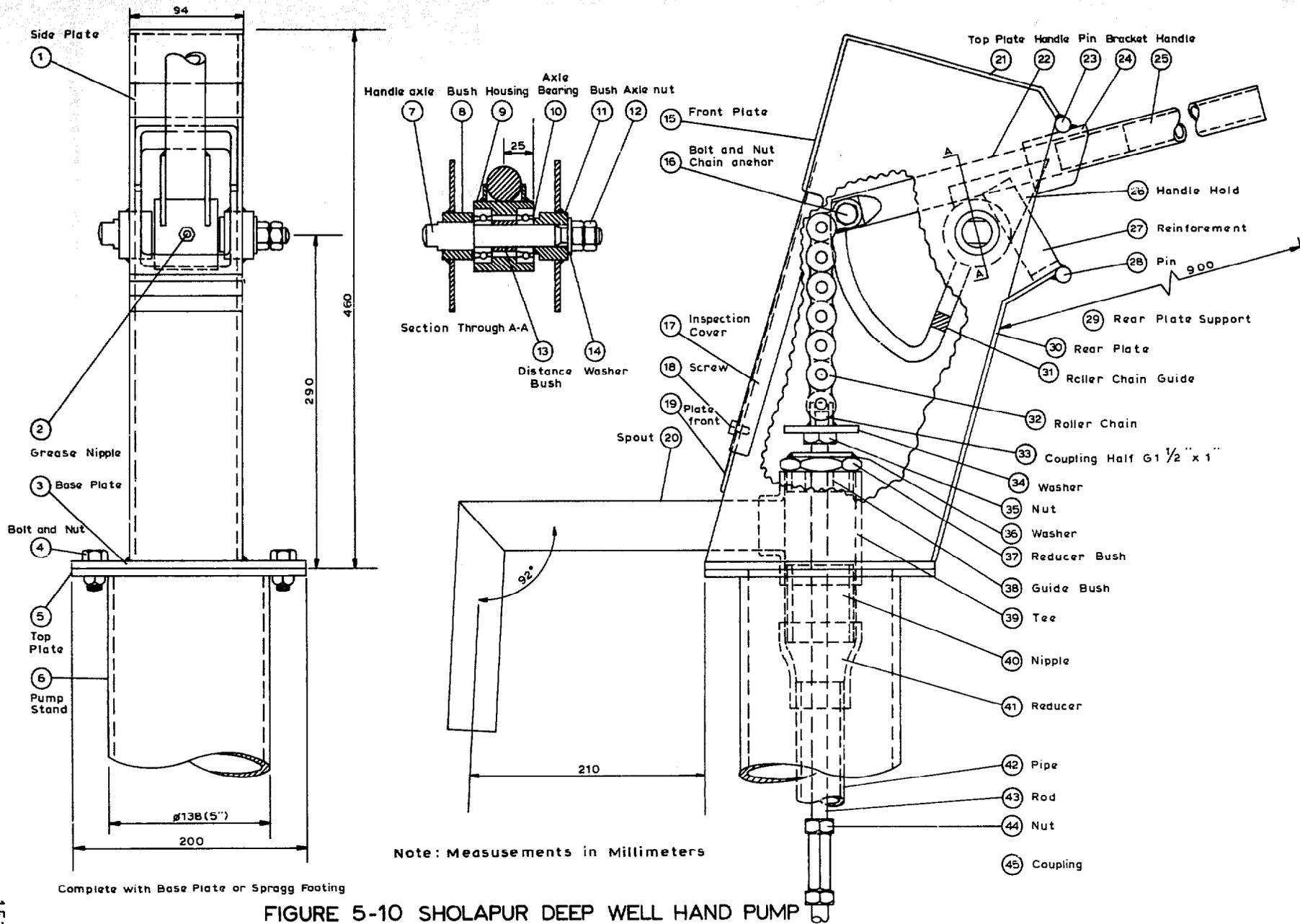
According to the manufacturer (Mengin), of the 2000 "Vergnet" pumps installed so far (June 1977), about 70% operates at pump depths between 20 m (70 ft) and 60 m (200 ft). In most African countries "Vergnet" pumps have been installed, with the largest number (500) in Ivory Coast where a first government programme has just been completed (June 1977). Outside Africa, the pump has not yet found wide-spread use.

Factors likely to influence wider acceptance of the "Vergnet" pump are:

- (1) It is relatively high priced at U.S. \$ 600 (October 1976 price list) for pump Type A or C complete with one set of service parts and tools. (A set of maintenance parts including one pedal guide and four leather piston rings, is quoted at U.S. \$ 4).
- (2) The need to import the unique parts, i.e. the flexible diaphragmatic hose, the stainless steel cylinder and foot pedal, and piping.

5.6.3 CIEH Report

The report of this study is scheduled for some time in 1977. An earlier CIEH study (circa 1964) is a descriptive account of the man and animal powered pumping methods then in use in West Africa including many of ancient origin. (Also see papers by Benamour, CIEH, Gagara, and Vergnet and manufacturer's literature from Mengin).



Complete with Base Plate or Spragg Footing

FIGURE 5-10 SHOLAPUR DEEP WELL HAND PUMP TOP END MECHANISM

Courtesy : Sholapur Well Service

5.7 OTHER RESEARCH AND DEVELOPMENT

5.7.1 Sholapur or Jalna-Type Pumps

Many breakdowns of deep well hand pumps occur in the handle assembly. A sturdily constructed pump developed in India over the past few years by a group of voluntary agencies is called variously the 'Sholapur', 'Jalna', or 'Mission' pump. This pump can be expected to work for a year between overhauls for maintenance (McLeod, 1974). Locally manufactured, it is being installed in Indian villages, complete with 100 feet of drop pipe and pump rod, for about US \$ 235 per unit. This pump uses welded steel fabrication, roller bearings, sealed lubrication and has a single pivot action connecting the handle to the pump rod through a short length of motorcycle chain. All moving parts are enclosed in a steel housing. (See Figure 5-10). This pump is widely used in hand pump rehabilitation programmes (Jagtiani).

5.7.2 U.S.T. or Kumasi Pump

A pump suitable for local manufacture has been developed since 1972 at the University of Science and Technology, Kumasi, Ghana. This pump, shown in Figure 5-11, has a welded steel, 3-inch diameter pump stand; two-pin handle linkage with a roller bearing at the fulcrum and a brass bushing at the connection of the pump rod joint to the handle; a plunger cast from brass^{*}; and a leather cup seal. The cylinder is a 3-inch diameter plastic pipe section that hangs from the pump body. Preliminary testing has been carried out at depths up to 100 feet (30 meters). Testing is still in progress.

5.7.3 The Petro Pump (Sweden)

An interesting new variation of the diaphragm pump, suitable for use in deep wells, is the Petro pump. The pumping element or 'cylinder' consists of an elastic rubber hose, reinforced by two layers of spirally wound brass-coated steel and equipped with a stainless steel check valve of the poppet type at each end. The suction valve housing at the lower end of the hose is fixed within the well by expander jaws which are wedged against the well

*

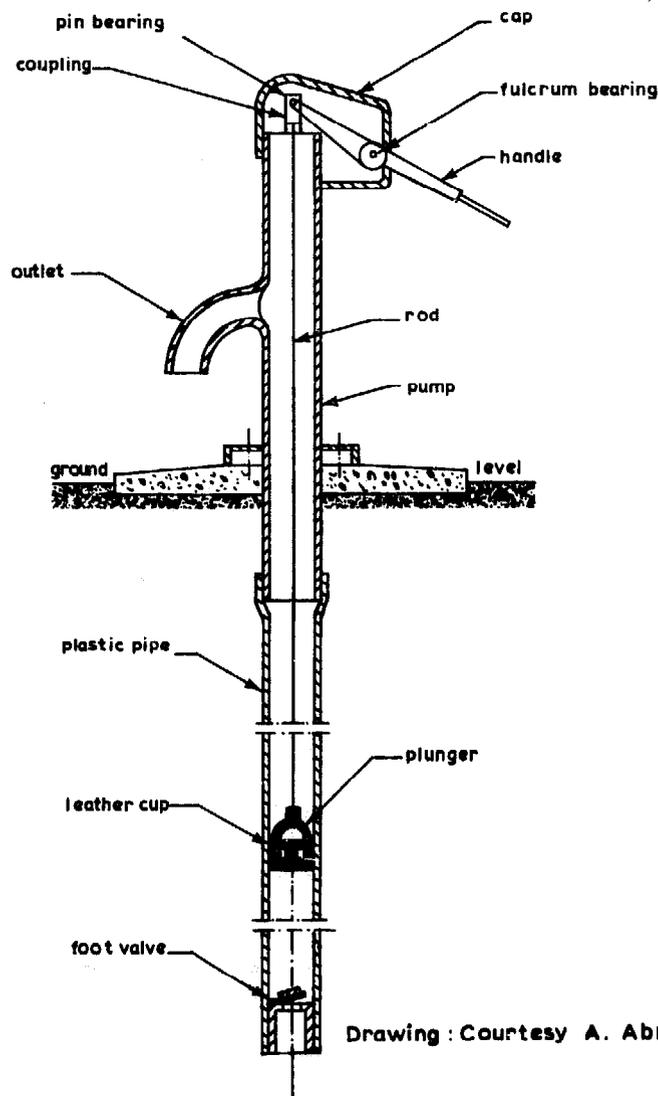
Casting is by the "lost wax" process used for centuries in Africa and Asia.

casing, and which can be disengaged by turning the pipe string a dozen turns clockwise. The discharge valve housing is attached to a string of $\frac{3}{4}$ -inch (19 mm) galvanized pipe serving as both the pump connecting rod and the drop pipe. The upper end of the pipe string with the delivery spout is connected to the pumping head.

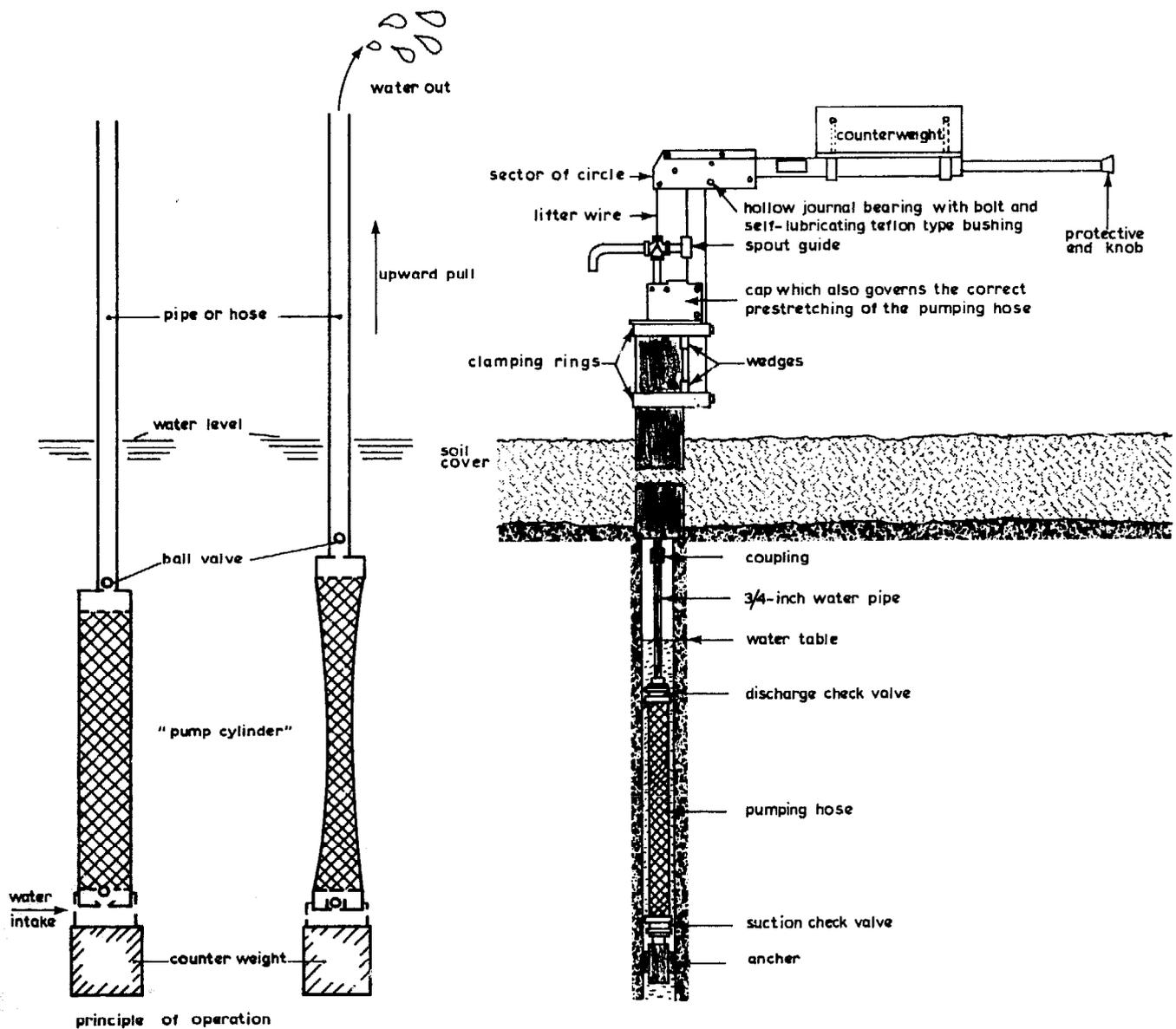
A new pumping head has been specially designed to work in correct conjunction with the elastic characteristics of the pumping hose, but a traditional pumping head may also be suitable.

The discharge capacity of the standard pumping element is approximately 0.5 liter per 10 cm (4-inch) stroke, and can be increased by using a longer hose. The 'Petro' pump can be made in small diameters.

FIGURE 5-11 U.S.T. (KUMASI) HAND PUMP



Drawing : Courtesy A. Abrobah-Cudjoe



note : alternative method for fixing lower end of pump cylinder to well casing is by use of expanding wedges or jaws

FIGURE 5-12 THE PETRO PUMP

The 'Petro' pump is operated as follows:

- (1) Push down the handle, thereby lifting the pipe string and stretching the reinforced rubber hose approximately 10 cm (4 inches).
- (2) Due to the effect of the spirally wound steel wires, the hose decreases in volume (displacement); the increased pressure within the hose opens the discharge valve, and water is forced through the pipe string to the surface.
- (3) On the return stroke of the handle, the rubber hose retracts to its original, larger volume; the suction check valve opens, and fresh water is sucked in.

Obvious advantages of this new pumping concept are:

- (1) The elimination of the usual cup seals or buckets. There is practically no mechanical friction during pumping, and water containing fine sand or silt may be pumped without appreciable wear to the pumping hose.
- (2) The combining of pump rod and drop pipe results in considerable savings in piping. The relatively low weight of the required piping facilitates installation, inspection and maintenance. It is claimed that the pumping element together with the string of pipes can be readily installed by hand, so that no tripod, scaffolding or installation truck will be needed.
- (3) No stuffing box is needed, when the pump is used as a force pump.

At present (June 1977), two types of the 'Petro' pump are commercially available:

- Type 95, with standard wedges, suitable for wells of 4 to 4½ inch (95 to 120 mm).
- Type 48, suitable for 2-inch wells (diameter 48 to 60 mm).

The latter type should be of particular interest for use in small-diameter wells with the water table deeper than 22 feet (6.7 meter), i.e. where suction pumping is not practicable.

The price for one complete pump (pumping element with anchor, and pumping head) is: Swedish Kronor 2,000 (U.S. \$ 440).

Shipping weight of a complete pump is only 43 kg (95 lbs) which should save on transport costs.

5.7.4 Shinyanga Pump

The Shinyanga District Shallow Wells project was started in October 1974 as a bilateral project of the governments of Tanzania and the Netherlands. (Shinyanga Shallow Wells Project, 1976).

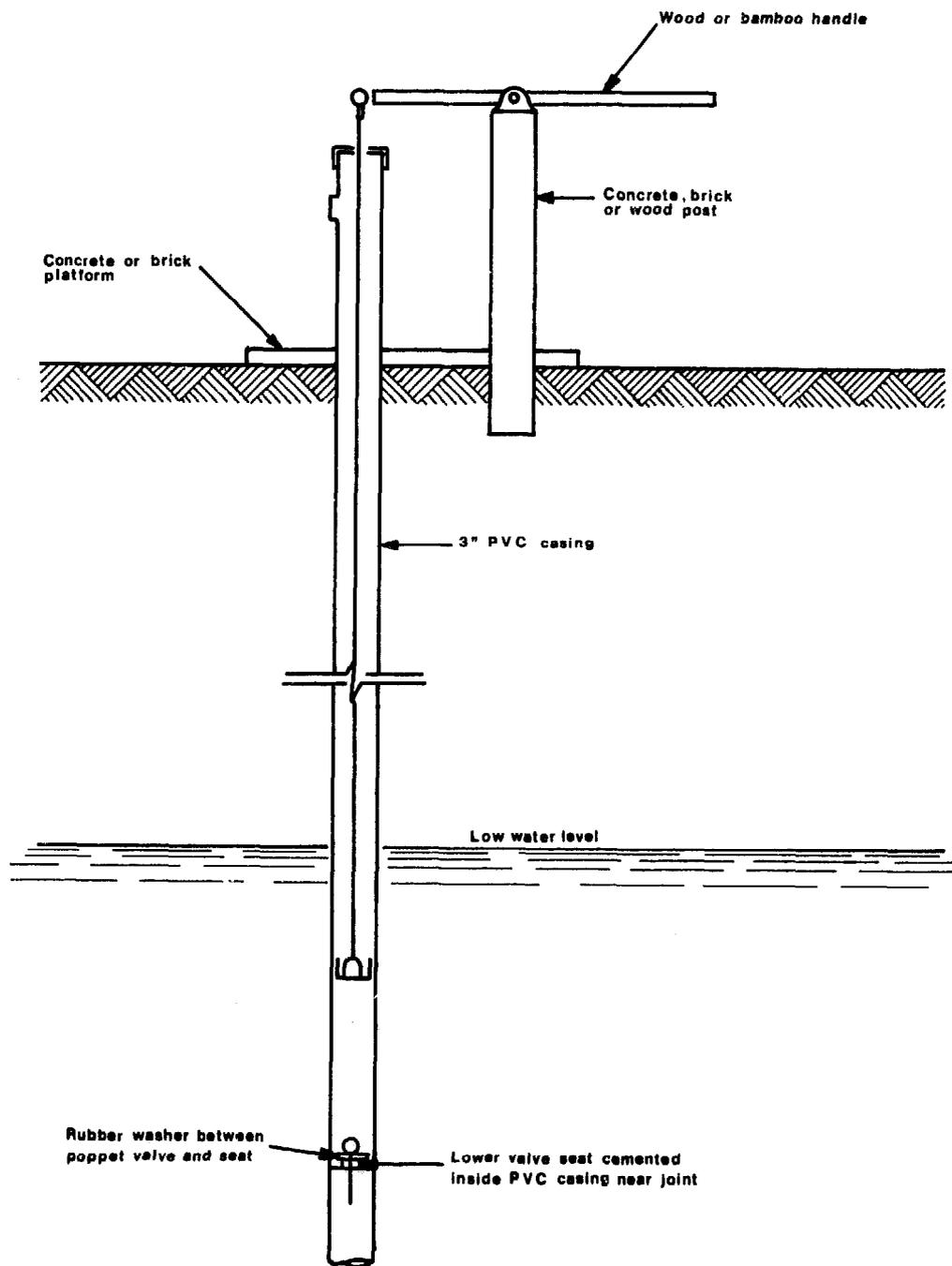
This project has created its own manufacturing facility. The pump made and used, termed the Shinyanga Pump, has a wooden pumping head which closely resembles the Craelius Uganda, manufactured in Nairobi and widely used in East Africa. (See Figure 6-3). However, whereas the Uganda pump uses a brass cylinder, the Shinyanga pump uses a polyvinyl chloride (PVC) plastic cylinder. The groundwater in Shinyanga, with its laterite soils, has a pH of 3. The life of some cast iron parts is measured in months. Initially brass cylinders were used, but "39 of 50 Craelius brass cylinders went to earrings".

The Shinyanga cylinder also uses a rubber double ring cup seal with an internal, shape retaining stainless steel ring, manufactured and used in Europe for hydraulic machinery. The cup must be imported and is relatively expensive (about US \$10 each). However it is expected to last longer than the rest of the pump - perhaps 10 years. The cylinder also uses neoprene ball valves.

5.7.5 Plastic Pipe Pump

A spreading idea is the use of polyvinyl chloride (PVC) plastic pipe in pump construction. Cylinders made of PVC pipe are commercially available (e.g., Dempster) but many designs (e.g., DIY, SISCOMA, U.S.T., et al. pumps) incorporate PVC well casings as cylinder walls. That is, the well casing itself is one long cylinder although the stroke length is normal, generally less than a foot (0.3 meter). Figure 5-13 is an example (Spangler, 1976). This "novel" idea, a return to common practice of earlier times of dug wells with wooden or lead-bodied pumps offers potential opportunities for economy and local production but is yet untested on a large scale.

FIGURE 5-13 POLYVINYL CHLORIDE (PVC)
PLASTIC HAND PUMP



After: Spangler (VITA)

The most complete presentation is that of Journey (1976) who outlines potential PVC valves as well and describes several experimental pumps tested in Bangladesh in 1974. The latter are perhaps the only hand pumps in which the pump stand itself was plastic. Plastic pump stands are less sturdy and more subject to wear and breakage than stands of other materials.

Plastic pump stands in which the plastic must support the fulcrum are not likely to give good service because of the susceptibility of plastic to weathering and to notch effects (fatiguing). Attaching the pump stand to the casing in the traditional sense becomes with plastic pumping systems a problem of housing the plastic above grade with a protective covering which also supports the mechanical load. A pump stand which must be assembled at the well site should incorporate a device, such as a jig, to maintain the proper alignment of the pump rod.

Pumping sand in a plastic cylinder can result in rapid wear but may be avoided by properly selecting the wellscreen slot size and by adequately "developing" the well, which stabilizes the aquifer.

Development and evaluation of various pumps using plastic components with wood pumping stands is planned by the International Development Research Centre and the World Bank.

5.7.6 Other Research and Development

(1) With WHO assistance, the Asian Institute of Technology (AIT) investigated the use of foot powered, low lift, pumps as standby or replacement pumps at rural water plants. (Thanh, et al.). This work is in response to a 1973 study (Frankel) of operation of 165 village water supply plants in Thailand which found that pumping problems kept the plants shutdown 17 percent of the time period studied and were the cause of 57 percent of all shutdown time. The pumps in question were electrically or petroleum powered.

One pump under test was developed for low lift irrigation at the International Rice Research Institute in the Philippines under an AID research contract.

(2) A standard hand pump (Dempster Model 23F-Ex) of U.S. manufacture has been widely used by UNICEF and others in wells of moderate depths following adoption of special modifications including ½-inch stress proof, cadmium plated steel pins equipped with nylon bushings, a urethane "bumpblock" on the fulcrum link to cushion blows from the handle, and non-rotating pin cotters. This pump is commonly sold with brass cylinders with spool valves. A major attraction is its price, less than \$150 (as of 1975). Dempster has also developed and is marketing PVC cylinders.

(3) Two pumps, the "Pompe a Balancier" and the "Pompe a Pieds", under development by SISCOMA in Dakar incorporate two design features previously described: use of the PVC drop pipe or well casing as the pump cylinder (as in the U.S.T. pump); and a steel cable as the pump rod (as in the Bangalore pump). The "Pompe a Pieds" is foot operated using a treadle. (Christensen, de Pury).

(4) A foot-operated pump named the "Kangaroo Pump" (see figure 5-14) is marketed by a Dutch manufacturer. The pump has been tested in several water supply projects. The pump head consists of two pipes sliding over each other, with a spring fitted in between. The outside sliding pipe is connected to the pump rod, and operates the piston in the pump cylinder. The downward stroke serves to compress the spring, which is then left to produce the water discharge upward stroke. A similar pump has been tested in Ethiopia (Jensen, 1976)

Normal cylinder diameters are 4 inches up to 6 meters depth, 3 inches up to 10 meters, and 2 inches up to 20 meters. The capacity range is 600-2000 liters/hours.

(5) A firm in the Federal Republic of Germany is developing plastic cylinders. A preliminary report of an extensive testing program is available (Journey, 1976).

(6) Local adaptation and production of the AID Battelle pump is under consideration in several countries.

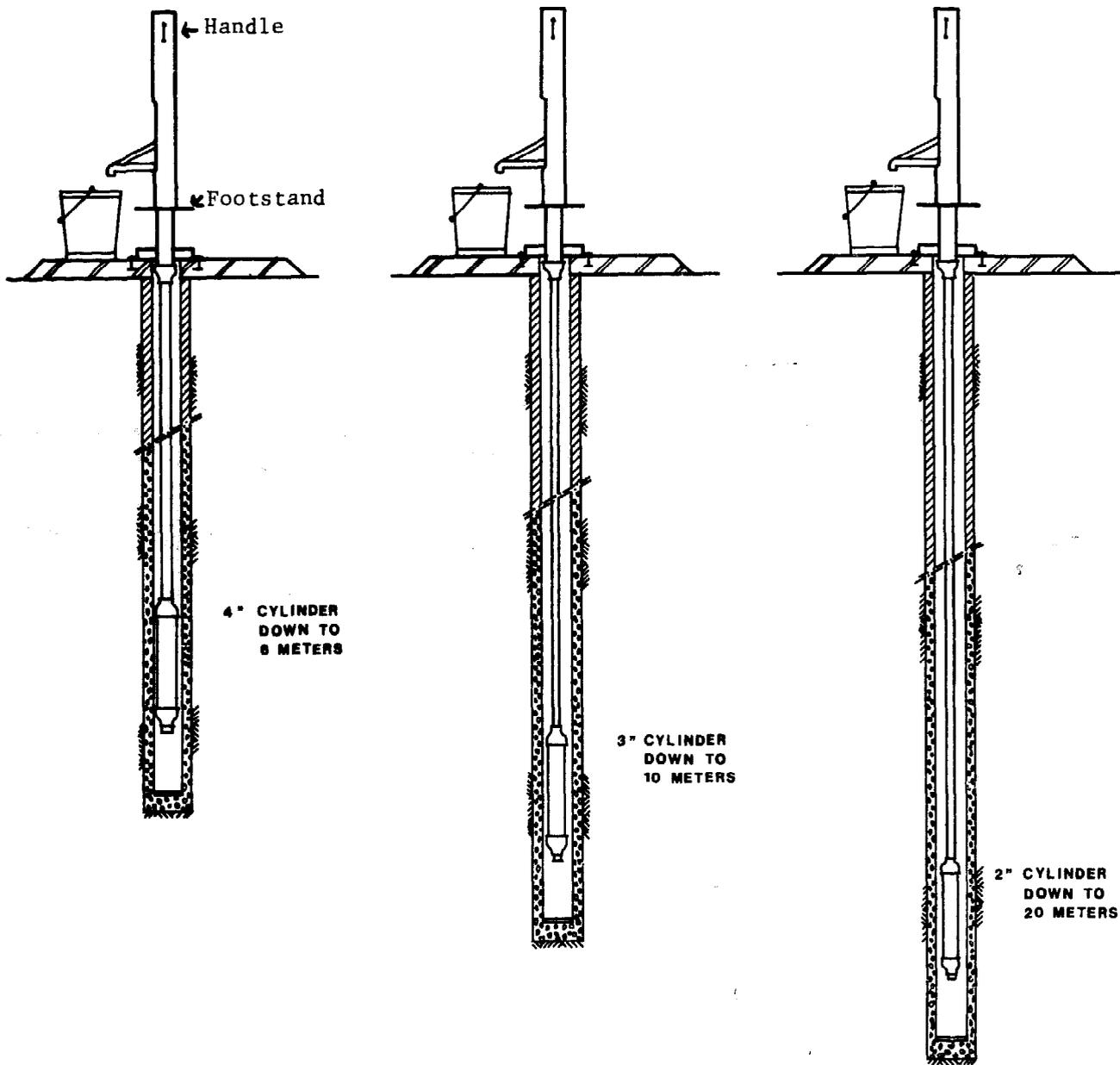


FIGURE 5-14 THE "KANGAROO" PUMP

- (7) Testing of wood bearings is underway at the University of Maryland (USA).
- (8) Possible refinements of the "Uganda" pump are being evaluated in Ethiopia.
- (9) Comparative pump testing and evaluation programs are underway or planned in several countries, including Ghana and Ethiopia.
- (10) A pump using a galvanized iron pipe body, the Sialkot pump, is under development in Pakistan.
- (11) An English manufacturer is experimenting with top of the well hand driven ejector pumps.
- (12) The International Development Research Centre is sponsoring evaluative work on new pump developments in such fields as chemical engineering and bio-medical engineering and their possible use in hand pumps.
- (13) Considerable research is underway in such related subject areas as solar pumping and windmill technology.

5.7.7 Pump Development by National Agencies

In recent years agencies in many countries have undertaken, some informally, to develop or improve indigenous pumps. Such work is underway in Afghanistan, Bangladesh, Burma, India, Indonesia, Pakistan, the Philippines, and Thailand; Ethiopia, Kenya, Malagasy Republic, Malawi, Mali, Tanzania, Tunisia, and Zambia; Bolivia, Costa Rica, Honduras, Ecuador, and Nicaragua.

5.8 INTERMEDIATE TECHNOLOGY

Such organizations as Volunteers for International Technical Assistance (VITA), the Intermediate Technology Group, Ltd. (ITG), and others maintain a continuous interest in development of "appropriate" or "intermediate" technology for rural areas and have collected considerable information on pumps suitable for manufacture by village artisans and labor intensive shops. Many ideas collected by VITA and ITG and by an IRC survey are listed in the bibliography. Some of the more promising are described in Sections 6-4 to 6-8. VITA has recently published a report (Spangler, 1975) on village well

hand pumps of plastic pipe, wood, and rubber suitable for construction by local machine shops. (See Figure 5-13.) Similar pumps have been produced in small quantities in several countries.

5.9 GENERAL OBSERVATIONS

The following observations are based on a review of recent hand pump research and development:

- (1) Pump improvements that seem obvious in the office or laboratory often do not work in the field. A corollary is that successful performance in the laboratory does not guarantee success in the field.
- (2) Many investigators seem unaware of the work of others on hand pumps. Literature reviews are virtually non-existent and communication between investigators is poor. Communication media are inadequate.
- (3) Cost data are generally insufficient for operational decisions. Life cycle costs are never analyzed.
- (4) Comparison and evaluation of hand pumps on an international basis will require common definitions, criteria, and methodologies which are presently unavailable, even as a checklist. Some investigators have even failed to measure the pumping head, others to count the cycles in their tests.
- (5) Experimental methodology is rarely stated, often even the hypothesis is only implicitly stated. Scientific objectivity leaves much to be desired. Conclusions are awesomely extrapolated from limited, short term testing of single, handmade prototypes.
- (6) Many basic assumptions are untested. For example, no thorough, fully conclusive, definitive study of wear and abrasion of PVC pipe for use as pump cylinders has yet (1976) been published.

(7) Cross-disciplinary studies have been rare. With a few notable exceptions, modern findings from such subjects as ergonomics, anthropometrics, metallurgy, lubrication, friction, materials science, et al., have been ignored.

(8) Many investigators have grossly underestimated bearing wear and loading common to deep well hand pumps for community use. Many hand pump handles (and other working parts) receive over 5 million strokes per year. The average pump rod tension for a 3-inch (approx. 75 mm) cylinder under a head of 100 ft. (30 m) is over 300 lbs. (140 kg); instantaneous loading may be much more.

(9) For all but the largest, most research and development programs should start small with improvements to existing models, locally available; and concentrate on improved maintenance, larger bearings, better cup seals, and smoother cylinders.

6. LOCAL MANUFACTURE OF HAND PUMPS

6.1 BACKGROUND

The desirability of local manufacture of hand pumps is based on possible opportunities for:

- (1) Lower capital costs of production
- (2) Transportation savings
- (3) Reduction in foreign exchange requirements
- (4) Stimulation of local industry and labor forces
- (5) Better access to replacement parts
- (6) Production of a hand pump tailored to local conditions.

The above objectives are achievable but not automatically so. There are hundreds of thousands, possibly millions, of broken and abandoned hand pumps around the world. There are no savings to be had in nonfunctioning pumps. Thus locally manufactured (and imported) hand pumps must be of the necessary quality for the performance sought.

Before beginning local manufacture available alternatives must be evaluated. For example, should parts be purchased locally, imported from a foreign country, or made nationally. Should parts be made from castings (requiring foundry facilities), fabricated (using welding techniques) or, perhaps, from various forms of plastics. The economic and the technical feasibility of each alternative must be evaluated.

There are two types of local manufacture to be considered. The first is mass production in foundries, machine shops, and factories of cast iron or steel pumps similar to those in the international export market. Such manufacture is practical and practised in many developing countries. The second type of local manufacture requires a lower level of technology and lends itself to production in small quantities by village artisans. Both types are important, but for all but the smallest or most sparsely populated or least developed countries, the first type will generally be much more important due to its capacity for mass production of more durable, more interchangeable pumps.

Hand pumps are made of many dissimilar components. Thus a complex of suppliers of castings, leathers, rods, pipe, valves, pins, nuts and bolts, and other parts may be necessary to assemble the complete pump.

6.2 CONVENTIONAL CAST IRON HAND PUMPS

6.2.1 Foundry Practices

The majority of the world's hand pumps for drinking water utilizes cast iron bodies and cast iron or brass cylinders. These materials have over 100 years of successful and economical service and are likely to continue in use for many years although other materials will also be used. As numerous foundries in the developing countries have demonstrated, such castings are within their ability to produce. Frequently however, too little attention has been given to quality control, particularly in the face of price competition without product standards.

6.2.2 Composition and quality of iron and coke

The raw materials for gray iron castings are pig iron and coke. Pig iron used in pumps should meet the specifications outlined in Table 6-1 (Fannon and Varga, 1972).

TABLE 6-1 SPECIFICATIONS FOR FOUNDRY PIG IRON

Values given in percent

<u>Silicon</u>	<u>Carbon</u>	<u>Manganese</u>	<u>Sulfur</u>	<u>Phosphorus</u>
2.50 - 2.75	4.10 - 3.85	0.50 - 1.25	0.05 max	0.30 - 0.50
2.76 - 3.00	4.05 - 3.70	0.50 - 1.25	0.05 max	0.30 - 0.50
3.01 - 3.25	3.90 - 3.65	0.50 - 1.25	0.05 max	0.30 - 0.50
3.26 - 3.50	3.85 - 3.60	0.50 - 1.25	0.05 max	0.30 - 0.50

After Fannon and Varga (1972)

The carbon ranges listed are only an indication of the desired carbon content of the pig iron. To make foundry pig iron to specified silicon and carbon contents is difficult. However, the carbon content and silicon content should be in balance in order to produce gray cast iron castings with less variation in composition. The silicon content should and can be supplied to the designated ranges, and the carbon content should be reasonably close to the values indicated. As an example, the silicon content may be specified as 2.76 to 3.25 percent - the corresponding carbon content should be in the range of 4.05 to 3.65 percent. (The carbon contents are shown in a reverse order intentionally because as the silicon content increases in pig iron, the carbon content will decrease. This is a characteristic of the blast furnace process used to manufacture pig iron). High phosphorous content may result in formation of massive steadite, a eutectic mixture of iron carbide and iron phosphide that can cause brittleness and excessive breakage, has low resistance to impact, and is difficult to machine.

As a part of the specification, a periodic chemical analysis of the pig iron should be provided by the supplier and verified by chemical analyses before the pig iron is accepted.

Foundry coke should also be purchased to specifications. Coke is more difficult to make to narrow specifications than is foundry pig iron; the specifications should act as a guide in purchasing agreements. A recommended specification (Fannon and Varga, 1972) is shown in Table 6-2. Additionally the caloric content should average 2500 million BTU per short ton. Coke should be covered in storage and protected from moisture.

TABLE 6-2 FOUNDRY COKE SPECIFICATION*

<u>WEIGHT BY PERCENT</u>			
<u>Fixed Carbon</u>	<u>Volatile Matter</u>	<u>Ash Content</u>	<u>Sulfur Content</u>
88.0 min	1.0 max	12.0 max	1.0 max

* After Fannon and Varga (1972)

The values specified are a guide for purchasing foundry coke; however, every effort should be made to obtain foundry cokes that have a minimum ash content. Sulfur content also should be as low as possible. The higher the sulfur content in the coke, the higher will be the sulfur content of the gray cast iron produced, and the greater possibility for metallurgical problems produced by high sulfur contents.

6.2.3 Making molds and cores

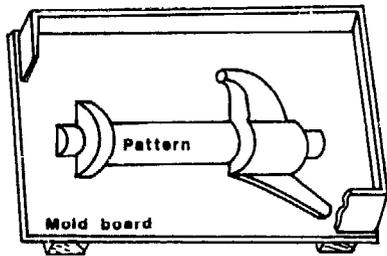
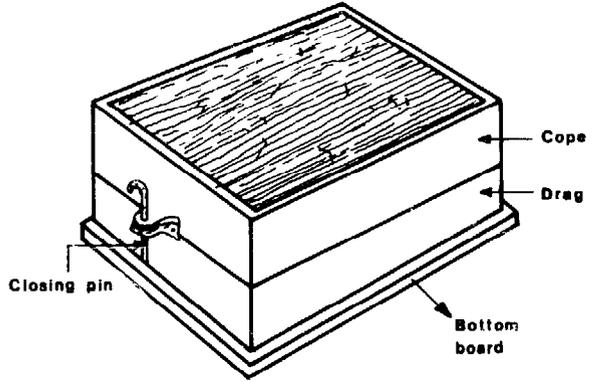
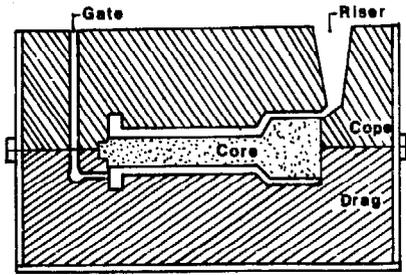
The making of iron pumps requires a manufacturing scaled drawing which is turned over to the pattern maker who carves and turns on a lathe a wooden model the size and shape of the main body of the finished pump. The handle and other loose parts are made separately. The main body of the pump, being hollow, is the most difficult part to make. The model is cut in half lengthwise. Dowel holes are bored so it can be put back together in perfect alignment. A second model, made to fit the bore of the pump, is known as the "core". See Figure 6-1.

The core is used to form the cavity in the pump which is later machined to the specified dimension and tolerance to accommodate the plunger in many shallow well pumps. This cylindrical core is inserted in the mold after the wood pattern has been removed from the mold. The core is prepared in wooden molds (core boxes) and kept in an oven at a low temperature (about $400^{\circ}\text{C}.$ = $752^{\circ}\text{F}.$) to harden and dry.

The core is surrounded by hot metal during pouring, therefore, it is subjected to very high temperatures and must be made of special core sand with a high silica content. Special bonding materials must be mixed to the core sand for binding purposes. These come in both liquid and dry form and are typically made of wheat flour, rye meal, powdered resin, and linseed oil.

The most important part of the job is making the cavities in the sand, that is, preparing the molds, because if this is not done correctly, a defective casting results. The molds are built into the required shape by hand,

ASSEMBLY READY FOR POURING



TYPICAL SECTION THROUGH SMALL PUMP FOR SHALLOW WELLS

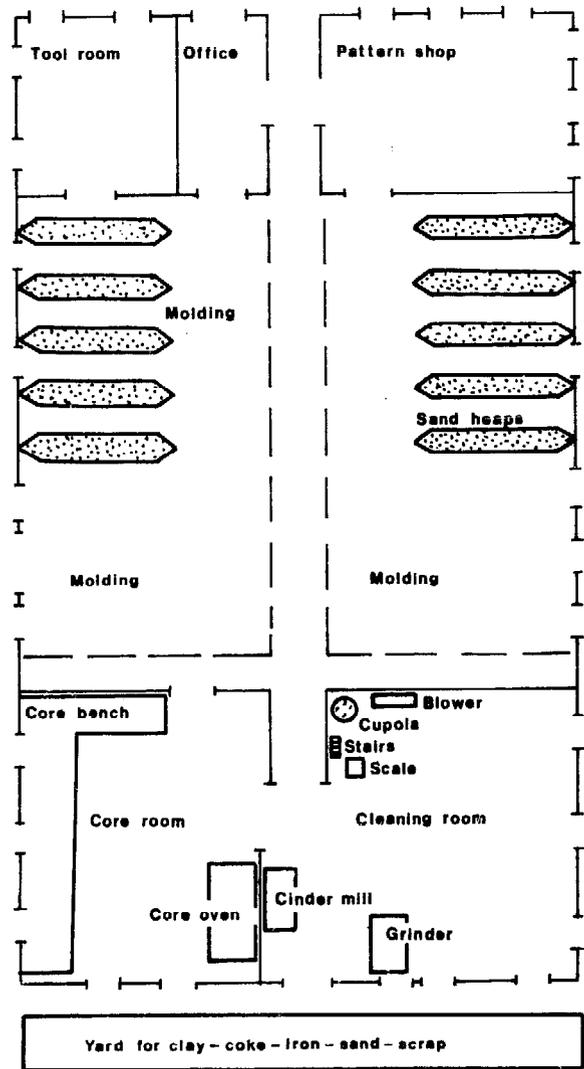
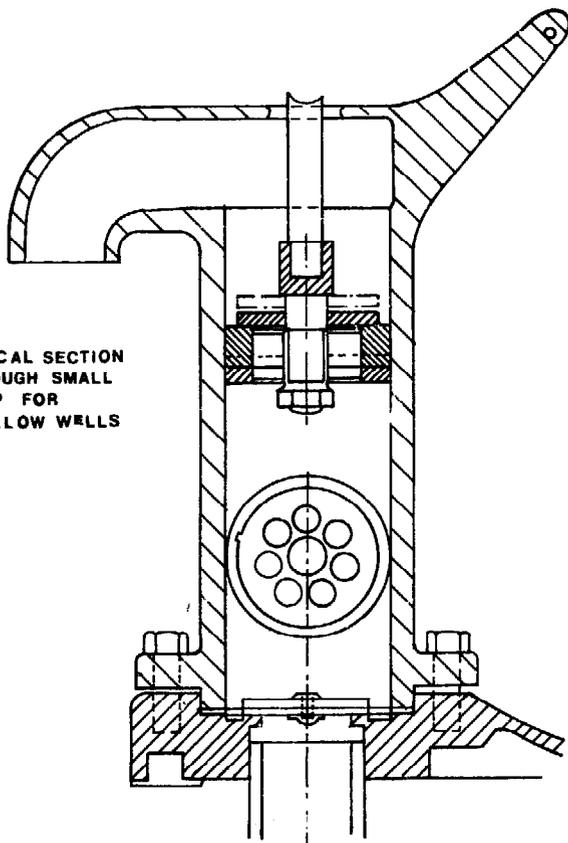


FIGURE 6-1 TYPICAL FOUNDRY LAYOUT AND EQUIPMENT

and the wood pattern for the mold should be oversize to allow for shrinkage in the casting. Cast iron shrinks about 1/8-inch per foot (about 1 percent) in cooling from the molten state to room temperature.

The best quality sand adapted for foundry use can be obtained only through careful examination of the sand available. The sand should be well graded, tested and should stand a high sintering point of 2500°C (4532°F.) For each pouring operation a new mold must be made. Properly selected sand can be retamped and used for successive molds by adding a small amount of new sand to provide bond. Permeability or the ability of the tamped sand to permit the passage of gases through it is a very important property. Finer grained sands composed of sharp, angular-shaped particles are best for general molding work as they have good porosity and form a good bond, having more open structure than sands of round grain.

To make the mold, a long box, with no top or bottom, called the "drag" is laid on a long flat plank. One half of the pump is laid flat side down, on the plank, inside the drag. Molding sand is put in the box around the pattern then tamped and rammed until firm.

The half mold is then carefully turned over and the sand scraped off level. The other half of the pattern is set in place on dowel pins to get the two halves in perfect alignment. Parting sand is sprinkled on to keep the mold from sticking.

The cope or top half of the flask is then set on, clamped, filled with sand and tamped firmly. A pour-hole is made by putting a round stick through the sand to, or near the pattern. The two parts are then separated and the pattern lifted out, which leaves the mold the exact size and shape of the pump.

The core is now ready to be put in the mold. But first it and also the inside of the mold box are coated with plumbago (graphite) which prevents adhesion and leaves a fairly smooth surface on the casting. A pin or

extension protruding out at each end of the core, rests in a groove, which holds it suspended in the mold. Small metal separators, like short nails with two heads, called "chaplets" are used as dividers to help keep the core in adjustment. They are absorbed in the casting.

The making of a complete set of aluminum master patterns for a hand pump may cost several thousand dollars. Thus an agency seeking standardization of its hand pumps and wishing to retain price competition on small orders may wish to consider owning its own patterns for its pumps and loaning them to successful bidders for measuring against for large lots, or for directly casting small lots.

Gates are channels cut into the mold to permit the molten metal to reach the casting cavity. The riser is that part of the mold where the excess metal above the casting flows and serves to keep the body of the mold full and to receive any dirt or scum which rises. The riser is designed also to carry off the air pushed out of the mold by the inflowing metal, when the mold is filled with the metal. For a small casting, a single riser and gate are sufficient as the hot metal does not have far to run.

6.2.4 Melting the Metal

The cupola is the most widely used foundry furnace for melting iron for ordinary castings. The cupola is charged with pig iron, limestone, iron scrap (defective castings, gates and risers), and steel scrap, the relative proportions depending upon the desired composition of the castings to be poured. This cupola is a straight shaft furnace, open at the top, lined with special fire-clay brick and charged through doors about halfway up the shell, with alternate layers of coke and iron and with a little limestone added to flux the coke ash and make the slag more fluid. The slag consists of ash from the coke, impurities from the metal and material from the sidewalls of the cupola. The amount of coke used for each charge is from one-fourth to one-twelfth of the weight of the melted iron, depending

upon the amount of steel scrap used and the pouring temperature desired.

Air is blown in through tuyeres near the bottom to burn the coke and to produce the heat of combustion necessary to melt the iron. At the bottom of the cupola is a pair of hinged cast-iron doors which are dropped after all molten metal has been withdrawn. This is to let the residue of iron in the cupola fall out and be taken away. The cupola is encircled near its base by the wind box, into which air is forced by a blower. The wind box is connected to the interior of the cupola by the tuyeres, which are of cast iron and flare upward slightly.

Chemical composition of the metal tapped from the cupola is determined by the chemical composition of the metallics charged, the amount of coke used, and the rate at which air is blown into the cupola. Minor adjustments in the chemical composition can be made after the metal is tapped by the addition of ferro alloys in the ladle or in a holding furnace (known as a fore-hearth) if such equipment is used. Such techniques may not always be easily carried out in developing countries.

6.2.5 Pouring the Casting

The upper part of the mold, called the cope, must be weighted down so that the buoyant force of the metal will not lift it and allow some metal to flow between the cope and the lower part called the drag, and solidify there. The molder takes a ladle-full of metal at the proper temperature from the furnace and pours it down the gate of the mold in a steady stream, taking care not to break the stream at any time. The gate should be kept full of metal at all times in order to minimize the washing of sand into the mold. Pouring is continued until the level of the metal reaches the top of the riser. The metal, allowed to solidify and cool before being shaken out of the mold, now emerges as a raw casting. The gate and riser are cut off the surface of the casting, and the raw pump body is passed on for cleaning.

6.2.6 Cleaning the Casting

To prepare the casting for use, it is necessary to remove the gate and riser, fins, scabs, and sand. Removal of the dry sand core by rapping is usually the first operation. Gate and riser can be broken off with a hammer and chisel, or cut off with a hacksaw. Removing the fine chips and lumps is done with an electrical, portable grinding wheel, and the surface sand which might have fused with the casting may be brushed off with a coarse iron brush.

6.2.7 Casting Handle, Cap, and Other Parts

While these are much simpler castings, the processes used are the same as for the pump body.

6.2.8 Machining

Finishing of the pump body, the bottom plate, and the piston is done in the tool room.

Some sand adheres to the surface of castings even after the considerable amount of impact the casting may receive during shake-out and removal of gates and risers. This tightly adhering sand may be removed by wire brushing or the use of a technique called "shot blasting". Castings are placed into a unit, usually having a cylindrical chamber, and small balls of steel, or other hard metals, are thrown at the castings at high velocities. The impact of millions of these balls does a very effective job of removing the tightly adhering sand. Another method uses high-pressure water to remove the adhering sand. Tumblers may be used for small pieces.

Abrasive grinding is used to remove the stubs of metal protruding from castings. The grinding operation consists of grinding away the excess metal and blending that part of the casting with the desired contour at that particular location. Certain defects may also result during the casting process and leave positive, or excess metal protrusions, on the castings. These also are removed by grinding. Grinding is done by two general methods,

one employs grinders that are fixed to a floor mounted base, and the other makes use of hand grinding tools. The first method is used for castings that can be hand held during the grinding operation. Jigs and fixtures are usually used to permit removal of only the desired amount of metal. Hand grinders having grinding wheels 6 to 8 inches (15 to 20 cm.) in diameter are usually used in removing excess metal from larger castings that cannot be hand held. Smaller grinding tools, using cylindrical and pointed abrasive wheels are used on all sizes of castings to grind away excess metal in deep cavities or complicated surface configurations.

Following the grinding operation, the castings are ready for the next processing steps, which consist of boring, drilling, threading, and facing operations. All of which can be done with turning and drilling type tools such as lathes and drill presses. In high production operations, automated, mechanical-fed and indexing machines are used. However, small shops depend largely upon in-house made jigs and fixtures, specially ground tools, and small tool indexing devices for increased production and accuracy of machining. Indentations in the castings for starting drilled holes and jigs and fixtures are needed to insure interchangeability of parts as well as gauges and special tooling for increased production.

6.2.9 Requirements for Establishment of Manufacturing Facility

A complete set up for the manufacture of hand pumps would require an iron foundry and a machine shop. If the use of a jobbing foundry is possible, it might be more economical initially to purchase the castings. This would reduce the initial capital requirements to the costs of establishing a machine shop. If a foundry is built as part of the investment, other castings could be produced as well.

The necessary tools and machinery will depend on the level of production. The basic operations include grinding, boring, drilling, threading, and cutting. A simple grinder or a disc or belt sander can be used to smooth

all contact surfaces. A lathe is used for boring larger holes as for the cylinder in a pitcher spout pump. Tools for threading are necessary including pipe tapping die sets (to provide a connection for the drop pipe). A bench drill press is used to drill small holes. A hand press (and dies) could be used for cutting leathers.

Figure 6-2 shows a "model" layout proposed by Battelle for a machine shop and foundry that provides for about 256 square feet per machine (16 feet by 16 feet, approx. 5 metre by 5 metre). The layout does not designate exactly where machine tools are to be placed, where aisles are to be provided, or where pieces to be worked on are to be placed as these are largely dependent on the facility management. The layout is constructed so that there is a natural flow of materials and parts through the shop. The foundry is on the left; castings proceed from left to right to the machine tools, through inspection, painting, and storage, to assembly and, finally, to shipping. Finished parts are put into storage and then assembled prior to shipping. There is no reason that assembly could not be made before storage. However, as indicated in the layout, all parts are stored and components can be withdrawn for assembly into complete pumps or shipment as spare parts.

Table 6-3 indicates machine shop personnel for producing 20 to 40 or more pumps per day. The estimate of 20 pumps per day is based on using minimum jigs and fixtures in all operations and using single-point cutting tools. By changing from single-point tools to more complicated, semi-automatic tooling, production could be increased to 40 or more completed pumps per day without increasing personnel.

Approximately 3600 square feet (330 square metre) has been allowed for the foundry area. More or less area would be required depending upon the foundry operator and his requirements for aisle space and his method of setting the molds and pouring. The 3600 square feet (330 square metre) does not include much area around the cupola or area for storage of raw materials, coke, etc.

Table 6-4 shows needed foundry personnel.

Note: All measurements in feet and square feet

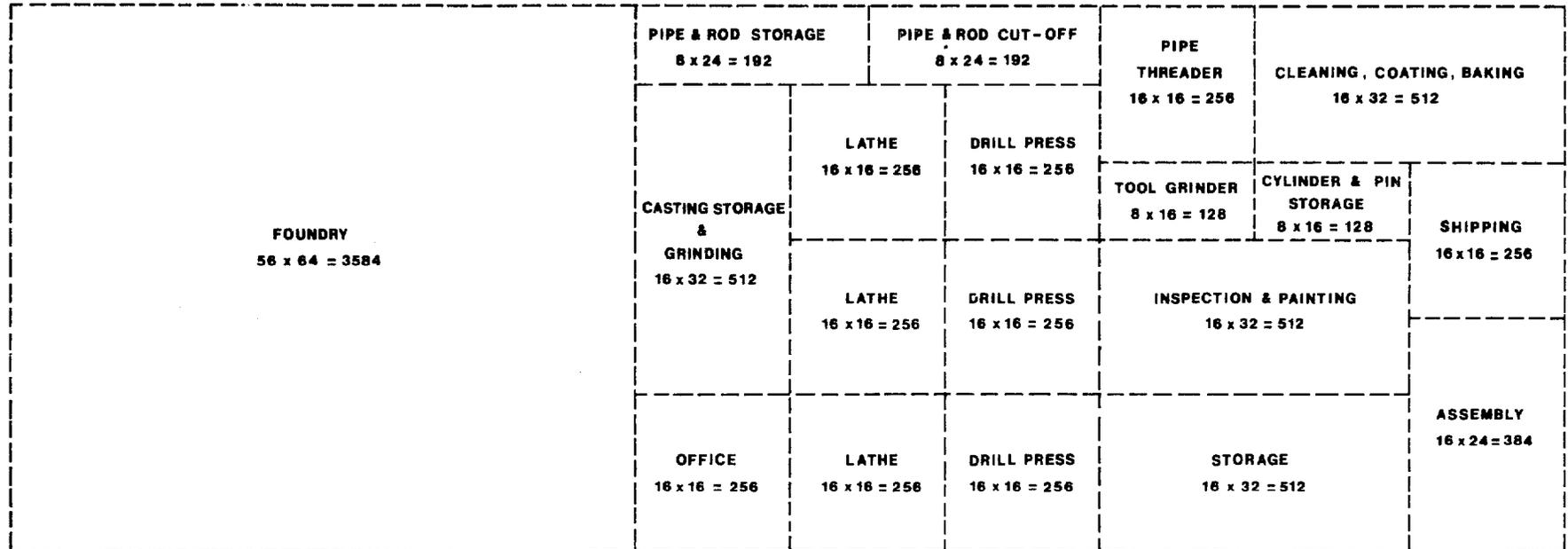


FIGURE 6-2 LAYOUT OF POSSIBLE FOUNDRY AND MACHINE SHOP
 TO PRODUCE A HAND PUMP
 (After Frink and Fannon)

TABLE 6-3 MACHINE SHOP PERSONNEL*

Operation	Number of Persons
Material, handling, shipping, receiving (laborers)	2
Grinding	1
Lathes	3
Drill Press	3
Cut off	1
Pipe threading	1
Pipe coating	1
Inspection and painting	1
Tap-die assembly	1
Foreman	1
Total	<u>15</u>

* Number of personnel based on a minimum of 20 pumps per day. After Frink and Fannon (1967).

The foundry operation is actually based upon the machine shop requirements. This amounts to about 1200 pieces per week and if two pours per week are made, this is 600 pieces per pour or about 4300 pounds. It is estimated that 10 persons can handle this amount of work, depending upon incentive and the tools with which to work. For an increase in production, more personnel might have to be added in the foundry before any persons were added in the machine shop. Personnel in foundry would be expected not only to make the molds but also to assist in pouring, shaking out the castings, and transporting them to the machine shop. The foreman and the material handlers would make the initial charge in the cupola and then would be assisted by the molders during the pouring.

The shop as shown represents approximately 9000 square feet and 25 persons, and this arrangement can be expected to produce anywhere from 20 to 40 or more completed pumps per day. An increase in production could be

made with few additional personnel in the foundry. No specifications are given for the cupola; however, the smallest cupola commercially made in the United States can produce about half a ton per hour and it would occupy a small area in the foundry.

TABLE 6-4 FOUNDRY PERSONNEL *

<u>Position</u>	<u>Number of Persons</u>
Molders	7
Core makers	1
Material handlers	1
Foreman	1
Total	<u>10</u>

* Number of personnel based on pouring 4300 pounds (600 pieces) twice per week. After Frink and Fannon (1967).

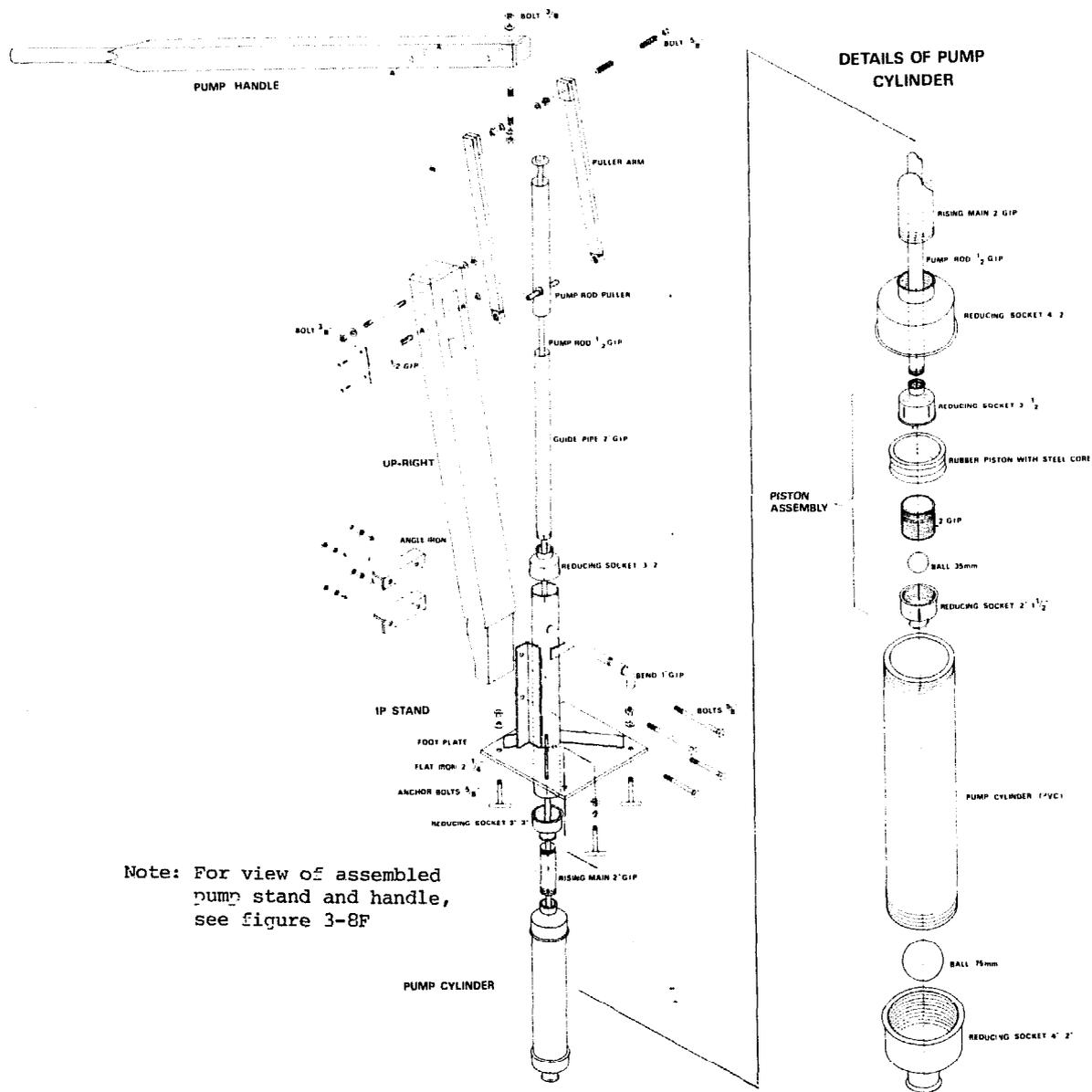
6.2.10 Additional Information

The American Foundrymen's Society, Golf and Wolf Roads, Des Plaines, Illinois 60016 (U.S.A.) publishes a large number of guides, manuals, and other aids on practical aspects of founding. The Intermediate Technology Group (ITDG), 9 King Street, London WC2 8HM publishes a foundry profile.

6.3 HAND PUMPS MADE FROM STEEL, WOOD, OR PLASTIC PIPE COMPONENTS

An alternative to pumps made of cast iron components is the use of pumps made of standard pipe components or of welded fabrication. These are not necessarily less expensive, but they do obviate the necessity for a foundry. They are made up typically of galvanized iron or steel pipe or, in a few instances, plastic pipe.

Examples are widespread. One used in East Africa is the "Uganda" or "Craelius" shown in Figure 3-12. This pump is manufactured in Nairobi and also uses wood in the handle and the fulcrum link. The pump is claimed to



Courtesy: Shinyanga Shallow Wells Project

FIGURE 6-3 SHINYANGA HAND PUMP

stand rough handling and requires little maintenance. It might be noted that it uses a brass cylinder with ball valves - an expensive construction.

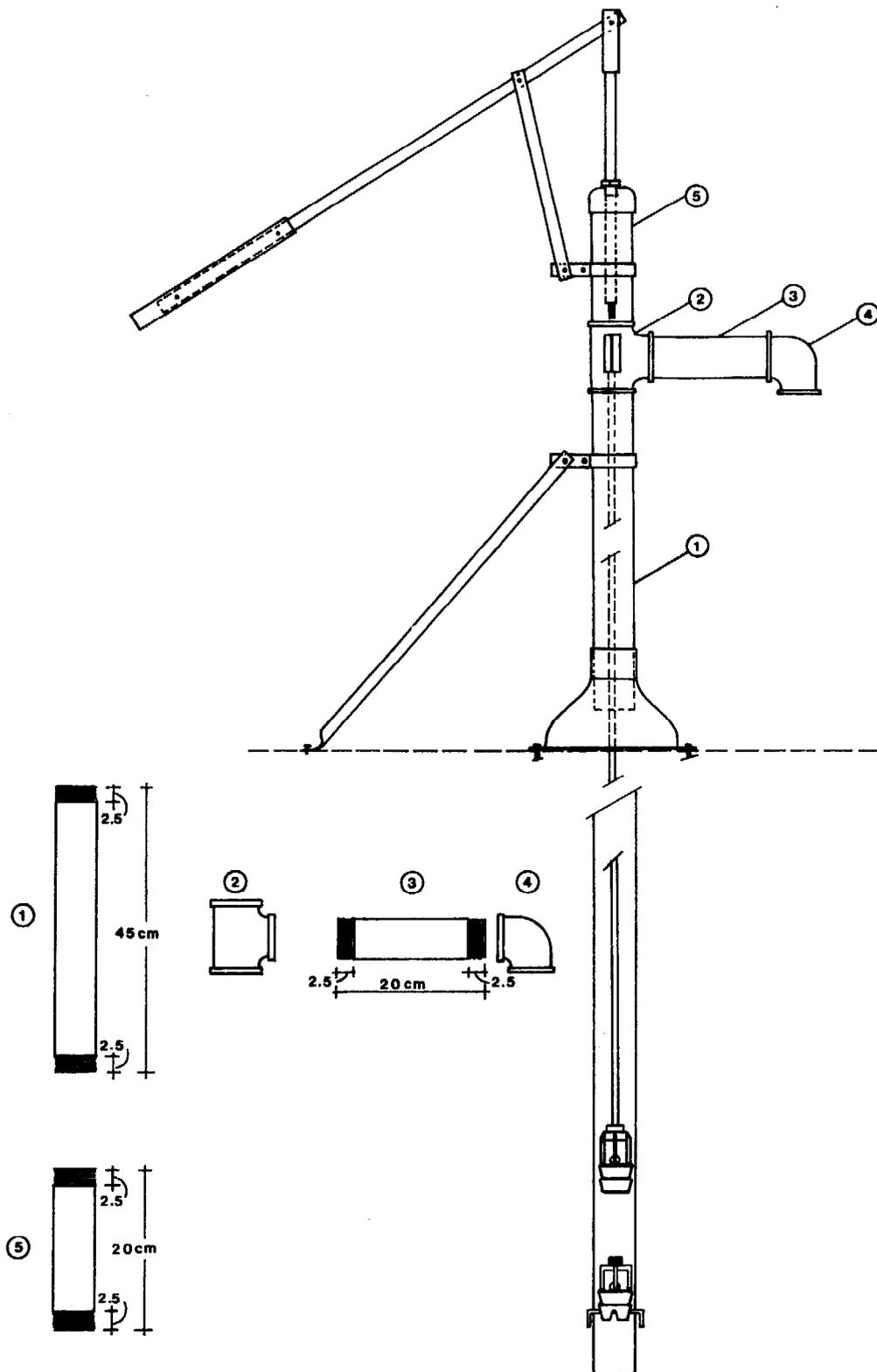
Another hand pump used in East Africa is the "Shinyanga" pump manufactured on site by the Shallow Wells Project, Shinyanga Province, Tanzania. The "Shinyanga" pump uses a wooden handle and fulcrum upright. Many other parts are standard galvanized iron pipe and fittings, angle and plate iron, and standard nuts and bolts. The "Shinyanga" pump stand and handle assembly strongly resembles that of the "Uganda". (See Figures 3-11 and 6-3).

The "Shinyanga" pump uses a unique deep well cylinder assembly. The pump cylinder is a short length of unplasticized polyvinyl chloride (PVC) plastic pipe selected because of the corrosiveness to cast iron of local groundwaters (pH 3) and the high rate of theft of brass cylinders (to make jewelry). Neoprene ball valves are used in both the plunger and suction check valves. The valve seats are standard reducing sockets. A standard industrial rubber piston with a steel core (cost about US \$4), imported from western Europe where it is used in hydraulic machinery, is used in lieu of the usual cup seals.

Several maintenance features are noteworthy. Project officials project the reinforced rubber piston's life expectancy at 10 years, about the life of the pump and the well. The journals (holes) in the wooden handle wear out rapidly (2-3 months); however, the addition of 1/2-inch (13 mm) pipe sleeves - with regular lubrication - has extended their life expectancy to two years or longer.

The Korat Provincial Health Department of Thailand endeavored to develop a pump made of parts found throughout rural Thailand, both for purposes of manufacture and of maintenance (Unakul and Wood). The pump body and the cylinder are made of 2-inch seamless pipe. Steel balls taken from anti-friction bearings are used in the check valves; local leather is used for the piston cups; local hardwood in the handle. The pump was assembled by a local machine shop. This pump is shown in Figure 6-4. Somewhat similar pumps have been made, generally in small numbers, in Kenya (Stanley),

FIGURE 6-4 PUMP MADE IN KORAT (THAILAND) OF PIPE COMPONENTS



the Philippines (Valdes-Pinilla), Zambia (Suphi), and elsewhere.

Plastics have been widely used in pump cylinders but rarely in the pump head although frequently proposed for this use. Field tests on plastic-bodied prototype pumps in Bangladesh and Thailand were inconclusive (Journey, 1974; Beyer, 1975). Many plastics are sensitive to ultraviolet radiation and should not be constantly exposed to sunlight (McJunkin, 1971). Plastic pipe has been proposed for use as drop pipes. However, in many deep wells the pump rod may rub and wear the pipe wall. VITA (Spangler, 1975) has published plans for shallow well plastic pumps. Also Chatiket (1973) and others.

6.4 SHOP WELDING AND FABRICATION

Machine shop practices are too diverse to readily summarize as for foundries. Excellent guidance may be found in widely available standard works (e.g., Baumeister; Camm and Collins; Lascoe, Nelson, and Porter; Le Grand; Maynard; Oberg, Jones, and Horton; Rothbart, *et al.*). This section focuses on some elements that may be useful for pump programs in evaluating or inspecting manufacturing quality.

6.4.1 Welding

Visual inspection is one of the most important methods for inspection of welding. For many types of noncritical welds, reliance for integrity is based principally upon visual inspection. This is the most extensively used method of inspection because it is easy to apply, quick, relatively inexpensive and seldom requires special equipment. Visual inspection gives important information with regard to the general conformity of the weldment to specification requirements.

The inspector should be familiar with the applicable documents, workmanship standards and all phases of good shop practices. During the performance of the inspection the part should be well lighted; an extension

lamp or flashlight may be needed. A low power hand magnifier is helpful, and should be used when needed to evaluate a surface condition. Other tools such as a borescope and dental mirrors are useful for the inspector of welds inside vessels or in confined areas. Scales and gauges are used for checking the accuracy of physical dimensions of the weld head. Welds that are inaccessible in the finished product should be examined during the progress of the work.

The faces and edges of material to be welded should be examined for laminations, blisters, scabs and seams. Heavy scale, oxide films, grease, paint and oil, and slag from previous welds should be removed. Pieces to be welded should be checked for size and shape. Warped, bent or otherwise damaged material should be detected in the early stages of fabrication. Edge preparation, bevel angle, alignment of parts and fitups should be checked. During welding the speed with which the electrode is moved across the work will determine the size and shape of the weld. Too fast a speed produces a rough bead with undercut.

Visual examination is usually the first stage in the inspection of a finished weld. The following quality factors can usually be determined by this means:

- (1) Dimensional accuracy of the weldment (including warpage).
- (2) Conformity to specification requirements regarding the extent, distribution, size, contour and continuity of the welds.
- (3) Weld appearance.
- (4) Surface flaws, such as cracks, porosity, unfilled craters and crater cracks, particularly at the ends of welds, undercutting, etc.

Welds should be free from cracks, crevices, pits, drastic undercuts, and excessive splatter; be smooth; and have reasonable fillets. An occasional welded piece should be bent to failure to test penetration of the weld.

6.4.2 Machining

Machined valve seats should be free of flaws, cracks, crevices, or pits. Cylinders and journals should be inspected for smoothness of bore. Beads of

galvanizing should be removed from contact surfaces. Mating parts, including nuts, should fit flat in one plane. Pump stand covers should lie flat on the pump stand without rocking. Holes should be snug to pins and vice versa. Longitudinal axis of pins and bearing holes should be properly aligned.

Saw cuts should be deburred. Pipe threads should be fully cut and insure proper engagement, not less than 0.420 inch for 1½-inch and 1½-inch pipe, 0.436 inch for 2-inch pipe, 0.682 inch for 2½-inch pipe, and 0.766 inch for 3-inch pipe.*

6.4.3 Jigs and Fixtures

A fixture is a device which holds an article while the cutting tool is performing the work, whereas a jig is a device which not only holds the object but also incorporates special arrangements for guiding the tool to the proper position. Jigs are used principally for drilling, boring, etc., while fixtures are used in milling and grinding.

Use of jigs and fixtures not only increases production rate but makes it possible to use less skilled labor, to improve dimensional accuracy, and to improve assembly fits and interchangeability of parts.

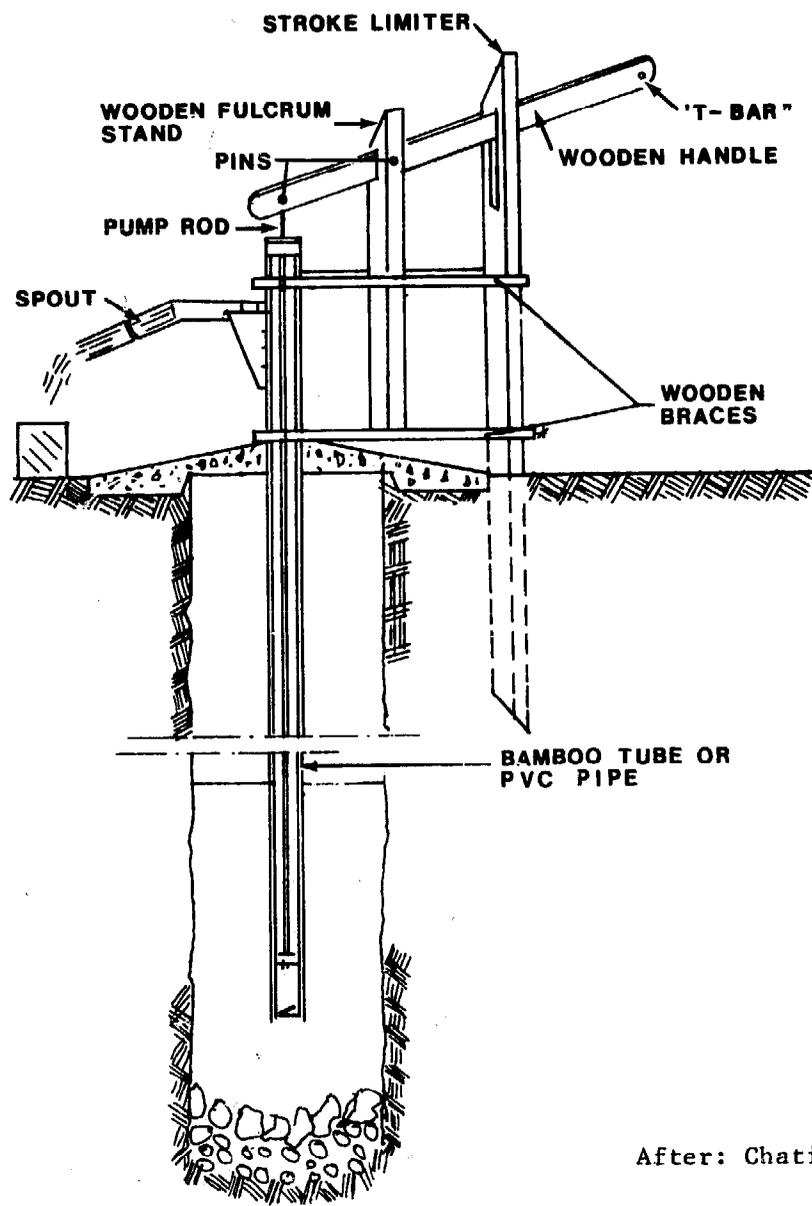
6.5 HAND PUMPS MADE BY VILLAGE ARTISANS

6.5.1 Wood and Bamboo Reciprocating Pumps

Until the middle of the 19th century wood was a standard material of construction for hand pumps (Robins). With the resurgent interest in "appropriate technology" wood is getting a new look. However the old problem, durability, remains. Properly constructed and maintained wooden or bamboo pumps, with light use, may last several years. They may be an economic choice in some circumstances, e.g., where pumps are privately owned.

Figures 6-5A and 6-5B show the "DIY" pump used in Nigeria (Chatiketú) in shallow wells. One long unjointed length of bamboo can be used. PVC

* Drop pipe in metric diameters should have comparable minimum thread engagement



After: Chatiketu

FIGURE 6-5A BAMBOO OR PVC PIPE HAND PUMP (GENERAL)

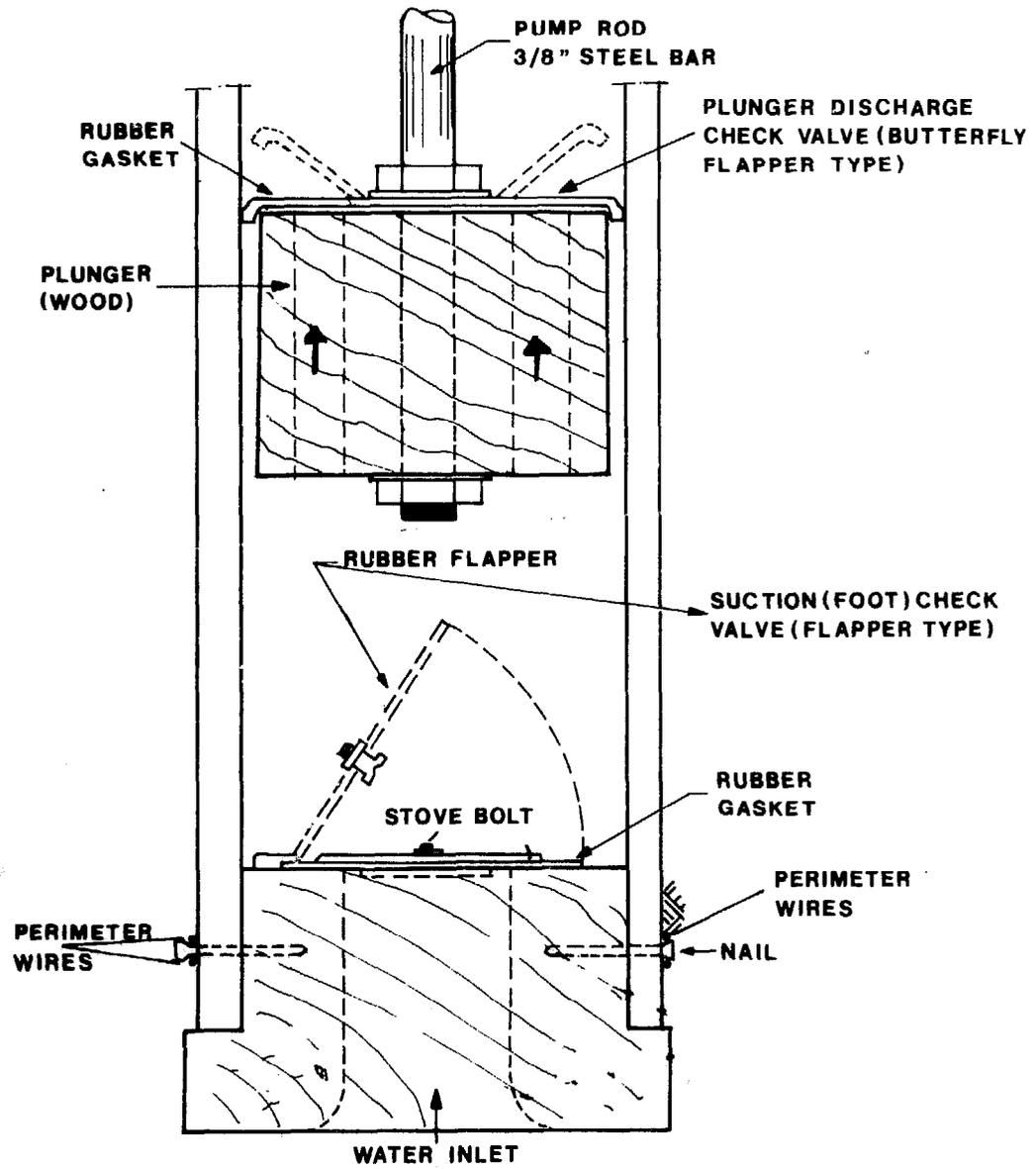


FIGURE 6-5B BAMBOO OR PVC PIPE HAND PUMP (VALVES)

plastic pipe may be substituted for the bamboo. References to several other wood or bamboo pipes are listed in the bibliography (Bradley; Hazbun; Jolly; Mann (ITDG); and VITA, 1969).

6.5.2 Chain Pumps

Chain pumps such as shown in Section 2 are readily manufactured by village blacksmiths. Several examples are shown in VITA's Village Technology Handbook and in ITDG's 21 Chain and Washer Pumps. An extremely simple version is shown in Figure 6-6. They are also available commercially.

6.5.3 Windlass Pump

A sanitary rope and bucket windlass type of water lifting device was shown in Section 2. These are easily manufactured with indigenous materials and give good, if not convenient, service. Their use is limited to shallow, large diameter wells.

6.5.4 Hydraulic Rams

The hydraulic ram is readily adaptable to manufacture from standard pipe components. Complete instructions, including drawings, are readily available (Kindal or Watt).

6.5.5 Other Pumps

Diaphragm pumps as well as reciprocating pumps lend themselves to manufacture by village artisans. An example of such a pump developed by Canada's Brace Research Institute (Bodek, 1965, instructions may be ordered from Brace) is shown in Figure 6-7.

6.6 "TRADITIONAL" WATER LIFTING DEVICES

There are numerous types of water lifting devices in use in the developing world, especially for irrigation, which date back many centuries. These in a sense were designed by "survival of the fittest" and include saktias, mnotes, norias, shadoofs, water wheels and others. Except for the rope and bucket they have not been widely adopted for drinking water supply.

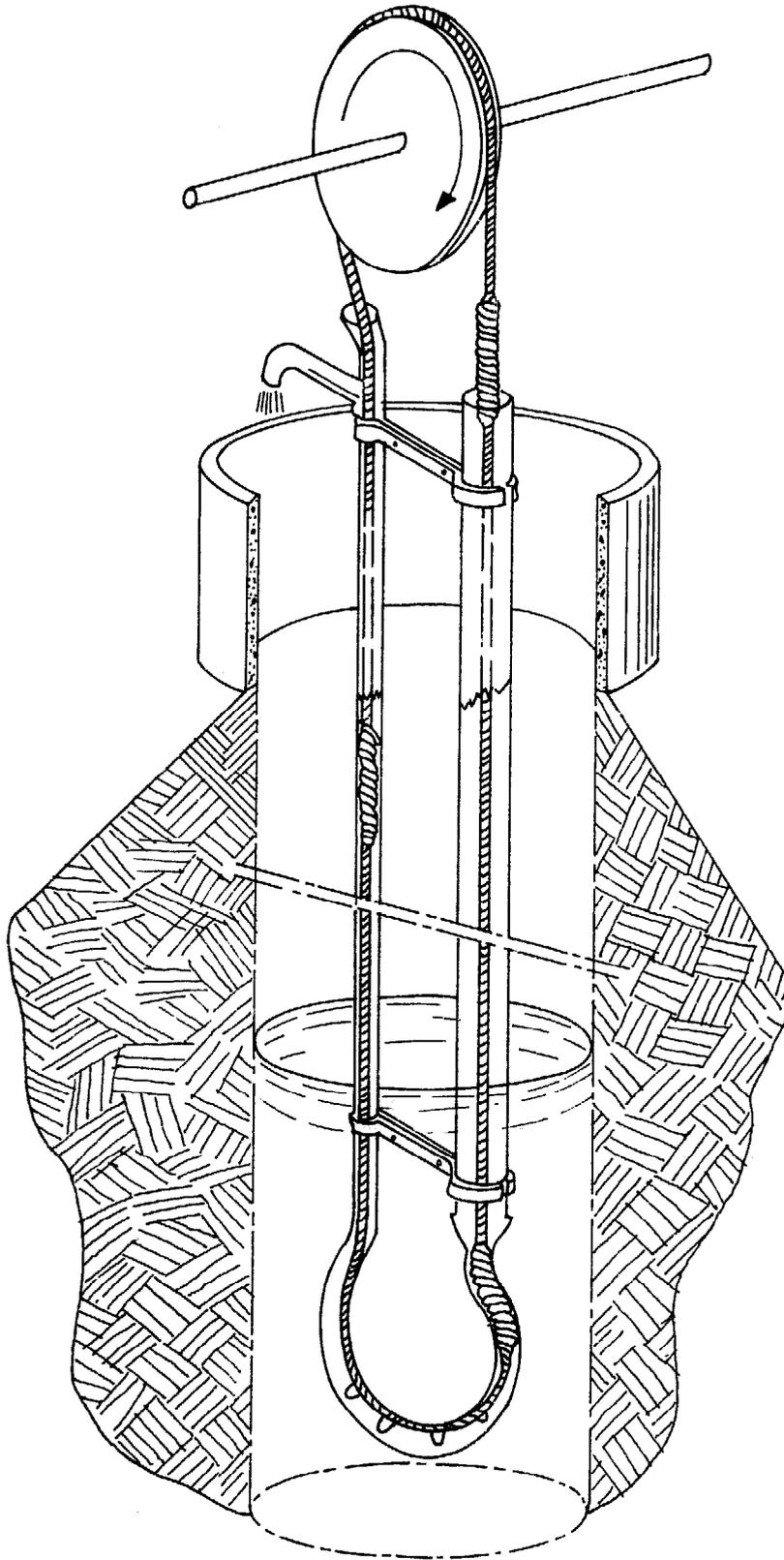


FIGURE 6-6 CHAIN-TYPE PUMP MADE OF ROPE

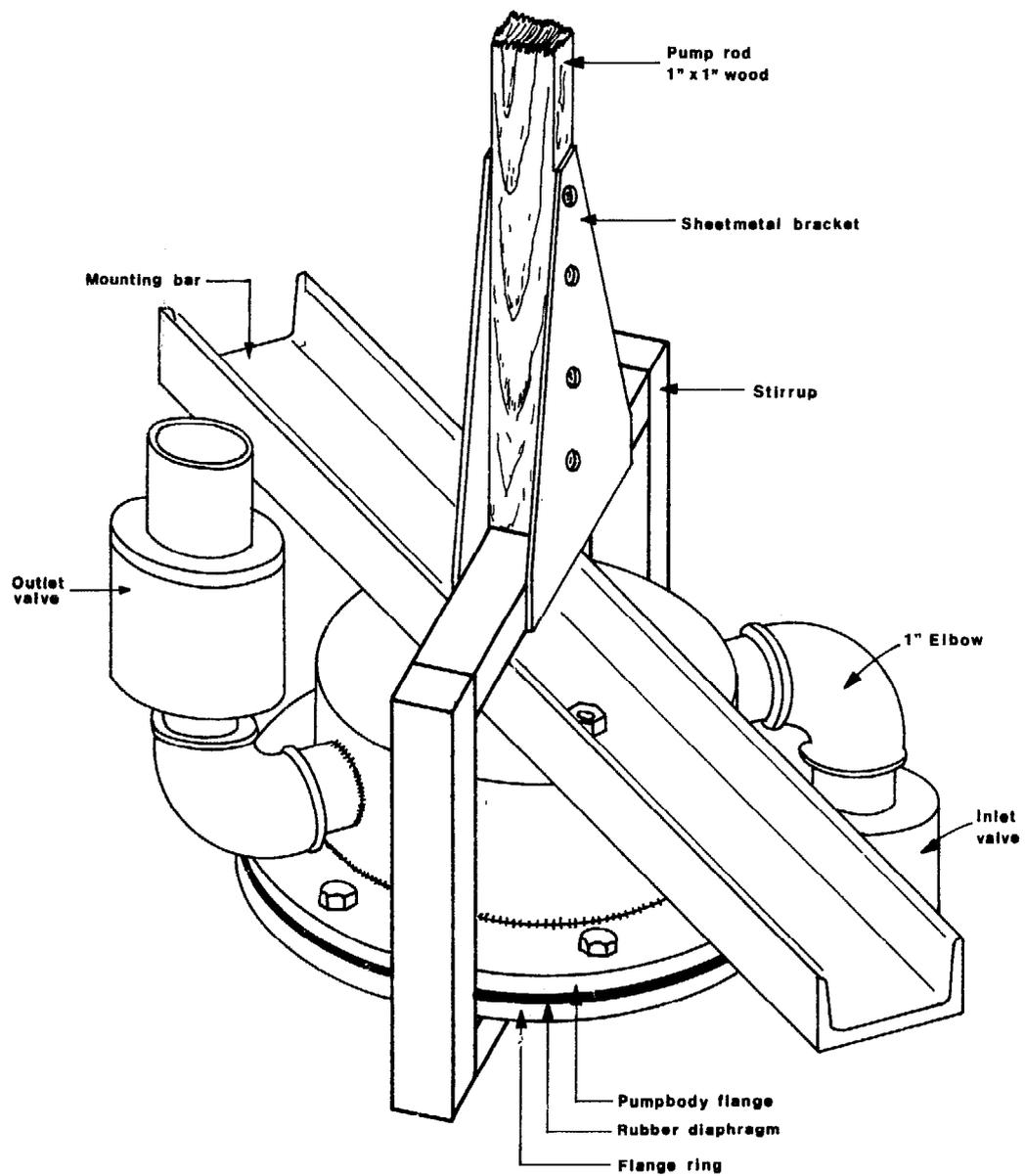


FIGURE 6-7 DIAPHRAGM PUMP (BODEK)

6.7 PUMP CYLINDERS

The roughness of the cylinder wall and consequent cup wear are key elements in pump maintenance and life. Poor machinery in many areas has resulted in poor quality cast iron cylinders. Brass is a more suitable material but may be prohibitively expensive. However, plastic pipe now widely available (McJunkin & Pineo, 1971) has smooth wall surface, is inexpensive, and thus offers an opportunity for local manufacture of cylinders. The possible use of epoxy coatings for improving cast iron cylinders also shows promise (Fannon, 1970, 1975).

6.8 PUMP LEATHERS (CUP AND VALVES)

The manufacture of cup leathers is as much an art as a science but can and has been done locally even at the village level. In an emergency, take industrial belting or good harness leather, soak it in water, clamp it onto the plunger (or object of same diameter) and drive into a pipe of same diameter as the pump cylinder, let dry, remove and trim the wrinkled edge with a sharp knife (including the center hole), soak for 12 hours in an edible oil (preferably neat's-foot), wax, and lightly apply graphite grease to the wearing surface.

For "mass production", wooden forms can be used. To make the forms, use wooden boards about 3/4-inch (approx. 19 mm) in thickness, having holes of the same diameter as the pump cylinders, and nailed to a stiff backboard. Cylindrical blocks, 3/8-inch (approx. 9.54 mm) less in diameter, are bolted concentrically within the circular openings. The bolts should be long enough so that the wet and pliable leather, laid over the holes, can be drawn down by the bolts and blocks, forcing the leathers into position. Then proceed as before.

Recent formulations of polyvinyl chloride (PVC), neoprene, and rubber have been used in Asia and Africa to replace leather for the cups. PVC cups are easily made at low cost.

One of the principal advantages of flap valves is that the leather flapper, generally the part requiring replacement, can also be manufactured locally. Satisfactory PVC check valves have not yet been produced.

6.9 PUMP HANDLES

Many village hand pumps are equipped with locally made wooden handles. This may even be advantageous: (1) they are more readily replaced locally than iron or steel; (2) they may be made in very large sizes with greater length and mechanical advantage, making them more suitable for use in deep wells or by smaller people; and (3) the bearing surfaces of the handle wear out rather than those of the pump body or of the pins which are more difficult to replace. A splinter and termite resistant hardwood should be used. Many of the large wooden handles use a fulcrum detached from the pump which reduces stress on the pump body. However, if it is poorly aligned it may increase wear on pins, cylinders, and cups. This malalignment has been a prominent factor in the failures of plastic bodied pump stands.

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- Kawamoto Pump Mfg. Co. "Kawamoto Dragon Hand Pump (Model No. 2C & No. 2D)." 4 pp.
(Japan)
- Kitrick Mgmt. Co. "GEM G.I. Chain Pump." 2 pp.
(U.S.A.)
- Kumar Industries. "Kumar Lift Hand Pumps." 2 pp.
(India)
- Lee, Howl & Co. Ltd. "Oasis Pump." 4 pp.
(U.K.) "Patay Pump." 5 pp.
- Maurer, A. "Impact Pressure Pump DSP 20-15." 10 pp.
(U.S.A.)
- Maya Eng. Works Pty. Ltd. "Maya Water Pumps." 6 pp.
(India)
- Mengin, Ets. Pierre. "Hydro-Pompe Vergnet." 18 pp.
(France) "Instructions pour l'emploi des Hydro-Pompes 'Vergnet'."
Notice No. 821. 15 pp.
"Vergnet Hydro-Pump." Report to World Bank. 6 pp.
- Mono Pumps (Eng.) Ltd. "Mono Rotary Hand Pump." 7 pp.
(U.K.) "Mono Lift Borehole Pumps." 8 pp.
"Mono Pumps - Applications." 12 pp.
"Mono Pumps - Installation Instructions." 5 pp.
"Mono Turbolift - Borehole Pumps." 4 pp.
- Myers, F.E. & Bros. Co. "Force Tank Pumps." 2 pp.
(U.S.A.)
- Petro Pump. "The Petro Pump." 4 pp.
(Sweden) "Performance Tests of the Petro Pump (20 May 1976, Stockholm)." 1 p.
- Pijpers Water Supply Eng. "The Kangaroo Pump." 1 p.
(Netherlands)
- Rife Hydraulic Mach. Co. "Rife Ram." Various paging.
(U.S.A.)
- Robbins & Myers. "Moyno Hand Pumps." Bulletin 277. 4 pp.
(Canada)

Rochfer, Industries Mecánicas Ltda. "Bombas Hidráulicas." 8 pp.
(Brazil)

Standard Pressed Steel Co. "New Quick-Click Self-Retained Pins." 1 p.
(U.S.A.)

Stewarts & Lloyds. "Hand Pumps." 3 pp.
(South Africa)

Tsuda Shiki Pump Mfg. Co. "Tsuda Shiki Pump." 24 pp.
(Japan)

Vammalan Konepaja Oy. "NIRA Pressure Pumps." 2 pp.
(Finland)

Warner Danby Corp. "Hand and Windmill Force Pumps." 2 pp.
(U.S.A.) "Complete Water Well Supplies for Farm and Home."
Catalog No. 31. 10 pp.
"Windmills. House Force Pumps." Various paging.

Toowoomba Foundry Ltd. "Southern Cross Hand Operated Diaphragm Pump." 2 pp.
(U.S.A.)

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A PARTIAL DIRECTORY OF
HAND PUMP MANUFACTURERS *

ARGENTINA

Iquiniz Sociedad Anonmia
Hortiguera 1882
Buenos Aires
Argentina
("Lago")
("Brisa")
("Aeromotor")

AUSTRALIA

John Drake and Son Pty. Ltd.
391-403 Bourke Street
Melbourne
Australia

Intercolonial Boring Co. Ltd.
450-466 Ann Street
Brisbane
Australia

Metters
Murray House
77-79 Grenfell Street
Adelaide
Australia

Southern Cross Engine and Windmill
Co. Pty. Ltd.
Grand Avenue
Granville
Sydney, New South Wales
Australia
(manufacturing under name of
"Toowoomba")

Toowoomba Foundry Pty. Ltd.
259 Ruthven Street
Toowoomba, Qld. 4350
Australia

BANGLADESH

Bangladesh Light Casting, Dacca
Eastern Foundry, Dacca
Essential Products Ltd., Dacca
National Iron Foundry, Khulna
Unique Metal Industry, Dacca
Zahed Metal Industries, Bogra

All above and several other small
foundries may be contacted through
UNICEF Supply Section
UNICEF Dacca
P.O. Box 58
Dacca
Bangladesh

BELGIUM

Ateliers Deplechin
Avenue de Maire, 28
B-7500 Tournai
Belgium

Duba S.A.
Nieuwstraat
B-9200 Wetteren
Belgium
("Tropic I", "Tropic II")

* This list is intended solely as a source of information on addresses of manufacturers of hand pumps and hand pump components. Inclusion on this list is not an endorsement, recommendation, warranty, or evaluation of any listed manufacturer's products. Similarly, omission from this list is not a rejection.

This list was compiled by the author on the basis of a brief survey. Its accuracy or currency has not been fully verified. Corrections and additions are welcomed.

Names of some manufacturers' hand pump models are shown in parenthesis, for example ("Lago") is a series of hand pumps manufactured in Argentina by Iquiniz S.A.

BRAZIL

Industrias Mechanicas Rochfer Ltd.
Caixa Postal 194
Franca, São Paulo
Brazil
(water operated piston pumps)

CANADA

Beatty Bros. Limited
Fergus, Ontario
Canada
("Beatty") ("Dominion")

Monarch Machinery Co. Ltd.
Winnipeg
Canada
("Monarch")

Robbins and Myers Company
of Canada Limited
Brantford, Ontario
Canada
("Mcyno")

Tri-Canada Cherry Burrell Ltd.
Mississauga, Ontario
Canada
(Helical rotor-stator type)

CHINA (People's Republic of)

China National Machinery and
Export Corporation
Kwangtung Branch
61 Yanjiang Yilu
Kwangchow
People's Republic of China
("SB 38-1", "SB 40-1")

CZECHOSLOVAKIA

Vaclavske Namesti 60
Praha
Czechoslovakia
("Intersigma")

FINLAND

Vammalan Konepaja Oy
38200 Vammala
Finland
("Nira")

FRANCE

Les Pompes Andrés Bodin
37150 Bléré
France
("Solo")
("Majestic")
("Celtic")

Ets. Pierre Mengin
Zone Industrielle d'Amilly
B.P. 163
45203 Montargis
France
("Hydropompe Vergnet")

Briau S.A.
B.P. 43
37009 Tours Cedex
France
("Royale")
("Murale")
("Aral")
("Classique")
("Africa")
(Hydraulic Rams)

Etablissements Champenois
Chamouilley 52710 Chevillon
France
("l'Africain", chain type of pump
using a nylon band)

GERMANY (Federal Republic of)

Moderne Pumpen Ernest Vogel
Prager Strasse 6
Stockerau
West Germany
("Vogel")

Preussag Aktiengesellschaft
Kunststoffe und Armaturen
Postfach 9, Eixer Weg
D-3154 Stederdorf, Kr. Peine
West Germany
(PVC casing, screens, cylinders)

Pumpenfabrik Beyer
2400 Lubeck 1
Glockengiesserstrasse 61
West Germany

INDIA

Balaji Industrial and Agricultural Castings
Hill Street Ranigunj
Secunderabad-3
India
("Balaji" - Jalna Type)

Charotar Iron Factory
opp. New Ramji Mandir
Anand. Gujarat
India
(Wasp Type)

Coimbatore Water and Agricultural
Development Project
69 Venkatasami Road, R.S. Puram
Coimbatore 641002
India
(Jalna Type)

Dandekar Brothers
Shivaji Nagar Factory Area
Sangli
Maharashtra
India
("Jal Javahar")

Gujarat Small Industries Ltd.
Nanavati Estate, near
Chakudia Mahadeo
Rakhial, Ahmedabad-23
India
("Kirti")

JPSR Company (Mittra Das Ghose & Co.)
Howrah, near Calcutta
India
(low-lift & deep well pumps)

Kumar Industries
P.O. Edathara 678611
Palghat District, Kerala State
India
(several models)

Lifetime Products Corporation
Post Box No. 102
Jodhpur
India
(Wasp Type)

Marathwade Sheti Sahayya Mandal
Jalna, Dist. Aurangabad
Maharashtra
India
(Originator and non-commercial
manufacturer of Jalna Type)

Maya Engineering Works Private Ltd.
200A Shyamaprosad Mukherjee Road
Calcutta-700 026
India
("Maya Nos. 4, 5, 6")

Mohinder & Co.
Kuruli, Dist. Ropar
Punjab
India
(low-lift pumps)

Richardson and Crudass Ltd.
(A Govt. of India undertaking)
Madras
India

Senco Industries
A-12, Coimbatore Private Industrial
Estate
Coimbatore-21
India
("Senco", also Jalna)

Sholapur Well Service
560/59 South Sadar Bazaar
Civil Lines
Sholapur-3
Maharashtra
India
(non-commercial manufacturer of
Jalna Type)

Vadala Hand Pump
Marathi Mission
Ahmednagar
Maharashtra
India
(non-commercial manufacturer of
Jalna Type)

Water Supply Specialists Private Ltd.
Post Box 684
Bombay-1
India
("Wasp")

IVORY COAST

Abidjan Industries
Boite Postal 343
45, Rue Pierre et Marie-Curie
Abidjan Zone 4c
Ivory Coast
(ABI-type "M")
("Africa")

SAFICOCI
B.P. 1117
Abidjan
Ivory Coast
("Africa"
Agent for Pompes Briau)

JAPAN

Kashima Trading Co., Limited
P.O. Box 110
Higoshi, Nagoya
Japan

Kawamoto Pump Mfg. Co. Ltd.
P.O. Box Nagoya Naka No. 25
Nagoya
Japan
("Dragon")
("No. 2 (C) and (D)")

Tsuda Shiki Pump Mfg. Co. Ltd.
2658 Mimani-Kannon-Machi
Hiroshima Prefecture
Japan
("Keibogo")
("Delta")

KENYA

Atlas Copco Terratest Ltd.
Norwich Union House
P.O. Box 40090
Nairobi
Kenya
("Kenya" previously "Uganda")

MALAGASY REPUBLIC

Comptoirs Sanitaires de Madagascar
B.P. 1104
Tananarive
Malagasy Republic
("Mandritsara")

NETHERLANDS

Pijpers International Water Supply
Engineering
Nijverheidsstraat 21
P.O. Box 138
Nijkerk
Netherlands
("Kangaroo Pump")

PHILLIPINES

Avenue Mfg. Co. Inc.
P.O. Box 3629
Manila
Phillippines
(Pitcher Pumps)

Dong Tek Foundry
699 Elcano Street
Manila
Philippines
(Pitcher Pumps)

M/S Sea Commercial Co., Inc.
3085 R, Magsaysay Blvd. Cor
V. Crus, St. Mesa
Manila
Philippines
(Kawamoto Licensee)

New Asia Foundry Mfg. Co. Inc.
272 Rizal Avenue Ext. Calcoocan City
Philippines
(Pitcher Pumps)

Occidental Foundry Corp.
Km. 16 McArthur Highway
Malanday, Vanlenzuela
Bulacan
Philippines
(Pitcher Pumps)
("England" deep well)

Triumph Metal Mfg. Corp.
P.O. Box 572
Manila
Philippines
(Pitcher Pumps)

SENEGAL

SISCOMA
B.P. 3214
Dakar
Senegal
(various pumps, some
of French origin)

SOUTH AFRICA

Stewarts and Lloyds of South Africa Ltd.
Windmill Division
P.O. Box 74
Vereniging 1930
South Africa

Southern Cross Windmill
and Engine Co. (Pty.) Ltd.
Nuffield Street
Bloemfontein
South Africa

SPAIN

Bombas Borja
Avda. P. Emilio Baro 25
Valencia
Spain

Bombas Geyda
Avenida Carlos Gens, S.L. Burjasot, 54
Valencia
Spain
("Geyda"
mainly for Spanish market)

SWEDEN

Petro Pump
Carl Westmans Väg 5
S-13300
Saltsjöbaden
Sweden

TANZANIA

Shallow Wells Programme
Shinyanga Region
P.O. Box 168
Shinyanga
Tanzania

UGANDA

Craelius East African Drilling
Company Ltd.
P.O. Box 52
Soroti
Uganda

UNITED KINGDOM

Autometric Pumps Ltd.
Waterside
Maidstone
Kent
United Kingdom
(Rotary Vane)

Barclay, Kellett & Co. Ltd.
Joseph Street
Bradford, Yorks. BD3 9HL
United Kingdom
(Rotary Vane)

Barnaby Engineering Co., Ltd.
Bourne Road
Bexley, Kent
United Kingdom
("Climax")

John Blake Limited
P.O. Box 43
Royal Works
Accrington, Lancashire BB5 5LP
United Kingdom
("Hydrams")

Consallen Structures Ltd.
291 High Street
Epping, Essex. CM16 4BY
United Kingdom
("Consallen")

English Drilling Equipment Co. Ltd.
Lindley Moor Road
Hudders Field, Yorkshire HD3 3RW
United Kingdom
("EDECO")

H.J. Godwin Ltd.
Quenington, Cirencester
Gloucestershire GL7 5BX
United Kingdom
("W1H")
("X")
("HLD")
("HLS")

Jobson & Beckwith Ltd.
62-6 Southwark Bridge Road
London SE1
United Kingdom
(Diaphragm)

Lee, Howl & Co. Limited
Alexandria Rd.,
Tipton, West Midlands DY4 8TA
United Kingdom
("Oasis")
("Colonial")

Mono Pumps (Engineering) Limited
Mono House
Sekforde Street
Clerkenwell Green
London EC1R OHE
United Kingdom
("Mono-lift")

Saunders Valve Co. Ltd.
Grande Road
Cwmbran
Mon
United Kingdom
(Diaphragm)

Stanhope Engineers (Bradford) Ltd.
92 Harris Street
Bradford BD1 5JA
United Kingdom
(Hand Lift and Lift and Force)

Thomas & Son, Limited
P.O. Box 36
Worcester
United Kingdom
("Climax")

Wilkinson Rubber Linatex Ltd.
Stanhope Road
Camberely
Surrey
United Kingdom
(Diaphragm)

UNITED STATES

Aeromotor
800 E. Dallas St.
Broken Arrow, Oklahoma 74012
United States of America
(discontinued handpump production in U.S.,
but Argentine licensee)

Baker Manufacturing Company
133 Enterprise St.
Evansville Wisconsin 53536
United States of America
("Monitor")

Colombiana Pump Co.
131 E. Railroad
Columbiana, Ohio 4408
United States of America

Dempster Industries, Inc.
Box 848
Beatrice, Nebraska 68310
United States of America
("23F")

Heller-Aller
Perry and Oakwood Streets
Napoleon, Ohio 43545
United States of America
("Heller Aller")
("H.A.")

Kitrick Management Company
4039 Creek Road
Cincinnati, Ohio 45241
United States of America
("Gem" chain pump)

Mark Controls Corporation
International Division
1900 Dempster Street
Evanston, Illinois 60204
United States of America
("Clayton Mark" cylinders,
valves and leathers)

A.Y. McDonald Mfg. Co.
P.O. Box 508
Dubuque, Iowa 52001
United States of America
("Red Jacket")

F.E. Meyers & Bro. Co.
400 Orange Street
Ashland, Ohio 44805
United States of America

Rife Hydraulic Engine Mfg. Co.
Box 367
Milburn, New Jersey
United States of America
("Rife Ram")

INTERNATIONAL AGENCY ABBREVIATIONS

AID	Agency for International Development (U.S.)
CARE	Cooperative for American Relief Everywhere
CIEH	Inter-African Committee for Hydraulic Studies
IBRD	International Bank for Reconstruction and Development
IDRC	International Development Research Centre
IRC	International Reference Centre for Community Water Supply
ITDG	Intermediate Technology Development Group
OXFAM	Oxford Committee on Famine Relief
PAHO	Pan American Health Organization
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VITA	Volunteers in Technical Assistance
WHO	World Health Organization

CONVERSION OF MEASUREMENT UNITS

Annex E

LENGTH

1 Inch (in)	=	2.54	Centimeter (cm)
1 Centimeter (cm)	=	0.394	Inch (in)
1 Foot (ft)	=	0.3048	Meter (m)
1 Meter (m)	=	3.281	Feet (ft)

AREA

1 Square inch (in ²)	=	6.4516	Square centimeter (cm ²)
1 Square centimeter (cm ²)	=	0.1550	Square inch (in ²)
1 Square foot (ft ²)	=	0.0929	Square meter (m ²)
1 Square meter (m ²)	=	10.764	Square foot (ft ²)

VOLUME

1 Cubic foot (ft ³)	=	28.317	Liter (l)
1 U.S. gallon (US gal)	=	3.7854	Liter (l)
1 U.K. gallon* (UK gal)	=	4.5461	Liter (l)
1 Liter (l)	=	0.264	U.S. gallon (US gal)
1 Liter (l)	=	0.220	U.K. gallon (UK gal)

DISCHARGE

1 U.S. gallon per minute (US gal/min)	=	227.12	Liters per hour (l/hr)
1 U.K. gallon* per minute (UK gal/min)	=	272.77	Liters per hour (l/hr)
1 Liter per second (l/sec)	=	15.85	U.S. gallon per minute (US gal/min)
1 Liter per second (l/sec)	=	13.12	U.K. gallon per minute (UK gal/min)

MASS (Weight)

1 Pound (lb)	=	0.4536	Kilogramme (kg)
1 Kilogramme (kg)	=	2.205	Pounds (lbs)

* Also known as: Imperial gallon

PRESSURE

1 Pound per square inch (psi)*	=	0.07031 Kilogrammes per square centimeter (kgf/cm ²)
1 Kilogramme per square centimeter (kgf/cm ²)	=	14.223 pounds per square inch (psi)*
1 Foot (water column)	=	0.0305 kilogrammes per square centimeter (kgf/cm ²)
1 Meter (water column)	=	1.422 pounds per square inch (psi)*

POWER

1 Horsepower (hp)	=	0.7457 Kilowatt (kw)
1 Kilowatt (kw)	=	1.341 Horsepower (hp)

* Also: lbf/in²