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DEVELOPMENT OF A HAND OPERATED WATER PUMP
FOR DEVELOPING COUNTRIES



August 1, 1974

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DEVELOPMENT OF A HAND OPERATED WATER PUMP
FOR DEVELOPING COUNTRIES

by

R. D. Fannon, Jr.

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INTRODUCTION

A great number of requests have been received for information regarding the AID-Battelle program to develop an improved hand pump for rural domestic water supplies. Special funds have recently been appropriated to compile the results from this work to date and make it available.

BRIEF HISTORY OF EXPERIENCE

Early in 1966, the Agency for International Development (AID) and the Battelle Columbus Laboratories (BCL) discussed the increasing need for rural water supply systems for developing nations. It was decided during these meetings and subsequently substantiated that successful domestic water programs must be carried out within the country for which they are intended. Such programs not only provide a more reliable water system but also stimulate industry and business within the country.

The most basic need apparent was for a dependable hand pump. Basic specifications for such a pump were established early in the program and without exception they still prevail. These specifications are

- (1) Low production costs
- (2) Long life under severe conditions
- (3) Easy to maintain with simple tools and unskilled labor
- (4) Suitable for shallow or deep well installations with only minor changes (cylinder location)
- (5) Capable of being manufactured by established firms within the developing countries and/or with a minimum of capital investment

- (6) Easily operated by small people, including women and children
- (7) Include design features which will discourage pilfering and vandalism.

A shallow well pump is defined here as a pump in which the cylinder is attached to the pump body above the ground. A deep well pump is defined as a pump in which the cylinder is separated from the pump body and submerged below the level of the water being pumped.

In addition to these specification, it might also be appropriate to note here that any rural domestic water program of any size must contain the following:

- (1) Funds must be available by which pumps can be made and wells sunk and/or means by which pumps and their installation can be purchased by consumers.
- (2) Facilities must be available or provided in which pumps and associated products can be fabricated.
- (3) Governmental organizations or private sales organizations must be available for pump distribution and installation. This would also include well drilling.
- (4) Means must also be made available for spare parts distribution and pump maintenance.
- (5) Effectiveness of any program depends upon good coordination with the local people in regard to operations and pump configuration. Each area can be different depending upon the local conditions, customs, and aesthetic values.

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

Although steps 1 and 2 have been completed, some development in terms of improvements is still going on.

In the many visits to various developing countries the following conditions and practices are found to exist:

- (1) Lack of pumps and facilities to make them
- (2) Some areas had pumps given them, but many different kinds with little or no maintenance and with improper parts
- (3) Lack of community spirit toward community water supply systems even to the extent of vandalism
- (4) The ^{leaver} 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. The inadequacies may be described as follows:
 - (a) Cylinders too rough
 - (b) Plunger cups improperly sized (generally too large)
 - (c) Highly stressed fulcrums and handles
 - (d) Bearing surfaces too small
 - (e) Valve seats poorly cast and machined
 - (f) Fasteners (bolts and nuts) poorly made.
- (6) Inadequate storage facilities--many of the parts are so deteriorated that they cannot be used.
- (7) In many areas hand operated water pumps are in such demand that even so-called good pumps will not stand up under such rigorous usage. Good maintenance programs are required under all conditions.

A deep well and shallow well pump configuration was developed incorporating improvements for many of the deficiencies noted. Sample pumps were tested in the laboratory and currently a field evaluation program is being conducted in three areas: Bangladesh (in cooperation with UNICEF), Nigeria (under direction of CARE), and Thailand (under direction of AID). The actual pump configurations vary some from one country to another, as it should, but the major design points remain the same. The pump configuration to be described reflects the latest field findings.

PUMP DESCRIPTION

Figures 1 and 2 are assembly drawings of the shallow and deep well pumps, respectively. A parts list follows the drawings for convenient part identification. It can be seen that there is little difference in the pumps except for the cap and fulcrum. It might be noted that the deep well configuration could well be used on both deep and shallow wells; however, the initial cost would be slightly higher than necessary for the shallow wells.

General Description

Except for the steel pipe and a few other parts, the pump is gray cast iron with a composition as close as possible to that shown in Table 1.

TABLE 1. RECOMMENDED SPECIFICATIONS FOR FOUNDRY PIG IRON

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

The carbon ranges listed are to be used only as an indication of the desired carbon content of the pig iron. It is very difficult, if not impossible, to make foundry pig iron to specified silicon and carbon contents. However, the carbon content and silicon content should be in balance in order to produce gray cast iron castings with less variations 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.

Coke specifications are also necessary to produce a satisfactory product. Table 2 indicates minimum standards.

TABLE 2. RECOMMENDED SPECIFICATION FOR FOUNDRY COKE (WEIGHT PERCENT)

<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

The values specified are to be used as a guide when purchasing foundry coke; however, every effort should be made to obtain foundry cokes that have a minimum ash content. An 8.0 to 10.0 percent ash content is very desirable. Sulfur content should also 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 metal problems caused by excess sulfur.

General Construction Details

The sample shallow well pump cap provides a strong fulcrum for heavy use and the deep well cap provides firm wear resistant surfaces.

The pump has a 7-1/2 inch to 8-inch stroke which is quite important when the water table is low, and a 6 to 1 ratio handle to help ease pumping. The center section is made of steel pipe and within limits can be made various lengths increasing or decreasing pump height. Jam nuts are used at all pump rod connections to help prevent rod separations. The pump base is sized to fit over 6-inch well casing and will accept 1-1/4" to 1-1/2" drop pipe. General construction is such as to stand up under heavy use and yet be as light as possible.

Cylinder Construction

Laboratory tests and field evaluation indicate the secret of long cup life is the smoothness of the cylinder in which the plunger operates. An extruded brass cylinder has a smoothness of 8 to 12 micro inch (CLA)*. In contrast, some of the machined iron cylinders taken out of storage were so rough (over 600) due to rust and poor castings that measurements were hard to make. Better castings with more careful machining measured between 200 and 300 micro inch (CLA).

To obtain a very smooth finish, coated cylinders were developed. Two types of coated cylinders have been tested in the laboratory. One coating consists of an epoxy-phenolic resin requiring a low-temperature bake as part of the curing process. This coating is the toughest and most wear-resistant of the two coatings with a smoothness of 12 to 18 micro inch (CLA). This coating performed well in limited field use and would be preferred if baking facilities can be made available. The second coating is an air cure epoxy coating which is not quite as tough and takes longer to cure than the baked coating. This has a smoothness of about 40 micro inch (CLA). This coating has no field evaluation to date. Both types of coated cylinders can be used for shallow well and deep well pumps and are quite inexpensive to apply.

As an alternative, plastic pipe may be used for cylinder construction. Polyvinyl chloride (PVC) plastic pipe is as smooth as extruded brass, costs much less than brass, and field tests have shown it to wear as well. It is recommended for deep well applications. Although the PVC pipe cylinder is more expensive than a coated cylinder, the ease of manufacture (a simple cut-off operation) makes its use for sleeves in shallow well pumps very attractive.

* Center line average

Cups and Valves

Good quality leather is recommended for making plunger cups. Dyes should not be used; however, wax impregnant is acceptable. No special treatment has yet been identified; however, a particular tanning or special treatment may be indicated by current testing. Cups should not fit tight in the cylinders, but instead depend upon the water pressure or suction to seal the cup against the cylinder walls.

Two types of valves are currently in use, poppet and flapper. There is much discussion about which type is best, and no firm answer is available. However, both types depend upon a generous, smooth, well-machined seat. Poppet valves are cast iron or brass which is preferred and leather or rubber washers can be used to help improve the seal. Leather is still the standard material for flapper valves with a cast iron weight. Plastics and composite materials such as nylon impregnated with neoprene should also be considered.

Bearings

The pinned joints should be no less than 5/8-inch diameter and the length such as to insure a projected bearing area of at least 0.94 square inch. If hard use of the pump is to be expected, even larger pins are recommended. Lubrication where possible almost always improves wear. Generally speaking, most shops in developing areas cannot afford the cost of special bearings, nor are they capable of properly fitting bearings, but hardening the cast iron bearing (hole) can be done and is recommended to greatly improve bearing life at a minimum cost.

Pump Options

The pump shown as Option A utilizing a bolt-on cover with fulcrum and a screwed-on center section and base is recommended; however, circumstances may require other configurations. Option B utilizes pinned-on covers

and fulcrums for areas where bolts and nuts are of poor quality, nonexistent, or where vandalism or stealing is a problem. For tube wells, the base can be omitted and the bottom cap with valve of the deep well cylinder can be substituted making up Option C. Option D is where the pump body and cylinder (shallow well pump) are cast as one piece and a PVC liner is inserted to provide a smooth bore. Other variations are available to match facilities and skills available and type of consumer operation, but simplicity is the key to the most reliable and inexpensive configuration. However, care must be taken not to compromise pump operations.

CURRENT EVALUATION

The shallow well pump as fabricated under several options has been proven to stand up well. The plastic deep well cylinder is also being used quite extensively; however, the deep well pump cap is a relatively new arrangement and more data are needed before its capability of withstanding hard use can be confirmed.

Data on valves are conflicting in that both the poppet and flapper types are preferred in different areas. It has been noted, however, that poorly prepared sealings surfaces are not acceptable under any conditions.

PUMP DESIGN PRINCIPLES

The fabricator, installer, and user should be aware of certain design limitations. First, it is recommended that no cylinder sizes over 3-inches diameter be used. It has been observed that leather cups tend to fail rather than wear out in 3-1/2-inch shallow well pumps. It is our feeling that the strength of the cup is not sufficient to withstand the pressure or vacuum created by the pump action and buckling occurs during one portion of the stroke (stretching during the opposite portion of the stroke) causing the cup material to split circumferentially and fail.

Neglecting friction or insufficient flow passageway which can create a substantial load, 3-inch cylinders will require 3.06 pounds lifting force per foot of water being lifted. This means, for example, that for a shallow well with a 26 foot deep water level, about 79.5 (26 x 3.06) pounds of lifting force will be required. This is about the maximum lift for a shallow well pump, and for the pump illustrated approximately 14 pounds ($\frac{79.6 \times 5}{28.5}$) of force is needed at the end of the handle for operation.

In contrast, a deep well pump must operate under much more severe conditions. Again, for the deep well pump illustrated, a 100-foot water lift would require about 357 (100 x 3.06 + 51.1) pounds of force (including the weight of 7/16 diameter pump rod but neglecting friction) and a handle force of over 62.5 ($\frac{357 \times 5}{28.5}$) pounds. Such an arrangement can be improved one of two ways: Make the handle longer or decrease the cylinder size. Most persons can see that increasing the handle length or lever arm decreases the force required for operation, but it may not be apparent in the case with the change in cylinder size. A 2-1/2-inch diameter plunger requires about 2.12 pounds per foot of water lift for operation and for a 100-foot water lift including the weight of the rod but neglecting friction, 263 (2.12 x 100 + 51.1) pounds of force would be required. The handle force would be 46.2 ($\frac{263.1 \times 5}{28.5}$) pounds, over 25 percent reduction from the handle force required by the 3-inch cylinder. A 25 percent increase in handle length decreases the handle force about 20 percent to 50.13 pounds. Every effort should be made to keep the handle force below 40 pounds to permit operation by women and children. Table 3 summarizes the forces discussed.

Decreasing the bearing loading is another factor for reducing cylinder size. Loading is not appreciably affected by a change in handle length. 300 psi is a maximum bearing load for mild steel pins and cast iron journals when lubricated and with a close "running" fit. Since most pumps operate with moving joints of a very sloppy fit, the bearing levels should be kept as low as possible for long life--perhaps below 100 psi if possible. The pumps currently under evaluation have bearings from 5/8-inch diameter to 3/4-inch diameter and at least 1-1/2-inch total length each

TABLE 3. SUMMARY OF PLUNGER LOADS AND HANDLE FORCES FOR VARIOUS PUMP/WELL CONDITIONS

Effective Handle Length, in.	Cylinder Size, in.	Water Depth, ft	Plunger Load, lbs	Handle Force, lbs
28.5	3	26	79.5	14
28.5	3	100	357	62.5
28.5	2.5	100	263	46
35.6	3	100	357	50.1
35.6	2.5	100	263	36.9

joint. Wear, although much improved, can still be a problem. To sum up these points, cylinder diameter, bearing area of each joint, and handle length must be seriously considered and balanced out to provide long life and easy operation.

One last comment on this topic; the greater the lift of water the greater pressure and increase of wear of the plunger cap. Therefore, as wear becomes excessive due to depth, the number of cups should be increased. Trial operation should soon determine when a second or third cup would be required. It has been suggested by one pump manufacturer that water levels at the 50- and 125-foot depths would be levels at which cups would be added for 3-inch cylinders. As pressures become too great, cylinder size would have to be reduced to increase the cup life.

ADDITIONAL REFINEMENTS

Four areas of further improvement to increase pump longevity are (1) Bearings, (2) Cups, (3) Valves, and (4) Piping. Bearing life, and consequently pump life with reduced maintenance, can be improved by the use of lubricated or nonlubricated ball bearings or bushings. The type chosen really depends upon the sophistication in machining the fabricator has available and the money available to buy and/or make the pumps. In most developing areas encountered to date, the degree of capability and money does not appear available; however, an improvement can be made that does seem within reason in many areas. The cast iron journals or "holes" should be hardened by heating to a cherry red and quenching in water. Almost any degree of hardness will improve the bearing life. Care must be taken, however, to guard against tempering one hole while hardening another.

New materials for fabricating plunger cups may soon be available including the reappearance of "Corfam", once manufactured by DuPont. For materials to be useful in cup fabrication, they must be leather-like in ability to expand against the cylinder wall proportionately to the pressure developed by the depth of water being pumped. Qualities to look for are

improved storage life, resistance to fungus, etc, improved abrasion resistance, and ability to withstand wet and dry cycling.

New materials available for plunger cups might also be considered for valves; here, the ability to expand is not required.

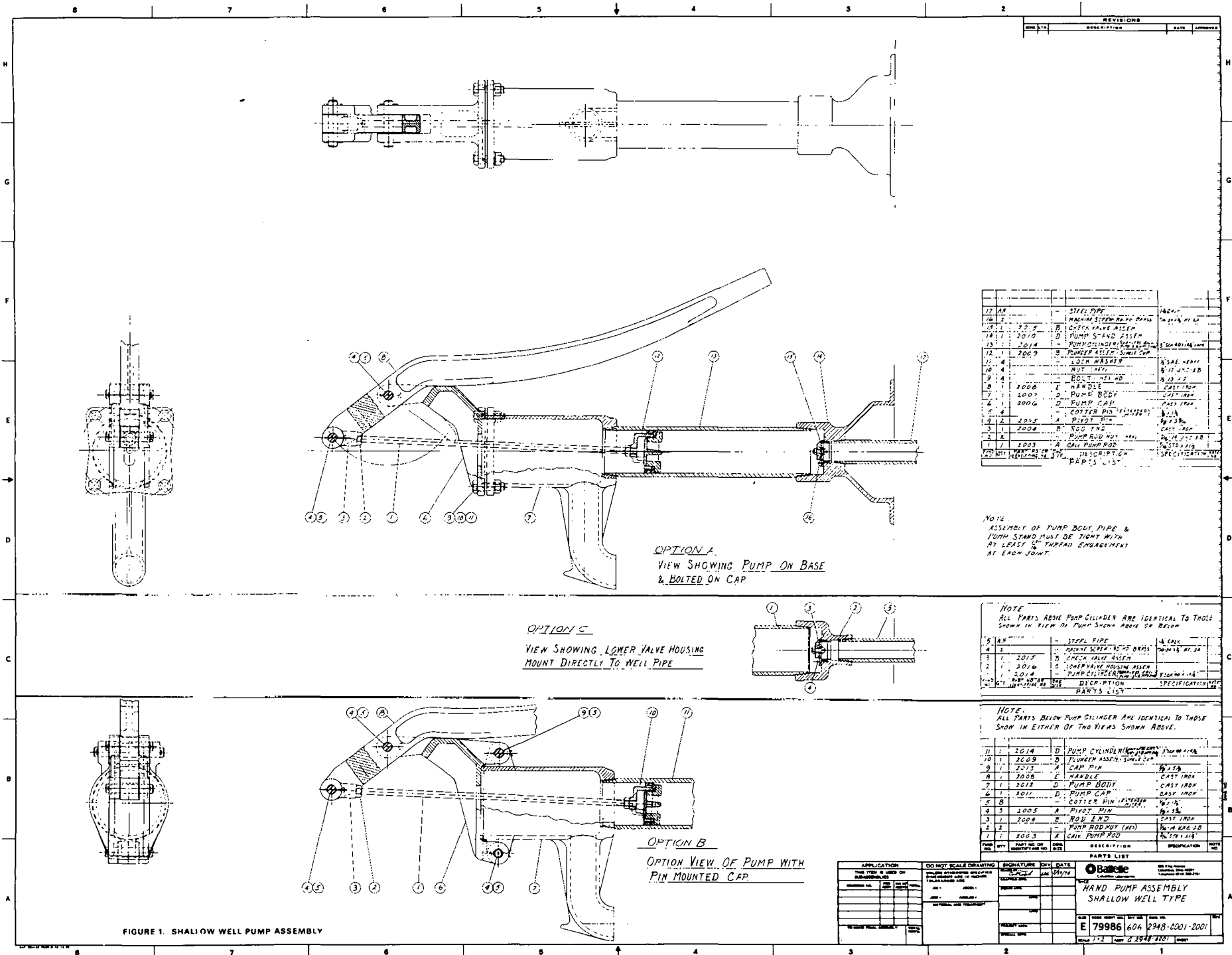
Plastic pipe for use as drop pipe should also be considered for cost-saving installations. Not only may plastic pipe be less expensive to buy, but lighter than steel pipe and cheaper to ship. Although plastic material has lower mechanical strength than steel, is more sensitive to temperature variation, and requires more careful handling, it is not as subject to corrosion as steel, has a lower friction factor, and can be easily jointed in the field. Care must be taken, however, to assure that no bending loads are placed on the pipe and that steel pipe be used for top sections and for securing the pump. Plastic screens are also being installed in some areas.

ADDITIONAL INFORMATION

It is hoped that the information included in this report is of some value to you. Additional data (Battelle's final report on Contract No. AID/csd-3305) will be available by Spring, 1975, and can be obtained through AID. If you are serious about pump production in your area or improving rural domestic water programs and additional information would be of help, please contact Mr. A. Dale Swisher of AID or Mr. Robert D. Fannon of Battelle at the addresses below. We also encourage you to participate with us in this program; and if you desire to do so, we invite you to contact us by writing to the addresses below.

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A. Dale Swisher, P.E.
Office of Health
Technical Assistance Bureau
Agency for International Development
Washington, D.C. 20523
USA



REV	DATE	DESCRIPTION	APPROVED

REV	DATE	DESCRIPTION	APPROVED
17	11	STEEL PIPE	
18	11	PISTON SCREW ROD END	
19	11	CHECK VALVE ASSEM	
20	11	PUMP STAND ASSEM	
21	11	PUMP CYLINDER HOUSING	
22	11	PUMP PLIST. SWIVEL CAP	
23	11	LOCK WASHER	
24	11	ROD END	
25	11	BOLT 1/2" ID	
26	11	HANDLE	
27	11	PUMP BODY	
28	11	PUMP CAP	
29	11	COTTER PIN 1/8" DIA	
30	11	PIVOT PIN	
31	11	ROD END	
32	11	ROD END	
33	11	CAV. PUMP ROD	
34	11	DESCRIPTION	
35	11	PARTS LIST	

NOTE:
ASSEMBLY OF PUMP BODY, PIPE & PUMP STAND MUST BE TIGHT WITH AT LEAST 1/8" THREAD ENGAGEMENT AT EACH JOINT.

REV	DATE	DESCRIPTION	APPROVED
36	11	STEEL PIPE	
37	11	PISTON SCREW ROD END	
38	11	CHECK VALVE ASSEM	
39	11	LOWER VALVE HOUSING ASSEM	
40	11	PUMP CYLINDER HOUSING	
41	11	DESCRIPTION	
42	11	PARTS LIST	

NOTE:
ALL PARTS BELOW PUMP CYLINDER ARE IDENTICAL TO THOSE SHOWN IN EITHER OF THE VIEWS SHOWN ABOVE.

REV	DATE	DESCRIPTION	APPROVED
43	11	2014 D PUMP CYLINDER HOUSING	
44	11	2009 B PUMP ASSEM - SINGLE	
45	11	2012 A CAP PIN	
46	11	2008 E HANDLE	
47	11	2012 D PUMP BODY	
48	11	2011 B PUMP CAP	
49	11	2005 A COTTER PIN 1/8" DIA	
50	11	2005 A PIVOT PIN	
51	11	2004 E ROD END	
52	11	2003 A PUMP ROD END (RD)	
53	11	2003 A CAV. PUMP ROD	
54	11	DESCRIPTION	
55	11	PARTS LIST	

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FIGURE 1. SHALLOW WELL PUMP ASSEMBLY

