TAMPERE UNIVERSITY OF TECHNOLOGY, FINLAND
The Department of Mechanical Engineering

Handpump Technology in Developing Countries with Special Reference to Experiences in South-East Tanzania

M.Sc. Thesis by Juhani Viiala

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Abstract

This study is based on the experiences gained in handpump program and development in Mtwara and Lindi regions in Tanzania and on the literature of handpump development, research and use.

The aim of the international drinking water supply decade (1980-90) is to provide all mankind with safe, accessible water supply. In rural areas in developing countries handpump wells are constructed to fulfil the water demand. Handpumps used for the wells have not been suitable for heavy use in developing countries.

The large number of tests in laboratories and in the field conditions have highlighted the shortcomings of the pumps. The development work has resulted in more durable and suitable pumps and improvements for the old pump designs to be used in developing countries regularly by 200 to 300 people.

The Governments of Tanzania and Finland are in co-operation improving water supply in two regions in the south-east Tanzania. The project includes constructing piped water schemes and over 2000 handpump wells. The project has tested and developed Finnish handpumps and a few other pump types together with the pump manufacturer and the UNDP/World Bank handpump program. The most important invention has been the Nira Af-85 direct action handpump. It is nowadays the only pump installed in shallow wells in the area. The pump uses plastic below ground components and a steel pump head. It is easy to operate and maintain. The pump is regarded as useful by the project and by other people who have tested it.

Tiivistelmä

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Tämä tutkimus perustuu käsipumppujen kehittelyä koskevasta kirjallisuudesta kerättyyn aineistoon, kirjoittajan työskentelyyn Mtwara ja Lindi läänien vesihuoltoprojektissa Tansaniassa sekä pumpunvalmistajien ja käsipumppuja tutkivien laitosten kokemuksiin.

Kansainvälisen vesihuoltovuosikymmenen (1980-1990) päämääränä on saada jokaiselle maapallon asukkaalle puhdasta juomavettä. Kehitysmaiden maaseudun vesihuolto-ongelmia yritetään ratkaista rakentamalla kyliin käsipumppukaivoja. Veden tarve on suuri ja siksi pumppuja tarvitaan paljon. Yhden perheen käyttöön kehittyneissä maissa tarkoitettu pumppu ei kestä kehitysmaissa, joissa pumpulla on päivittäin 200-300 käyttäjää. On osoittautunut tarpeelliseksi kehittää pumppuja erityisesti kehitysmaiden olosuhteisiin sopiviksi. Yhtenäisillä laboratorio- ja kenttäkoemenetelmillä saadaan vertailukelpoisia tuloksia pumppujen ominaisuuksista ja kestävyydestä.

Tansanian ja Suomen valtiot rakentavat yhteistyössä Tansaniaan Mtwara ja Lindi läänien maaseudun vesihuoltoa. Alueelle rakennetaan vesilaitoksia, putkiverkostoja ja yli 2000 käsipumppukaivoa. Noin 90 % alueen 1,5 miljoonasta asukkaasta asuu maaseudulla. Lähes kaikki kaivoihin asennetut käsipumput on valmistettu Suomessa. Mtwara-Lindi vesihuoltoprojekti on kehitellyt pumppuja yhdessä valmistajan kanssa. Lisaksi Mtwara ja Lindi läänit ovat Maailmanpankin maailmanlaajuisen käsipumppuohjelman kenttäkoealuetta.

Tässä työssä selostetaan käsipumpputekniikkaa sekä pumppujen kehittelyä ja tutkimusta. Lisäksi esitellään Mtwara-Lindi alueen käsipumppuohjelmaa ja siellä tehtyä käsipumppujen kehitystyötä.

Käyttämällä sopivia materiaaleja ja kehittelemällä rakennetta pumput on saatu kestäviksi ja sopiviksi kehitysmaiden olosuhteisiin. Suomessa valmistettu Nira Af-85 suoravetopumppu on laajasti tunnustettu hyväksi pumpuksi kehitysmaiden olosuhteisiin. Se sopii rakenteen ja materiaalien puolesta myös valmistettavaksi kehitysmaissa.

List of acronyms

ABS	Acrylnitrilbutadienstyren
CATR	Consumers' Association Testing and Research laboratory
FINNIDA	Finnish International Development Agency
GOT	Government of Tanzania
HDPE	High density polyethylene
MAJI	Ministry of Water in Tanzania
NPSH	Net positive suction head
PE	Polyethylene
PUR	Polyurethane
PVC	Polyvinylchloride
TBS	Tanzanian Bureau of Standards
UNDP	United Nations Development Program
UNICEF	United Nations Childrens' Fund
U.K.	United Kingdom
VLOM	Village Level Operation and Maintenance
WB	The World Bank
WMP	Water Master Plan

List of symbols

A	Area
C,c	Consumption of water
d	Diameter
e	Eccentricity
F,f	Force
g	Gravitational acceleration
H	Head
m	Mass
N,n	Number of sth.
p	Pressure
P	Power
Ps	Pitch
Q	Volume flow
s	Displacement
V	Volume
v	Velocity
W	Work
ϱ	Density
η_{ov}	Overall efficiency
η_{m}	Mechanical efficiency
η_{v}	Volumetric efficiency

1. Introduction

The United Nations declared the 1980s as the International Water Supply and Sanitation Decade with the objective of providing basic water supply and sanitation facilities for mankind by 1990. Tanzania had already launched a twenty year water supply program in 1971 aiming to provide each person with a safe and accessible water supply by 1991. In rural areas one of the simplest, most reliable and least expensive methods for supplying water is to construct handpump wells and install sturdy and cheap handpumps which can be maintained by villagers and manufactured in the particular country.

The number of handpumps needed for rural water supplies in developing countries during recent years has been great but the quality, durability and suitability of the pumps for those conditions has been low.

It has been agreed that the research and development of handpumps is essential for the promotion of rural water supplies in developing countries.

In this study technology, development and research of handpumps for developing countries will be explained. Tanzania has its own specific conditions which are to be taken into account in the pump design.

The specific subject of this study is to report the experiences of the use of handpumps in South-East Tanzania where the Governments of Tanzania and Finland are in co-operation implementing the rural water supply program in the Mtwara and Lindi regions. Through the end of 1986 about 2200 handpump wells have been constructed. Most of them have Finnish made handpumps. The handpump manufacturer in Finland is continuously developing its products together with the Mtwara-Lindi Rural Water Supply Project in Tanzania which has provided the field experiences of the pumps.

An important invention has been the Nira Af-85 direct action handpump. Since the end of 1984 when the first prototypes were produced, the pump has been tested, developed and installed for actual use in Mtwara-Lindi where the number of Nira Af-85 pumps in 1986 exceeds 500. The experiences of two years of field use as well as laboratory tests will be described in this study. Few designs of the parts have been changed but the pump seems to be a real new generation handpump.

2. Operational principles and properties of handpumps

2.1 Fundamental hydraulics

2.1.1 Suction and lift

The suction pump is using the atmospheric pressure to push the water upwards to the cylinder which is placed above the static water level in the well. The pump reduces the atmospheric pressure in the suction pipe and the atmospheric pressure is pressing the water up. The suction capacity or the suction lift is not accomplished by any force applied directly by the pump to the water source but by developing the negative pressure head at the pump intake. The working depth of the suction pump is in practice a maximum of 7 meters. The cylinder and the piston are often inside the pump head (Mc Junking 1977).

The maximum suction lift is limited by four factors:
- atmospheric pressure
- vapour pressure
- head losses due to friction
- required inlet head of the pump

The suction capacity is often expressed with a net positive suction head NPSH. NPSH is defined as the gauge reading on the suction inlet minus the vapour pressure plus velocity head at this point (Stepanoff 1967).

$$NPSH = \frac{ps\ max}{g\varrho} - \frac{pv}{g\varrho} + \frac{vs^2}{2\ g} \qquad (\ 1\ )$$

where

ps = pressure gauge reading representing the maximum suction capacity in the suction inlet
pv = vapourizing pressure of water at the pumping temperature
vs = flow velocity of the water in the suction inlet

In practice the flow velocity head is often small and insignificant.

NPSH is a statement of minimum suction conditions required to prevent cavitation in a pump. The available NPSH in installation must be at least equal to the required NPSH if cavitation is to be prevented.

Lift pumps which are mostly piston pumps have a cylinder placed below water level. The displacement element is pushing the water upwards into a rising pipe. There is no absolute limit for the depth of a cylinder installed below the ground level. The depth is limited by available force, tension in the structure, leakage, installation and maintenance difficulties.

Lift pumps are used rather than suction pumps because leakage at the piston and at the bottom valve means that the suction pump is out of operation or that the performance is poor.

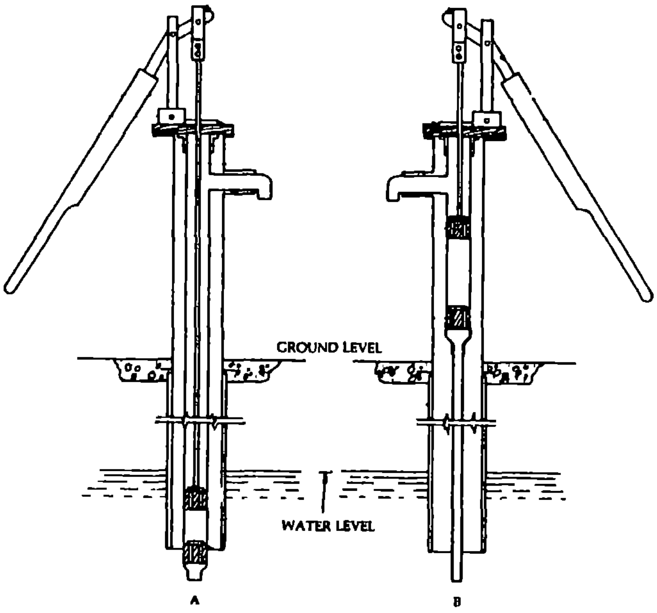


Figure 2.1 a) Lift pump, b) Suction pump

2.1.2 Work

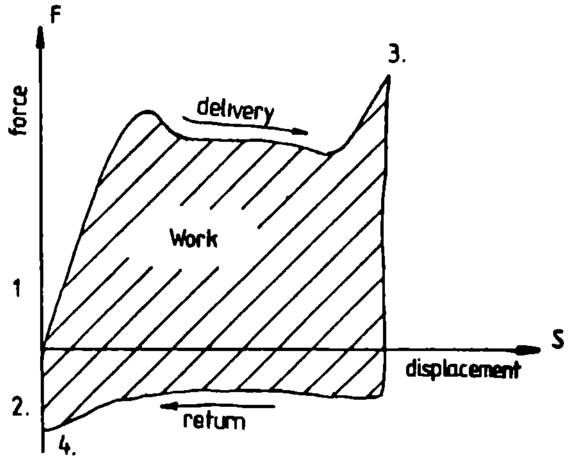
The work input for the piston pump can be calculated by the formula:

$$W = F\,s \qquad (\,J\,) \qquad (\,2\,)$$

where

F = force on the handle against the displacement (N)
s = displacement (m)

Because the force is not constant during the whole stroke the work can be measured by the force/displacement loop. An example is shown in Figure 2.2.



1. upward force
2. downward force
3. momentary contact with lower handle stop
4. momentary contact with upper handle stop

Figure 2.2 Work input on the handpump

The work output is an increase of potential energy of a mass which is lifted at the discharge spout level.

$$W = m\,g\,H \qquad (\,J\,) \qquad (\,3\,)$$

where

m = mass of water discharged (kg)
g = gravitational acceleration ~ 9,8 m/s^2
H = water head (m)

2.1.3 Power

The human muscle power 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, done by healthy young male laborers is often estimated at 60 to 75 watts. The power available during short work periods is much greater. Well trained athletes can generate up to 1,5 kW for efforts of 5 to 10 seconds.

The required power for the pumping can be calculated by the formula:

$$P = \frac{Q\ H\ g\ \rho}{\eta_{ov}} \qquad (W) \qquad (4)$$

where

Q = rate of discharge (m^3/s)
H = head (m)
ρ = density of water ~ 1000 kg/m^3
g = gravitational acceleration ~ 9,8 m/s^2
η_{ov} = overall efficiency

Table 2.1 describes the man generated useful power available by the duration of the effort.

Table 2.1 Man generated power (McJunking 1977)

Age of man years	Useful power in watts by duration of an effort in minutes					
	5	10	15	30	60	480
20	216	209	201	179	157	90
35	209	201	179	157	134	75
60	179	157	149	127	112	60

Most handpumps 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 men. With virtually no measured data from field tests of handpumps an average human power output of 75 watts appears reasonable.

An example:

$Q = 20$ l/min $= 3{,}3 * 10^{-4}$ m^3/s

$H = 13$ m

$\rho \sim 1000$ kg/m^3

$g \sim 9{,}8$ m/s^2

$\eta ov = 0{,}6$

$P = Q\,H\,\rho\,g\,/\,\eta ov = 70$ W

2.1.3 Efficiency

Handpumps have volumetric and mechanical losses due to leakage, pressure drops and friction. These factors are taken into account as a volumetric η v, mechanical η m and overall η ov efficiency coefficient.

$$\eta ov = \eta v * \eta m \qquad (5)$$

The volumetric efficiency of the reciprocating handpumps may be defined as

$$\eta v = \frac{\text{actual delivered volume per cycle}}{\text{volume displaced during the cycle}}$$

The volumetric efficiency is therefore a measure of the wasted potential volumetric output capacity. Valve delays and leakage through seals and valves decrease the volumetric efficiency.

In some cases volumetric efficiency can exceed 100 %. For example, in a long suction pipe of a small diameter below the cylinder may result in a sufficiently high velocity to keep open the plunger discharge valve during a part of its upward movement. This may lead to excessive pounding and even cavitation if the dynamic suction head losses lower the water pressure immediately below the plunger at its vapour pressure.

Volumetric losses are caused by a plunger seal and valve leakage, a bottom valve leakage and sometimes riser pipe and connection leak.

Overall efficiency may be considered as a measure of the wastage of an effort as a result of leakage, friction and pressure forces.

$$\eta_{ov} = \frac{\text{hydraulic power output from pump}}{\text{mechanical power input to pump}}$$

$$\eta_{ov} = \frac{m\ g\ H}{\int F\ ds} \qquad (6)$$

where

$g \sim 9{,}8\ m/s^2$

m = mass of water discharged (kg)

H = head (m)

F = force on the handle (N)

s = displacement (m)

Mechanical efficiency losses are caused by the friction and pressure drops. Friction appears at bearings, between the plunger and the cylinder, between the pump rod and the riser pipe. The greatest pressure drops are in the bottom valve, in the plunger and between the rod and the rising main if the pump rod diameter is large.

2.2 Operational principles

2.2.1 Lever action

Lever action pumps can be either suction or lift pumps. With the lift pump, the cylinder and the piston is located below the water level in the well. Lift pumps are used for all water depths up to about 80 m deep.

The construction of the shallow and deep well pumps is often different. Suction pumps used by one family or small groups and lift pumps with shallow cylinder installation depths do not need to be as sturdy as handpumps used by larger communities or pumps with deep cylinder installations.

The disadvantages of the lever action pumps are the easily wearing and breaking fulcrum bearing and lever mechanism. The lever and the bearing increases the pump price a lot. A benefit of the lever action pump is the possibility to utilize the mechanical advantage to reduce the force to operate the pump (McJunking 1977).

Pump rods have caused many failures in lever action piston pumps. Steel rods with the diameter of 10 mm to 16 mm are commonly used for pump rods. The pumps are operated with short strokes and at high speed so the pumping motion may be considered as an almost constant acceleration and instanteous deceleration. The forces in pump rods are caused by the hydraulic pressure force, weight of the rodding, acceleration of the rodding and water column and frictional losses. The top of the rod may be bent in the pumps which have a solid link and the pump is not completely in alignment with the borehole.

The damaging effect of the piston valves closing too late at the piston's lowest point can be confirmed by the mathematical model but this problem is, however, rather complex to solve.

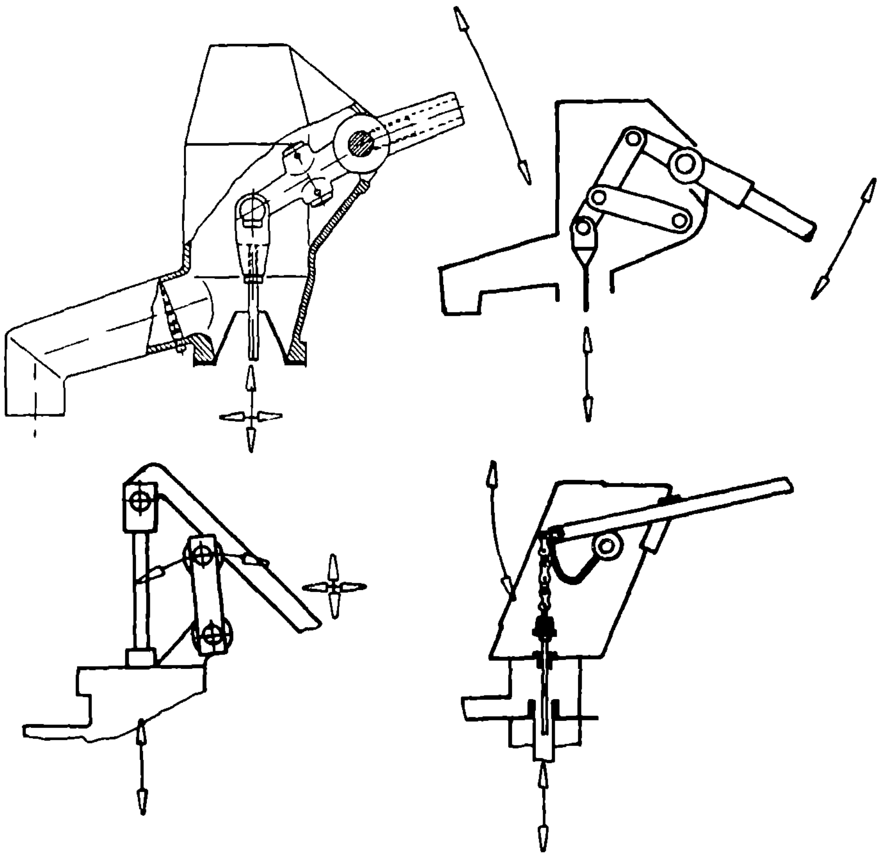


Figure 2.3 Lever mechanisms

2.2.2 Direct action

Direct action pumps are defined as those in which the pump rod is operated directly, by means of a handle attached to it, without the mechanical advantage which conventional handpumps achieve by means of a lever arm or a gear box. Because of their extreme mechanical simplicity, relatively low cost and relative ease of maintenance with only a few tools, the direct action handpumps potentially fulfil village level operation and maintenance (VLOM) objectives. Unskilled village well caretakers can maintain the pumps. Parts that need regular maintenance or replacement are easily dismounted and inexpensive. The rest of the parts that are wear-resistant do not need to be removed during the maintenance. The direct action pumps have become potential alternative handpumps for shallow and medium deep wells.

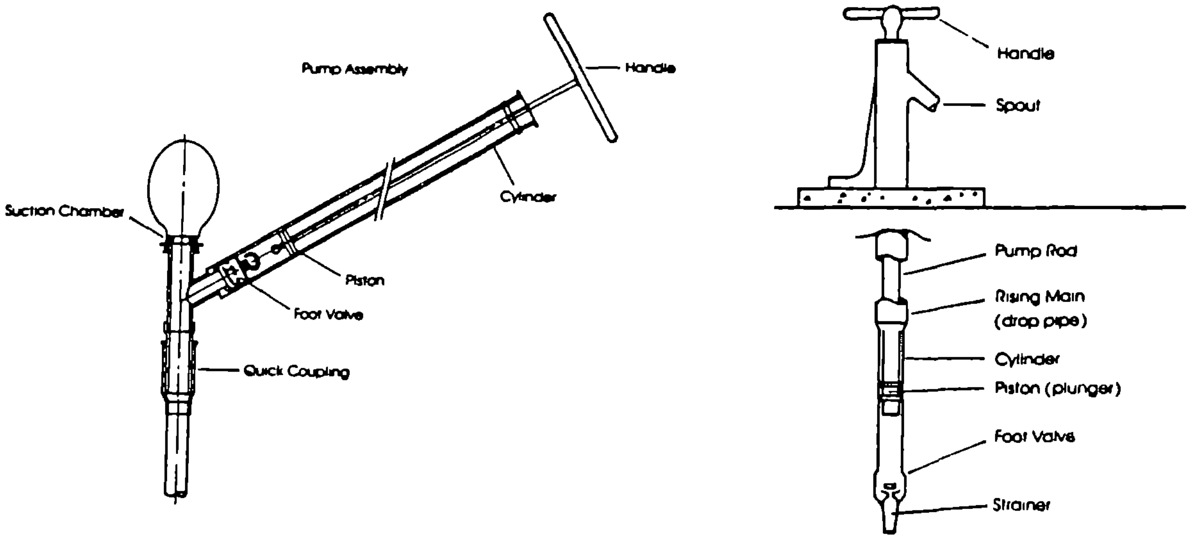


Figure 2.4 Direct action pumps

The bearing and the lever are probably the parts which fail most frequently in the lever action pumps. The direct action pumps do not have any lever. Thus one possible failure can be avoided. Less force is subjected to the pump rod than with conventional lever action pumps because the force applied to the handle by the user is not multiplied as it would be with a lever. This means that the rod is subject to less severe operating stresses and permits the use of a great variety of rod materials. For the below ground parts plastic materials are used rather than metals. The components are made simple to allow these to be manufactured locally.

Also the pump reduces the disadvantage of the eccentric application of the handle force which is necessary for the lever pumps and causes stress at the pump stand.

Most of the direct action pumps are comfortable to operate and the discharges are sufficient if recommended installation depths are followed. The comfortable operation of the direct action pumps has been achieved by using floating large diameter pump rods because the leverage can not be utilized. If the cylinder is installed very deep and the static water level is low the small diameter cylinder must be used and the discharge will be low.

The force required to operate the direct action pump is dependent on several factors. The down stroke force is in proportion to the length of the rod and is independent of the level of the water in the well. During the down stroke water is moving freely through the check valve in the piston and, therefore, for the purposes of analyses of the down stroke the piston almost does not exist. The down ward force required to overcome the buoyancy of the pump rod will be in direct proportion to the cross-sectional area of the pump rod and its weight. An advantage of the direct action pump is that it also delivers water during the down stroke. The volume discharged on the down stroke will be equal to the increase in the volume of the rod submerged in the water in the rising pipe, which will be proportional to the cross-section of the rod at the point where it enters the water column, i.e. at the top of the rod. The down stroke handle force is the sum of the forces required to overcome the rod buoyancy and friction, minus the assistance provided by the weight of the rod and the handle themselves. Down stroke handle force (Fd) can be calculated using the formula:

$$Fd = Ar\ lr\ \rho\ g + F_\mu - Fm \qquad (N) \qquad (8)$$

where

Ar = cross-section of the rod (m^2)
lr = total length of the rod (m)
ρ ~ 1000 kg/m^3
g ~ 9,8 m/s^2
F_μ = friction force (N)
Fm = rod weight in air (N)

During the up stroke most of the force required to lift the piston is proportional to the horizontal cross-sectional area of the piston exposed to the column of water above it and to the pumping head plus the additional frictional forces and the weight of the pump rod itself. It must be noticed that the pumping head is the distance from the static water level to a discharge spout outlet.

$$Fu = (Ac-Ar)\ H\ g\ \rho + F_{\mu} + Fm - Fb \qquad (9)$$

where

Ac = cross-section of cylinder pipe, inside (m^2)
Ar = cross-section of pump rod, outside (m^2)
H = pumping head (m)
g ~ 9,8 m/s^2
ρ ~ 1000 kg/m^3
F = frictional force (N)
Fm = rod weight (N)
Fb = buoyancy of the rod section below the static water level (N)

2.2.3 Rotating

The helical rotary pump has a rotating handle, a gearbox, a rotating shaft and a single thread helical rotor turning within a double helical stator with a pitch twice that of the rotor forming a series of sealed cavities 180 degrees apart. These cavities progress from suction to discharge as the rotor turns. As one cavity diminishes the opposite cavity increases at exactly the same rate. The meshing helical surfaces push the water up with uniform movement similar to a slow moving piston in a cylinder of an infinite length. Because the rotor to stator contact provides an effective, continuous seal, the helical rotary pumps require no valves.

The rotor rolls eccentrically within the stator. The rotor eccentricity is the maximum distance between the centerline of the rotor and the centerline of the stator found as the rotor rolls in the stator.

The volume of the cavity passed through the pump with one revolution of the rotor is a product of the rotor eccentricity, the minor diameter of the rotor and the stator and the pitch length of the stator. This volume is

$$V = 4 \quad e \quad d \quad Ps \qquad (10)$$

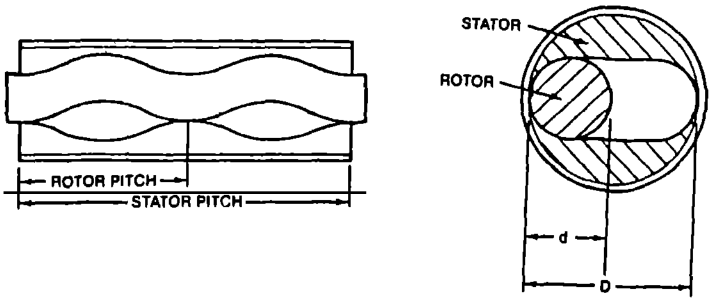


Figure 2.5 Rotor and stator

The slip past the seal line increases due to the increased pumping depth but it is independent of the pumping intensity.

The pressure developed by a pump can be increased by increasing the number of the seal lines or stages in the pump (Robbins Mayer).

There is normally a gearbox to transfer the handle rotation to the shaft rotation and to utilize mechanical advantage.

Reciprocating pumps with a piston may have a fly wheel above ground mechanism. They have a shaft which is joined to a fly wheel and to a pump rod with links. The pump rod moves up and down when the wheel is rotated. Mechanical advantage can be adjusted by changing the position of the handle grip or the shaft link.

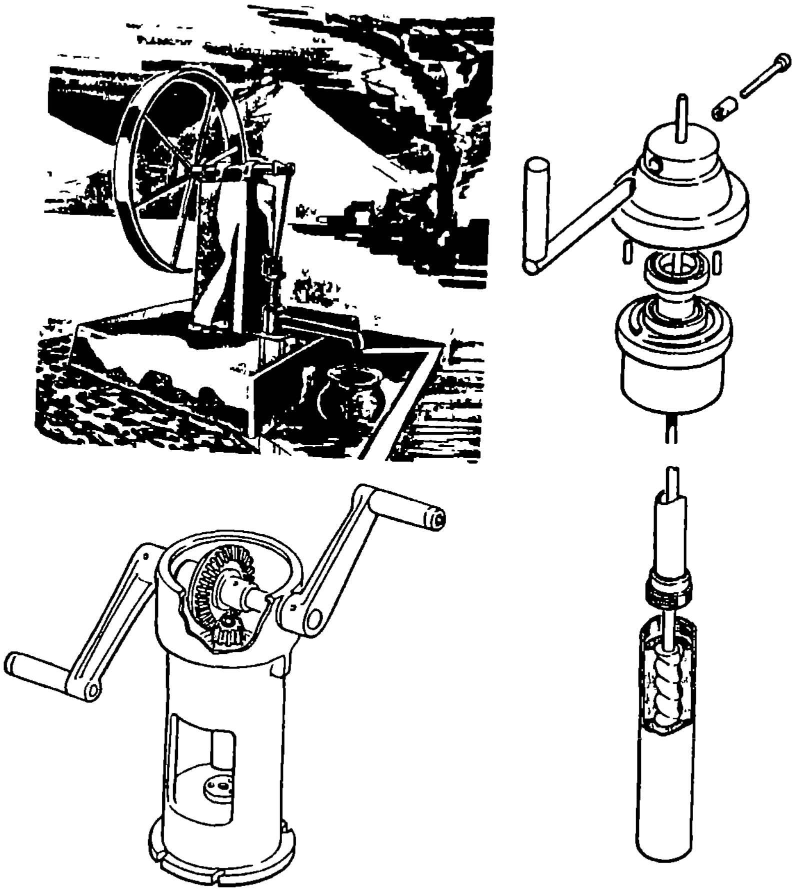


Figure 2.6 Rotating pumps

2.2.4 Foot operating

Foot operated pumps may have a below ground assembly similar to the hand operated pumps but the above ground assembly is different. The pump is operated by pushing a pedal to move the piston or by rotating two pedals similar to a bicycle. The single pedal is returned from its lower position by a spring, hydraulic or air pressure or by a handle connected to the pedal.

2.2.5 Diaphragm

With diaphragm pumps an elastic diaphragm is moved with a mechanical force, hydraulic or air pressure. Increased or decreased volume due to the diaphragm movement lets the water flow through the valves. Diaphragm pumps are of suction and lift type.

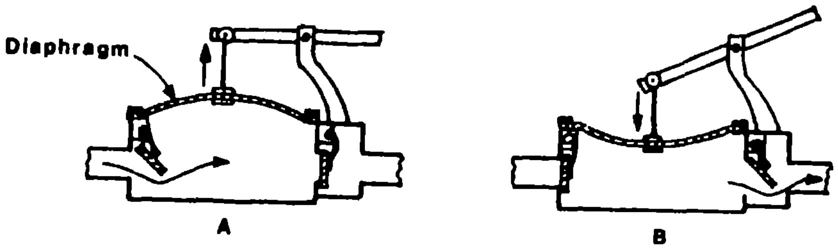


Figure 2.7 Diaphragm pump a)suction, b)delivery

2.2.6 Pulsating

One of the unusual pumps which has been tested in one University and in CATR laboratory but not yet widely in the field is a pulsating pump. The principle operation of the pump can best be understood by reference to the diagram, where a pipe of length L connects the lower cylinder and foot valve to upper master cylinder which is worked by the operator located at height H above the water source.

The lower cylinder contains a number of compressible balls or ovoids which act as a spring of rate K, while the water in the pipe has an effective mass m. As the operator moves the piston in the master cylinder back and forth he/she will set in oscillation the water column at or near its natural frequency.

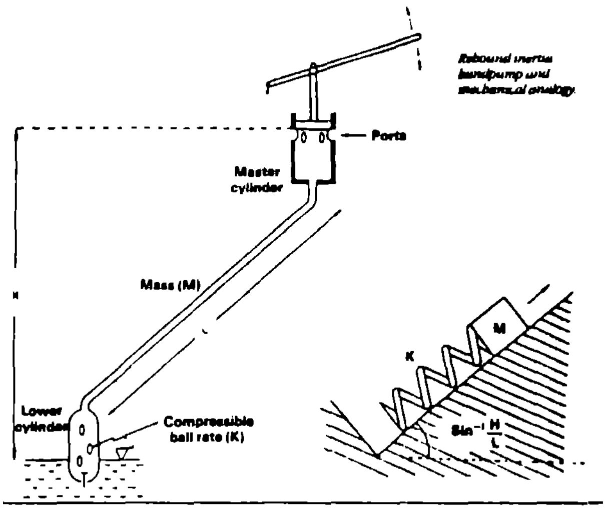


Figure 2.8 Pulsating pump principle

If this is done vigorously enough, then upon rebound the spring will expand and the mass m will travel up the inclined plane with a retardation of $g^{(h/l)}$. In terms of pump operation this means that the foot valve opens and a small quantity of water enters the lower cylinder. Once inside the system it cannot return and so by implication an equal quantity of water must be discharged through the lateral ports at the upper end of the master cylinder (World Water 1986).

2.2.7 Venturi

A venturi handpump uses an ejector with a foot valve, which is connected to the riser pipe and then submerged below the water level in the well. After installation or repair the pump must be filled with water in order to establish the hydraulic balance which is required for the above ground level piston to pump water down through the ejector.

The function of the ejector with its appropriate size nozzle and venturi is to suck up more water coming from the well than is pumped through it with the piston.

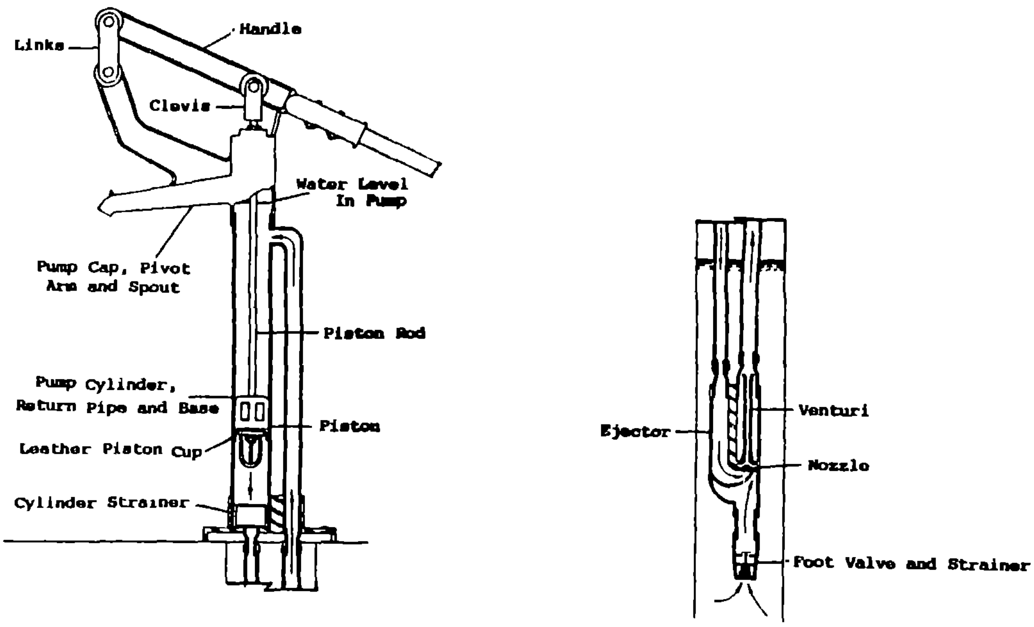


Figure 2.9 Venturi handpump

2.4 Materials

2.4.1 Metals

Metals are used for most of the pump parts. Pump heads are welded from mild steel plates and pipes instead of the previously used cast iron material. Painting or coating of the parts with protective material has been used in an attempt to reduce the corrosion of the steel parts. The presence of iron oxides in water is a problem in many countries. This is partly caused by using steel casings in a borehole well and metal below ground components. Galvanized steel is used for the rising main and pump rods. As soon as the galvanizing is worn away the pipe starts corroding. Stainless steel and brass are too expensive and are not available in developing countries. Aluminium pump rods are used also but aluminium is not strong enough.

2.4.2 Plastics

Plastics are increasingly used to replace other materials, particularly metals as a handpump material. The success of a plastic part is often more dependent on the design than on the type of the plastic used.

Variations of different kinds of plastics and their performance allow these plastics to be used for many parts. The advantages of plastics over metals are their chemical inertness, low weight and easy machining.

PVC is used both as a rising main and pump rod material. The pipes are joined together by solvent cementing and threaded joints. The PVC pipes being suspended are breaking due to tension. The wear of PVC when fine sand particles are present in water reduces its use as a cylinder material. This could be solved in clean water by using softer piston rings like HDPE to wear in preference to the harder PVC cylinder. This was found when the ring was rubbed against the PVC cylinder in clean water. The wear of the cylinder was very pronounced when sand was present and no significant wear was observed on the HDPE piston ring (Goh Sing Yau 1985).

HDPE has been used as a riser pipe, pump rod and bearing material. Its advantages are toughness, easy machining, flexibility and non-sensitivity to sunlight. The disadvantages are high heat expansion and softness. In the Mtwara-Lindi Regions in Tanzania, HDPE rods and riser pipes have been used for more than two years and none of the pipes have been cut. There were over 500 of these pumps in operation by the end of 1986. The wear appears but none of the pipes have been replaced due to the wear. HDPE is used also as bearing material with direct action pumps. The wear can be observed in tests of long duration which will show whether the wear is significant or not.

Polyacetal plastic bearings for lever action pumps have been developed and used for a few years by the UNDP/WB program. The results are promising and metal bearings for some pumps will be replaced with inexpensive and durable plastic bearings.

Most plastic materials can be machined by conventional methods of turning and milling. In machining careful attention should be paid to the shape of the cutting tools. Generation of excessive heat in the work piece should be avoided.

Thermoplastic components can be produced by a variety of moulding and forming processes. Extrusion is used to manufacture PVC and HDPE pipes. Injection moulding products can be very complex and dimensionally consistent within close tolerances and can offer high standards of finishing.

Plastic components can be joined together by cement or by welding, although the success varies with different materials. PVC and ABS are particularly suitable for solvent cementing, whereas polyethylene is not.

2.4.3 Others

Wood is available in most of the developing countries. The manufacturers have been requested to design pumps which use as much wood as possible. However, wood is not used very often because of its poor properties, but few pumps have wooden parts like handles, bearings, pump rods and valve and piston housings.

Rubber is used as a piston valve and bottom valve material. However, the plastics are also displacing rubber as a valve material. Nitrile rubber and natural rubber are shown to be the most successful for handpumps. Rubber is sometimes reinforced with other materials like nylon and textile fiber.

Leather is mostly used as a piston and seal material. The reasons for using leather are primarily:

- the porous structure allows particles to be embedded, thus preventing wear of the seal itself and the cylinder wall

- good leather seals could be manufactured locally in most countries

- leather seals with a comparatively long lifetime can be manufactured

With proper selection of raw material, tannage and impregnation the leather seal will last as long as high quality nitrile rubber (Hahn and Johansson 1985).

3. Requirements for the handpumps in Tanzania

3.1 National targets

About 85 % of the population of about 20 million in Tanzania (Figure 3.1) is living in rural areas and depends on the rural water supply. The increase of population in Tanzania is annually over 2,5 percent. This means that the growth is more than 500 000 people every year.

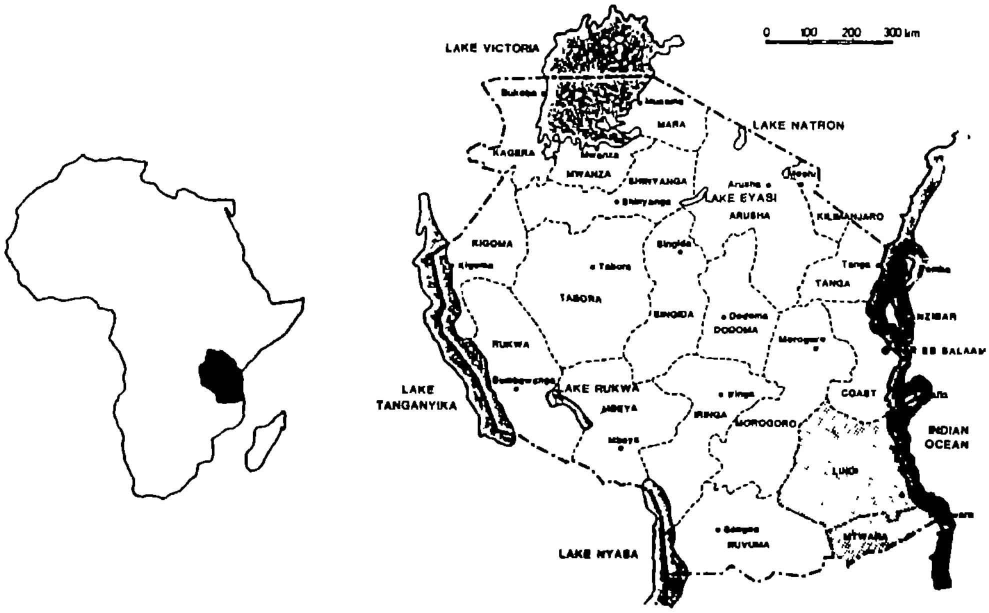


Figure 3.1 Map of Africa and Tanzania

Tanzania launched a twenty year water supply program in 1971 aiming to provide each person in the rural areas with safe, accessible and adequate water supply with a stand post about 400 m from each household. Due to various constraints such as the lack of funds it has been possible by the end of 1982 to provide water to less than 50 % of the people previously planned (Shallow wells 1984).

Therefore it has rightly been decided that the use of a handpump well as an inexpensive technology should be adopted wherever feasible. Further to enhance efficient and effective implementation of the rural water supply projects including handpump wells and piped water supply, the policy that water is provided free must change. Villages must own the wells or schemes, they must participate in all stages of the project implementation, be responsible for maintenance of the wells and pay for the spareparts, pump replacement and village well caretaker (Shallow wells 1984).

Tanzania must start the local manufacturing of handpumps and other equipment and prepare standards for handpumps and accessories. External finance should mainly be used for the procurement of materials and equipment that are not available in the country.

The Tanzanian staff should be involved in project implementations as much as possible instead of expatriate personnel. Proper organization for the procurement and maintenance should be instituted at the regional, district, ward and village levels (Shallow Wells 1984).

Handpump wells could also be constructed as a stand-by system beside the piped schemes in urban areas when possible. Many of the piped rural systems are not operating due to the lack of fuel or spareparts. The pipe net may not cover the whole town or other densily populated urban fringe areas. Handpump wells could provide people with water during an interruption in the piped water supply which may sometimes last for months. The current budget constraints affect further the Government's ability to operate and maintain these systems. Accordingly, handpumped ground water supplies are seen as a possible solution. The identification of easily maintained handpumps, the establishment of their manufacture in Tanzania and the development of an appropriate maintenance system are fundamental to a successful national rural water supply program.

There should also be a reserve system for handpump wells. If there are only handpump wells in the village and sometimes some of these are out of operation then the rest of the pumps must be capable of providing the village with water. Sometimes the repair of broken pumps takes a long time. The old water sources like contaminated pits or streams will hopefully not be used during the lack of operational handpump wells.

3.2 Handpump types

Most of the existing handpump wells in Tanzania have rather shallow static water levels. In approximately 70 % of the wells the water level is not deeper than 12 m. If there is deeper ground water potential, boreholes with deep well pumps should be constructed.

According to the shallow wells programme issued by Maji in 1984, it is feasible that 7 million people could be served through the shallow wells by 1991. This means that 30 000 wells would be constructed by 1991 or 3 800 additional handpumps are needed per annum. Assuming that the life time of each pump is five years, the estimated total hand pump requirement is about 50.000 until 1991. In other words the number of the shallow lift handpumps needed in each working day should steadily increase from about 15 per day in 1985 up to 30 per day by 1991 (Keller 1985).

The handpumps which are used in Tanzania must fulfil the village level operation and maintenance (VLOM) requirements.

VLOM handpumps are those which:
-are suitable for maintenance and repair by trained village handpump repairmen who have adequate tools and locally available spare parts
-are economically suitable for the people who will use them
-can be manufactured in developing countries
-can serve 200 to 300 persons for 8 to 10 hours a day

The pump may be considered as a VLOM pump in some circumstances but not in all. An example is a pump which could be manufactured only in certain developing countries because the manufacturing process and capabilities exist in these countries but probably not somewhere else. An other example would be a pump which can be maintained by a trained village repairer only when the cylinder is installed rather shallow.

3.3 Operation and maintenance

Handpumps are mostly used in rural areas where the level of technology is very low. Villagers should participate in all stages of a water supply construction, especially if it is based on handpump wells. Later, maintenance of these pumps and wells should be the responsibility of villages. People who use pumps should realize that pumps must be operated properly and the misuse of the pump will only do harm to their own village.

People seldom complain that the pump is difficult to operate. Users in Mtwara-Lindi were interviewed on the convenience of pumping but the answers concerned the water quality or pump durability, aspects that have nothing to do with the pump operation. There was, however, a case where a pump was asked to be replaced with a type which already exists in the village.

Once the water supply is provided it is important to ensure that the community continues to rely upon it. Thus, it is essential that the handpumps are kept in operation continuously. If the pump is out of service for a long time people will return to their traditional water sources. The high rate of abandoned or defective handpumps is a reflection of poor quality and inadequate maintenance and repair.

There are different alternatives to organize the maintenance of the handpumps and to keep the well surroundings clean. In the village level maintenance system villages have water committees which have the main responsibility of the well. The committee chooses one or two well caretakers from the village and they should repair the pumps, collect the spareparts from the stores, do the preventive maintenance and clean up the well surroundings. All the responsibilities lie on the water committee and the well caretakers.

In the two level system the village well caretakers chosen by the water committee do only preventive maintenance and service and clean up the surroundings. Mobile maintenance teams in either regional, district or even lower level visit pumps regularly and repair them when needed.

In the centralized system, regional and district level teams do all the maintenance and repair tasks of the wells. The wells are visited regularly and repaired if needed. This system is commonly used in the beginning of water project and before the well caretakers have been trained. The centralized maintenance organization takes care of urban handpumps and those which cannot be maintained by villagers e.g. many deep well pumps.

The pumps and wells can be owned privately by individuals or institutions. Privately owned wells and pumps are maintained by the owners and spareparts are bought from the suppliers.

If there are private repairmen who maintain community-owned wells they should get payment from the villages.

Village well caretakers who are trained are normally unskilled men without any basic knowledge of technology. They might not even know which way to turn a spanner to open a nut. After the training they should be able to repair pumps in the villages. This sets high demands for the training period, training material and supporting literature which they will later use on the job.

3.4 Standardization

There are rare cases where a country can standardize only one pump type. In Tanzania two pump types, one for shallow and one for deep wells, with as many interchangeable parts as possible would be good. There should be more than one manufacturer and dealer for the pumps to keep the quality high and the price low.

Standardization of only a few pump designs for a given country will facilitate local maintenance, the availability of spareparts to village well caretakers and manufacturing of the pumps locally.

Different assistance agencies have been involved in handpump well construction in different parts of Tanzania introducing their own pump preferences. Five different pump types are mainly used and each of them has several models and modifications of the parts.

Not only pumps but also tools, well covers, ergonomics, characteristics and even maintenance system could be standardized.

A procedure for formulating a Tanzanian Standard has several phases. In the case of a handpump standard, a Handpump Technical committee which is called the working group (WG) was established in 1986. The members of the committee are the Ministry of Water, Donor agencies, Contractors, the University of Dar Es Salaam and the secretariat from the Tanzanian Bureau of Standards (TBS). The committee works under the Mechanical Engineering Division of the TBS. TBS has very few technical people involved in standard preparations. Consequently, the committee consisting of handpump specialists is making proposals for standards. The Technical Committee (TC) and the Divisional Committee (DC) may reject the drafts and send them back to the Working Group. The approved drafts by the TC and DC are send for circulation to the public which includes people who are interested in the draft like consumers, manufacturers, institutions and professionals. A period of a few months is set for such circulation. All of the received comments from the public and the draft are presented again to the TC. After considering all the comments, necessary modifications are executed and the draft becomes a finalized Tanzanian Standard. The Executive Council (EC), which is the highest administrative organ of the TBS, can finally reject or approve the standard. The Ministry of Industries declares the standard to the public in the Government Gazette. The standards are revised every five years to take technical achievements into consideration and update the obsolete standards.

The working group has held three meetings prior to January 1987. There has been discussion about base plates, cover bolts and pump rods. The first preliminary drafts include specifications of measurements and materials.

It seems to be difficult for the working group to achieve consensus if the draft standard does not include most of the variations of the parts that are used now. Of course this should not be the objective.

3.5 Special conditions

People in many distant villages in Tanzania are not used to operating machines. The handpump is one of the few machines in the village, the others being bicycles, milling machines and sewing machines. People easily learn how to operate the pump but not how to maintain it. Mainly women and children draw, carry and use water whereas most of the trained well caretakers are men. The pump design should take into consideration the user's ergonometrics like height, available force, pregnancy etc. Women may resent the change in social life brought by the new water supply e.g. loss of privacy when new water points are placed near the houses.

It has been planned that one well supplies water for 250 people each using 25 liters daily. It takes about one minute to fill a 20 liter bucket. This means that the pump is operated about 5 hours daily excluding the time required to change the operator. There are certain rush hours in the mornings and in the evenings when people must wait in line. If some of the pumps in a village are out of operation then other pumps are highly loaded.

Table 3.1 shows how many strokes (N) one handpump is operated per one year.

$$N = 365 \quad n \quad c \; / \; V \qquad (11)$$

where

N = number of the strokes (nos.)
n = number of the people served by one pump (nos.)
c = consumption per day par capita (l/day)
V = volume of one stroke (l)

Table 3.1 Number of strokes on handpumps in one year

People served	200			300		
volume of one stroke	0,3	0,6	0,9	0,3	0,6	0,9
consumption per day	Strokes in millions per one year					
10	2,4	1,2	0,8	3,7	1,8	0,9
15	3,7	1,8	1,3	5,5	2,7	1,8
20	4,7	2,4	1,6	7,3	3,7	2,4
25	6,1	3,0	2,0	9,1	4,6	3,0
30	7,3	3,7	2,4	11,0	5,5	3,7

Wells with higher discharge than 5 liters per minute are accepted in Mtwara-Lindi area. 250 people with a consumption of 25 l per day need 6250 l per day. If the well discharge is 5 l per minute it takes about 21 hours to yield 6250 l of water.

It has been estimated that if the distance to the well is less than 400 m the time used for collecting water represents less than 3 % of her/his working time per day.

The handpump well is not always used even if the pump is operational. If the quality of water varies in the wells, different wells are used for different purposes. The taste of water might not be good because of the presence of iron oxides. Salty water is not used for drinking nor washing clothes. A well which is too far away may lead to the use of an old water source. Rain water is collected during the rainy season. Some unfounded beliefs exist about the suitability of the water. People do not always understand the importance of safe water for their health. There are difficulties with the use of pumps in certain cases. Some pumps must be operated while standing on the cover. The cover must be low enough or there must be steps to make the climbing easy.

Tanzania has a temporary standard of water quality. Polluted and open water points like open pits, streams, ponds and open wells are sources of waterborne diseases. These are for example malaria, cholera and diarrhoea. It cannot be guaranteed that the water in handpump wells is always safe. The quality of water must be tested continuously and particularly if water contamination is suspected. A broken well structure or the pump may let the contaminated water flow into the well. If the broken pump is not repaired the cover may be removed from the well and the water is soon polluted.

3.6 Local manufacturing

3.6.1 Technology

The local production of one type of shallow well handpump and one deep well handpump is essential to improve the development and maintenance of National Rural Water Supply in Tanzania. Until now the handpumps used in Tanzania have been produced mainly in the industrialized countries where the highest technology is available. However, recent development in handpump technology has taken into account the need to produce pumps in developing countries.

There are two types of local manufacturing to be considered. The first is mass production in foundries, machine shops and factories of handpumps often copied from those in the international export market. Such manufacture is practical in many developing countries. The second type of local manufacture has been variously termed "low technology" and lends itself to production in small quantities by village artisans and small shops. Where large numbers of community handpumps are used, the first type will generally be much more important due to capacity for mass production of more durable, more interchangeable pumps. The production of handpumps by villagers should include bamboo pumps, chain pumps, diaphragm pumps, rope pumps and windlass pumps.

It does not seem to be possible to transfer the handpump or sparepart production to the regional or even village level in Tanzania. One principle of the VLOM handpump has been that it should be possible to make some spareparts even in the villages. The quality of those spareparts would be low. Sometimes even original, replaced spareparts break down faster than factory assembled parts.

It seems impossible to design a handpump which does not use special materials or need special production methods which are not available in Tanzania. The import of raw materials or individual parts must be accepted if they do not cost too much compared to the total price and if the availability of those parts is guaranteed.

There are some companies in Tanzania which could manufacture good quality handpumps. It is recommended that a joint venture between a local partner and a donor agency to produce handpumps in some good workshop should be created. The donor input would be technical and economical assistance, foreign currency and material support.

Most of the factories and work shops in Tanzania are running at low capacity. The companies have good and expencive machines which they would like to utilize but some facilities are missing.

Several surveys and feasibility studies have been made recently on local handpump manufacturing in Tanzania. Two reports have been published in 1985 as part of the UNDP handpump program on feasibility for manufacture of handpumps in Tanzania. The special task of the UNDP study was to find out if local industries can produce simple, robust direct action handpumps. In Dar Es Salaam and near by, 27 companies were studied and 5 of those were found capable and interested in handpump production. One company was finally chosen for closer inspection.

As part of the study a few prototype direct action pump heads named Tanda were made in the chosen factory. Some of those were tested in the Mtwara-Lindi project and both the manufacturing quality and the design were found poor.

3.6.2 Raw materials

According to the study (Keller 1985) steel pipes and plates, HDPE and uPVC pipes and rubber products are available locally. Matters that limit their use are irregular availability, low quality and wrong price. Many materials are sold to the customers soon after arriving from abroad. Tests applied on 25 different types of hardwood have demonstrated that each wood differs from the other and that the wood "Mkarakati" (Erythrophleum guineese) which is tested also by the CATR laboratory shows promising results (Keller 1985). Present pump designs used in Tanzania do not have wooden parts but they have been tested as bearings and pump rods.

Morogoro Rural Water Supply Service Unit could use the following locally available materials for their pump production:

- Steel plates; supply irregular, plates imported through donor import support
- Galvanized steel pipes; supply regular, external account payment, low quality
- Round steel bars from size 10 mm upwards

The price of locally available materials is higher than that of the same imported materials (van der Wel 1986).

Mild steel and wood are materials which are mostly available in Tanzania. Some materials will most likely have to be imported if the handpump is to reach high quality. Injection moulded parts made from nylon or a similar material should be fabricated outside Tanzania.

3.6.3. Existing manufacturing

Some water projects, factories and organizations have made prototypes of handpumps in Tanzania. Most of those have been more or less copies or slightly modified models of already existing handpumps.

Serial production exists now only in Morogoro where the Morogoro Rural Water Supply Service Unit supported by the Dutch Government is manufacturing and assembling handpumps. The start-up phase of local production took place in 1983/84. The production capacity is 50-60 pumps per month. Presently the SWN 80 lever type pumps and the Kangaroo foot/spring vertical action pumps are produced.

Shinyanga handpumps which is a modification of the Uganda or UNICEF pumps were produced by the Shinyanga Shallow Well Project in the seventies. The production continued only during the project and after the handing over no more pumps were produced. The pumps produced in Shinyanga had some short-comings and they were not very robust.

During the feasibility study made by Keller in 1985 a prototype direct action Tanda handpump was made by Industrial and Technical Services Ltd., a company of Palray Group. The pump resembled the Nira Af-85 pump. Only the pump head was made in that factory.

Three Tanda pumps were also installed in the Mtwara-Lindi area. The quality was poor and they had to be removed after a couple of months. The top bush and its housing was broken, the chrome coating was removed and the corrosion on the handle went through the pipe. The Nira Af-85 down hole components were used.

3.6.4 Consequences

The local production of handpumps will improve the rural water supply and the handpump technology. It will increase productivity in local industries and generate foreign exchange.

If the pumps and spares are made in Tanzania they are likely to be sold in Tanzanian currency. Local constuctors and villagers are thus able to buy them.

The development of the locally produced handpumps would be efficient. The manufacturer can get field experience on its pumps easily; the pumps are near and thus they can be visited and observed easily.

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

1. Lower costs of production
2. Transport savings
3. Reduced foreign exchange
4. Stimulation of local industry and employment
5. Local availability of parts
6. Production of handpumps tailored for local condition

4. Testing and development of handpumps

4.1 General

Although the technology of handpumps is rather simple, the ideal handpump has not yet been made. This can be explained by the sometimes contradictory demands usually put on handpumps, for example:

low cost - durability
low weight - sturdy design
high capacity - easy to operate
high quality - local manufacturing

(Hahn and Johansson 1985)

Technically and economically inadequate handpumps, little information and few reliable test results were available when the market for handpumps was awakened by the international assistance programs for rural water supplies in developing countries. The funds allocated to handpump research and development have been small considering the investments made and needed in rural water supply development (McJunking 1977).

However, the results from the tests have been important and useful to manufacturers and constructors and handpump development has been a matter of great interest.

Initially, old pump models which are designed for one family or a small group and new designs without proper tests were used for large communities. Soon these pumps were found unsuitable for such conditions. It was agreed that tests and development are needed before the pumps can be taken for actual use.

After mathematical analysis and laboratory tests simulating field conditions have been done, the components can be modified according to the results and prototypes can be built for tests under actual field conditions.

The laboratory test results provide rapidly a useful insight into the pump's likely long term performance, but they cannot fully simulate the conditions under which the pumps must operate in developing countries. Therefore wide and well organized field tests of handpumps in the particular country will finally indicate the performance of the pumps under the real conditions.

In 1981, as one of the activities in support of the International Drinking Water Supply and Sanitation Decade, the United Nations Development Program and the World Bank initiated a project for Testing and Technology Development of Handpumps for Rural Water Supply and Urban Fringe Areas (the UNDP/WB handpump program).

The main objective of the program is to promote the development of designs and implementation strategies which improve the reliability of schemes based on ground water and handpumps, and which enable schemes to be managed by communities and replicated on a large scale.

The project has carried out laboratory tests mainly in the U.K. in the Consumers' Association Testing and Research Laboratory and field trials in 17 countries to measure the performance of 2 800 handpumps of 70 different pump models. The regional project offices are in Abidjan (West-Africa), Nairobi (East-Africa), Dhaka ?(South-Africa) and Bangkok (East-Asia and Pacific). The published reports are open and available for everybody.

The UNDP/WB program has field trials in four countries in East-Africa. They are Sudan, Tanzania, Malawi and Kenya. The project also maintains contacts with handpump related activities in other countries in the region. In the eastern Africa, the main activities of the project team have been the field testing of existing handpump models and the design and development of handpumps that can be manufactured locally and can be maintained at the village level (Arlosoroff et al 1984).

4.2 Laboratory tests

4.2.1 Objects being tested

Laboratories, universities and other research organizations are carrying out tests for handpumps. Areas ranging from a single part to a complete pump, from materials to pump performance and endurance are being tested. Theoretical analysis and mathematical models can be combined with laboratory tests.

The mathematical analysis explains and supports the experimental results. The most failure-prone parts and new designs are the most interesting test objects. The user trial where some users are asked to operate the pump can be carried out in laboratories. Endurance tests show which parts are wearing most and whether the pump is durable and performing well for field tests. The function and behavior of parts can be easily seen in laboratory conditions and, for example, transparent models can be built.

4.2.2 Methods

Laboratory testing, when compared with field testing, has the advantages, of being relatively economical and rapid, logistically simple, and allowing the testing of different types of pumps under identical conditions to provide comparable results. Nonetheless, there are many types of faults which will only be exposed under actual use in the field, and therefore pumps which have successfully passed laboratory testing should be further evaluated under field conditions.

In laboratories the actual conditions where the pumps are used in developing countries are simulated. Simulating field conditions has not always been successful. There must be a way to relate the conditions in laboratories to the field conditions. For example, in a laboratory the number of strokes in one year can be $30*10^6$ which corresponds to 5 years of use in the field.

Consumers' Association Testing and Research (CATR) laboratory is an independent laboratory in U.K. which is testing handpumps by an assignment of the UNDP/WB project, manufacturers and other institutions. Since January 1, 1986 CATR has conducted laboratory tests on 42 handpumps. This work supported by the Overseas Development Administration of U.K. began in 1977 with the testing of 12 pumps.

The main objectives of the laboratory work related to handpumps are the following:

1. Assist the manufacturers in improving the quality of their products.

2. Assist the authorities and agencies in developing countries in deciding between local manufacturing and the importation of handpumps.

3. Provide agencies in developing countries with an evaluation of handpumps to ensure a more informed choice of pumps and that the right pump is selected to suit the conditions of the particular developing country (WUDAT 1986).

CATR has developed its own standard method to test handpumps in laboratories. The summary of the test procedure is as follows:

1. Description
- manufacturer, pump model and type, cost

2. Inspection
- condition of pump, literature

3. Weights and measures

- weights of principal components, principal dimensions, cylinder bores, ergonomic measurements

4. Pump performance

- volume flow, work input and efficiency, leakage

Strain gauges will be attached to the pump handle to measure the applied forces, and a rotary potentiometer fixed to the body of the pump will measure the angular movement.

The computer is programmed to record the data and calculate the work done by the operator on the pump. The computer compares this work done on the pump with the work done by the pump in raising water (the product of the weight of water raised and the head) to calculate the efficiency of the pump. The pump will be tested at three operating speeds,normally 30, 40 and 50 strokes or revolutions per minute. Successive strokes retrace the force/displacement loop. The area inside the loop represents the work done on the pump (see Figure 2.1).

The leakage test will be carried out by removing the cylinder and one end of the drop pipes. The various heads will then be simulated by injecting compressed air above the cylinder.

5. User trial

- user comments, observations of users

A number of users will be recruited . Most will be women and children of various heights and ages. Each user will be asked to fill in a short questionnaire to record their opinions on the ease of operation.

6. Endurance test

- stage 1. 2000 hours, clean water
  stage 2. 2000 hours, water with particles

The handles of the reciprocating pumps will be driven in simple harmonic motion in 40 strokes per minute imposing no shock loads. The simulated depth will be the maximum agreed with the manufacturer.

Any failure is examined and an assessment made of the probable cause.

7. Abuse test
- handle shock load, side impact on handle and pumpstand

8. Engineering assessment
- materials, manufacturing methods, fitness for purpose, suitability for manufacture in a developing country, easy installation, maintenance and repair, resistance to contamination and abuse, potential safety hazards and suggested design improvements

9. Verdict
- short summary of the main good and bad features of the pump and its performance.

10. Reporting
- first interim report before the endurance test
- further interim reports if needed
- final technical report (CATR 1985)

Since 1982 Lund Institute of Technology in Sweden has implemented a project for handpump testing and development. It is an example of the testing procedure which concentrates on testing only a few items of the pumps. The project is specifically concerned with the below ground pump components such as parts in a cylinder, particle separators and flexible connection between the rod and handle. The test work comprises:

1. Long term endurance tests in a test rig where 12 cylinders can be operated at the same time. This provides mainly information of the materials which are most suitable for piston seals and the expected minimum wear on the valves and the connection between pump rod and handle.

2. High accuracy measurements of force, flow, mechanical effectiveness and pressure flux at the pump stroke. This is

done in another rig with only one cylinder in order to avoid disturbances.

3. Testing of new designs. These can be evaluated and compared with conventional designs under the same conditions in the test rigs.

(Hahn and Johansson 1985)

4.2.3 Equipment

The pumps are often installed in a test rig at different heights. There might be one or several pumps in one rig. The pumps are operated by mechanisms driven by an electrical motor or by a pneumatic cylinder.

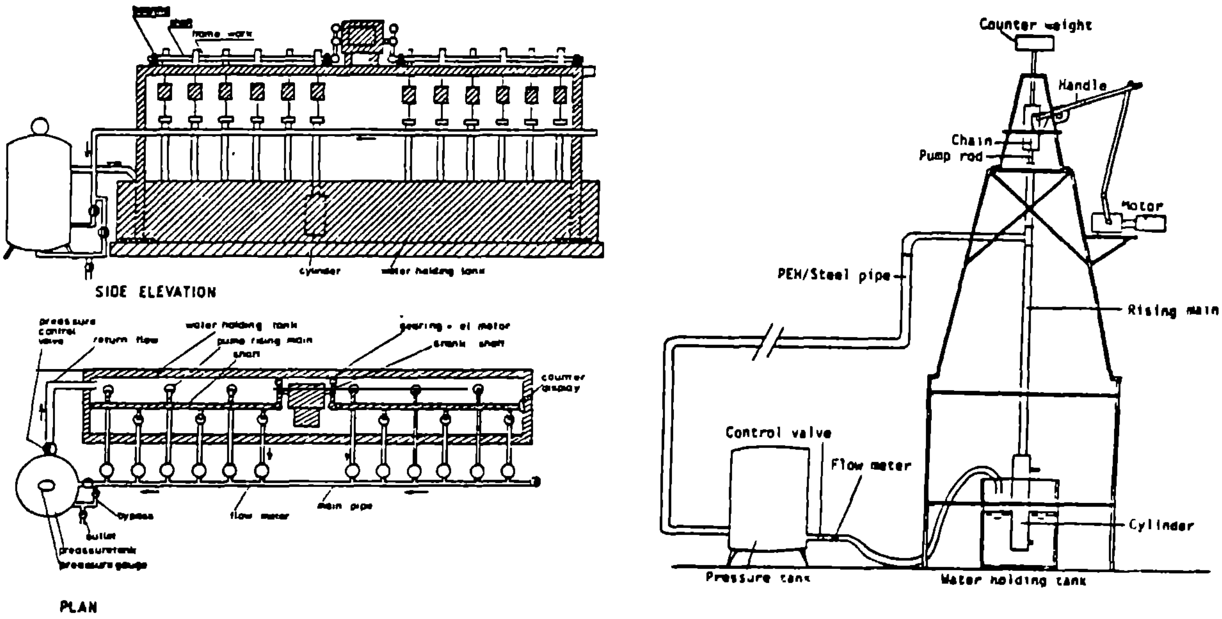


Figure 4.1 Test rig used in Lund University a) for 12 test units b) for one unit at a time

The measurement of force and pressure flux could not be made in the first rig without great difficulties because of disturbances caused by the other cylinders that were operating at the same time as one cylinder was studied. To obtain higher accuracy in the measurements, the second rig was taken into operation. The design is similar to the first one, but only one cylinder is run at a time.

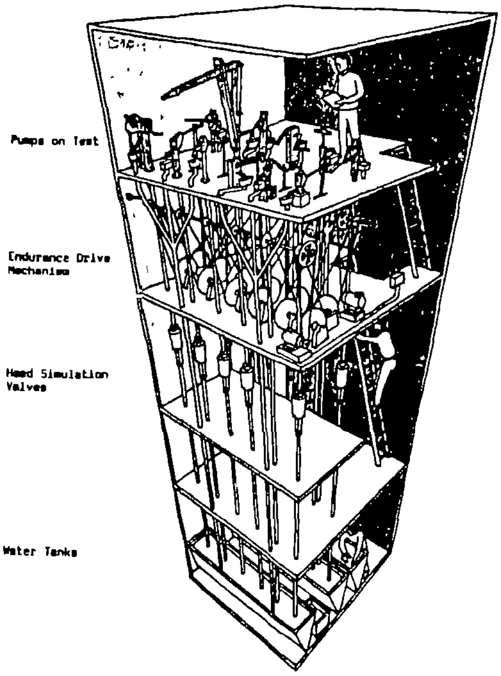


Figure 4.2 CATR test tower in England

Head losses over the plunger or the bottom valve can be defined by measuring the pressure in both sides of the measured object with simple Mercury pressure gauge and measuring flow with a flow meter. The head loss coefficient (Kv) at stationary flow can be calculated according to the formula:

$$dH = Kv\ v^2/2g \qquad (\ m\ )$$

where

Kv = Head loss coefficient
v = Flow velocity (m/s)
$g \sim 9{,}81\ m/s^2$

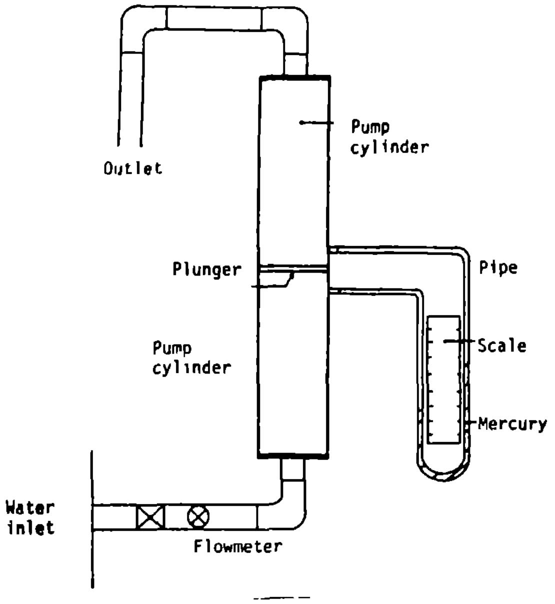


Figure 4.3 Head loss measuring equipment

Head simulating valves are used to simulate deeper heads than the rig allows. The volume of pumped water can be measured with water flow meters. Strain gauges are used to measure handle forces. With potentiometers the handle movements can be measured.

The performance of the pump can be calculated with a computer by using information from sensors and the results can also be presented easily with the computer.

4.2.4 Results

Laboratory evaluation is prompting manufacturers to modify their design to overcome flaws, thus ensuring better performance and longer pump life. This of course is benefical to the consumers in developing countries. The manufacturers are sometimes not informed about field problems of their pumps and the laboratory work has highlighted some potential areas of breakdowns.

The information and test results from the independent laboratories are more reliable than the information from the manufacturers. The manufacturers' own test results are for their own use and the results which are published mainly report positive aspects.

4.3 Field tests

4.3.1 Objects being tested

Handpumps which are tested in the field are almost always in actual use. The complete pump is then monitored according to a certain plan. Individual parts as units of a whole structure can also be observed. The users' behavior when pumping and his/her opinion gives information on whether the pump is ergonomically well designed and whether the user likes to operate the pump. Ease of maintenance is sometimes only a phrase whereas the truth comes up when trained well caretakers are asked to maintain the pump for a few years.

4.3.2 Methods

Field investigations are done in the places where the pumps have been installed for actual use. The pump usage is therefore uncontrolled and can only be estimated according to observations and some measurings.

It is good if a large sample of pumps of the same type are monitored at the same time for as long a period as possible. Then, most probably, all features and failures of the pump will appear at some point. If only a small number of pumps are observed, then the conditions where the pumps are operated should be variable and well recorded.

The pumps in the field may be dismounted every now and then, even if they are in good condition. The parts can then be measured and observations of the components can be made. If the pump is opened often, the long term endurance of the pump cannot be seen precisely because the joints etc. are tightened during the assembly, dust and sand is removed but also some things may be damaged or impurities may enter, for example, into the bearings.

If the pumps are dismounted only when they are broken the information of endurance of a complete pump is more reliable. During the visit only general observations, measuring of pump performance and probably preventive maintenance is done.

If there are several national field testing programs, field methodology and measurement techniques must be equalized to ensure that data collected in one program are compatible with those in another. Ideally, the same data collection sheets should be used for all programs. If this is not possible then a minimum set of data to be collected which is common to all programs should be agreed upon.

The UNDP/WB program for field trials of hand pumps and related activities are taking place in 17 countries in western Africa, eastern Africa, South Asia and Latin America and the Carribean. This is done in collaboration with national and international institutions in each country.

4.3.3 Equipment

In the field tests only very simple equipment can be used. Also there is no need to measure complicated areas with complex equipment which is difficult to use and easily breaks down. These areas can be measured easily in laboratories.

If the volume discharged is measured only occasionally it can be done with a bucket or for long periods of operation with a water meter. The bigger the pumped volume the better the accuracy. If the pressure drop in the water meter is high, water may be discharged from the handle and bearing holes not from the spout.

To measure the internal and external wear of the parts, Vernier calipers or micro meters can be used. Forces can be measured with a spring weighing machine.

The depth of the water level can be measured by an electronic measuring equipment which relies on the difference in the electrical resistance of water and air. The equipment makes the continuous measuring possible if the water table is not stable. The depth of a well and a momentary water level can be measured by a simple rope with the weight dropped in the well.

4.3.4 Results

Handpump field test results are often good only for the national level because the conditions vary from one country to another.

It was revealed that parts which did not wear at all in the laboratory showed serious wear in the field tests. The wear is relative to the usage of a pump and other factors. The wear can be decreasing or increasing depending on the wear and time.

People might not like to be observed at the well and they behave in a different way than is their custom. They go to another well than is their custom, they send their children to fetch water, they are afraid to wash themselves or clothes at the well. If the sample of wells is large, the time spent at the well should be long and the observer reliable and familiar with the users so that the results might be more reliable.

Transfer of information and results from the field to the manufacturers is essential so that suitable good quality pumps can be produced.

5. Handpumps in Mtwara-Lindi regions in Tanzania

5.1 Rural water supply development in the area

5.1.1 Area and population

The Mtwara and Lindi regions, with the total area of 84 700 km^2, representing 9,0% of the mainland's total area, lie in the south-eastern corner of the country. In 1978 Mtwara and Lindi had a population of 0,77 million and 0,53 million, respectively. Of these people 90 % are living in rural areas. The number are projected to grow to 1,14 million and 0,78 million by 1991 (Ovaskainen and Viiala 1986).

5.1.2 History of the Rural Water Supply Project

The Government of Finland has supported the planning and implementation of the rural water supply development in the Mtwara and Lindi regions since 1972. The work has been carried out by Finnwater Consulting Engineers. The preparatory phase for the implementation consisted of the feasibility study, the housing project and the Water Master Plan. The zonal Project organization was formed to carry out the implementation of the Water Master Plan in 1978. The organization was planned to work for a limited time. Three implementation phases of two years each have been completed by the end of 1984. The fourth phase which commenced in 1985 is due to be completed at the end of 1987. During phase 4, the project activities will be transferred to the local authorities and communities.

By the 1986 the project has constructed an improved water supply for about half of the population (1,5 million). This includes more than 2200 handpump wells and 14 piped water schemes. The costs of the project have been shared by the Government of Tanzania (GOT) and the foreign donors in the following way: Finnish Development Agency (FINNIDA) 63 %, GOT 11 %, U.K. 14 % and UNICEF 12 % (Ovaskainen 1986).

5.1.3 Water Master Plan (WMP)

As a part of the technical co-operation between the Governments of Tanzania and Finland an agreement was reached in 1973 on a water resources inventory and development plan for the Mtwara and Lindi regions. Finnwater Consulting Engineers was appointed to carry out the work which started in the same year and was completed in March 1977. The work was determined to include an inventory and development of the resources in Mtwara and Lindi regions, a survey of necessary improvements of current water supplies, a phased rural water supply development plan for the regions. The consultant also acted as an agent for the client in purchasing equipment and supplies needed for the service. The aim of the plan is to provide everybody with good and safe water 25 l/capita/day by the year 2001. An intermediate target is to provide improved water supply to all villages by 1991 guaranteeing a minimum requirement of water 10 l/capita/day. The results are shown in Table 5.1 (Finnwater 1986 b).

The importance to update the WMP 1977 was recognized and emphasized during the evaluation of the Project at the beginning of 1984. The revision of the WMP was published in 1986. The water master plan has a detailed plan of how the water supply will be improved in the area, in each town and village.

The water supply situation during the preparation of the first water master plan in 1975, a revision in 1984 and a projected water supply situation in 2001 according to the WMP revision are shown in Table 5.1.

Table 5.1 Population using different types of water sources in the Mtwara and Lindi regions in 1975, 1984 and 2001 (Finnwater 1986 b).

Source	1975		1984		2001	
Piped supply	458 000	37%	550 000	38%	1341 000	64%
Handpump well	76 000	6%	380 000	26%	770 000	36%
Pit	339 000	28%	360 000	25%		
River or stream	163 000	13%	80 000	5%		
Spring	78 000	6%	80 000	5%		
Dam or pond	73 000	6%	15 000	1%		
Not known	46 000	4%				
Total	1233 000	100%	1465 000	100%	2119 000	100%

Table 5.1 gives figures of the population within the service areas of piped schemes. Depending on the condition of the system and the availability of the fuel and spare parts, the number of the people actually served may have been considerable less than indicated above. The construction of handpump wells as a stand-by system in urban areas is recommended when possible (Finnwater 1986 b).

The average distance to the main water supply in 1984 was 1,8 km in Mtwara and 1,1 km in Lindi regions as can be seen in Table 5.2.

Table 5.2 Distribution of people at various distance from water in 1984 in Mtwara-Lindi area (Finnwater 1986 b).

distance, km	percentage of the population
0 - 0,5	66
0,6 - 1,0	4
1,1 - 2,0	10
2,1 - 5,0	8
more than 5	12

Water quality in 1975 was found bacteriologically satisfactory in most borehole sources and piped schemes, questionable in most wells and polluted in all traditional sources.

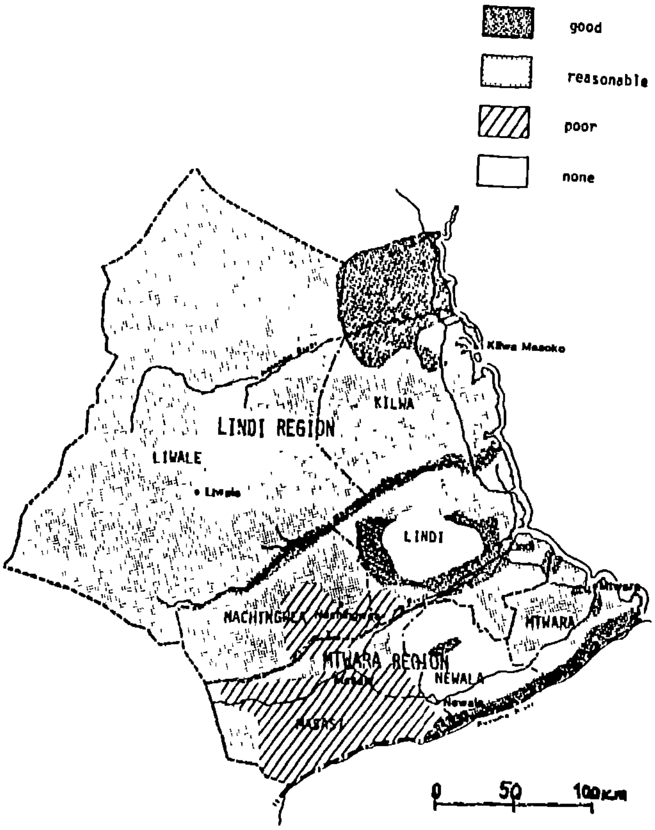


Figure 5.1 Ground water potential in the Mtwara-Lindi area (Finnwater 1986 b)

5.2 Handpump well program within the project

5.2.1 Production targets

The Tanzanian Government's objective is that all people in Tanzania will be provided with safe, accessible and adequate water, less than 400 m from each household by 1991 (Msimbira 1984).

As a water point the handpump well is in many cases a better solution for the rural areas than piped water supply. Handpump wells need only low technology and are the least costly alternatives. The reliability of the handpump well is higher than that of piped schemes and the operation is easier. The construction of handpump wells in Mtwara-Lindi started in full scale in 1978. Since then about 250-300 handpump wells per year have been constructed; totalling today over 2200 wells and serving about 500 000 inhabitants.

According to the Water Master Plan Revision about 2000 handpump wells more will be constructed before the year 2001. The type of the well is not specified, but most of the wells will be shallow ring and hand auger wells.

The design criteria of MAJI have been followed in all major technical solutions. The main criteria used are as follows:

- specific consumption per capita is 30 l / day
- one public tap for 200 people
- one handpump well for 200-300 people
- distance to a public domestic water point less than 400 m
- temporary water quality standard of Tanzania

5.2.2 Well types

Ring wells are either dug by an excavator or by hand. The wells are lined with concrete rings which are 0,5 m high and have an outside diameter of 1,0 m. One or more water permeable filter rings are placed at the depth of the aquifer. Shallow wells with concrete rings have a big storage capacity. Due to the limited capability of the excavator, the ring wells were not dug more than 4 m deep. To go deeper, the digging was continued by hand. Nowadays only the hand digging method is used. The deepest hand dug wells in the project area are about 7 m deep. Hand digging is also low cost and simple technology based largely on village self-help participation which is required.

Auger wells have been constructed by machine or hand auger equipment. Nowadays only the hand auger construction method is used. The auger drill is turned around by 6 to 8 men. The depth of the wells is up to 16 meters. The wells are lined with 6 inches or 8 inches diameter PVC pipes which have screen holes at the depth of the aquifer.

Bore holes have been drilled by Cable Tool or Down the Hole Hammer drilling equipment. Cable tool boreholes have 6 inches or 8 inches diameter PVC pipe lining and DTH holes 3 inches lining. The deepest boreholes are about 60 meters deep. A borehole as a handpump well is remarkably more expensive than a ring well or an auger well, but in some areas the ground water is so deep that the only way to reach the water is to use heavy drilling machines. If the yield of a bore hole is low and the storage capacity of the casing pipe is small, the drawdown of the static water level is fast. A well yield of more than 5 liters per minute is accepted.

The number of the wells, the construction method and the well type in 1986 is shown in Table 5.3.

Table 5.3 Types of handpump wells in the Mtwara and Lindi Regions in 1986.

Construction method	Well type	Number of the wells, at the end of 1986	
hand and excavator dug	ring wells	1520	68 %
hand and machine auger	auger wells	630	28 %
cable tool and down the hole hammer drilling	bore holes	100	4 %

5.2.3 Shallow well pumps

The project had more than 2000 shallow well handpumps installed by the end of 1986. These are mostly Finnish made Nira Af-76 lever action pumps. During the last two years 500 Nira Af-85 direct action pumps have been installed. The UNDP/World Bank hand pump program and the projects own test program had a small number of other pump types in the field which will be replaced later with Nira Af-85 pumps or with some deep well pumps.

Nira Af-76 is a lever action lift pump which has a submersible cylinder. The materials are mostly metals. The pump head is made of cast iron and it has Rilsan Nylon protective coating. The handle is tubular. The shock absorber in the lever is made of polyethylene. A slide bearing surface in the fulcrum has been added to increase durability and to make maintenance easier. The pump head is connected to the pump stand via a flange joint. The pump stand is made of hot dip galvanized profile steel. The riser pipes are standard steel pipes joined together with steel nipples. The pump rods and hexagonal couplings are made of stainless steel. The diameter of the rods is 10 mm. The cylinder materials are extruded brass tube, gun metal plunger, bottom valve limiter and cylinder caps and nitrile rubber bottom valve, plunger valve and plunger seal. The cylinder diameter is 75 mm.

The Nira Af-76 pump has been a good and robust pump for the Mtwara-Lindi area. It has been developed continuously and redesigned when needed. However, like all the lever action shallow well pumps the Nira Af-76 also belongs to the group of old generation pumps, which have properties that do not fit the VLOM principle.

The lever is one of the most commonly failing parts of the pump. It needs regular maintenance and lubrication. The bearing should also be replaced from time to time. If the bearing breaks down the softer brass lever and the steel fulcrum pin begin to wear and these cannot be repaired.

During the replacement of the slide bearing and the lever the fulcrum pin should be also replaced. Otherwise the old pin will easily cause a failure at the new bearing.

The handle is sometimes cut at the threads in the lever. To remove the piece of handle threads from its hole in the lever is difficult. This part of the pump is relatively expensive, about 20 % of the total pump price. The summary of the shallow well maintenance in 1982-83 shows that the cost of the lever and the handle was 45 % of all sparepart costs. The lever, fulcrum bearing and the rod coupling need to be redesigned and the material changed to be good for heavy use such as in Tanzania.

Galvanized riser pipes are commonly used for handpumps. In Mtwara-Lindi 2 inches pipes are used for Nira Af-76 pumps. The needed pipe lengths are cut from 6 m sections and threaded in the project's workshop. The threads and the pipes also get corroded easily in the aggressive water. This is because the galvanizing has been removed from the threads and the pipes are often damaged with the pipe wrenches during the tightening of the connectors. Protective coatings like grease or Teflon tape on the threads might reduce corrosion but their use for handpumps in Tanzania is not possible.

The pump rod cutting has been eliminated by rolling the threads instead of cutting them. The 10 mm stainless steel rods have been found to work best whereas the 8 mm rod is too weak and the 12 mm rod is strong but heavy and expensive. The cylinder and the piston are expensive parts of the pump but only seldom break. The bottom valve and the piston valve deform in the long run but are cheap to replace. The problem is that if the valves are replaced the whole pump must be removed from the well and the other parts might be damaged.

The tool set which is needed for the maintenance is large, heavy and costs about half of the pump price. It includes 3 locally made and 9 imported tools. The tool set is heavy to handle and difficult to transfer over long distances. Big forces are often used and tools of a good quality are needed which are also expensive. If the set is sold to the villages even at a subsidized price and all the other things are given free of charge, people are not eager to buy the tools and repair items. The tools are necessary to repair the pump. People could borrow the tools from other villages or from the district sparepart store but they do not do so. The reason again is the inconvenience of transporting the tools.

The project has used Nira Af-85 direct action handpumps for shallow wells since the end of 1984. Experiences on Nira Af-85 in Mtwara-Lindi are explained in Chapter 6.

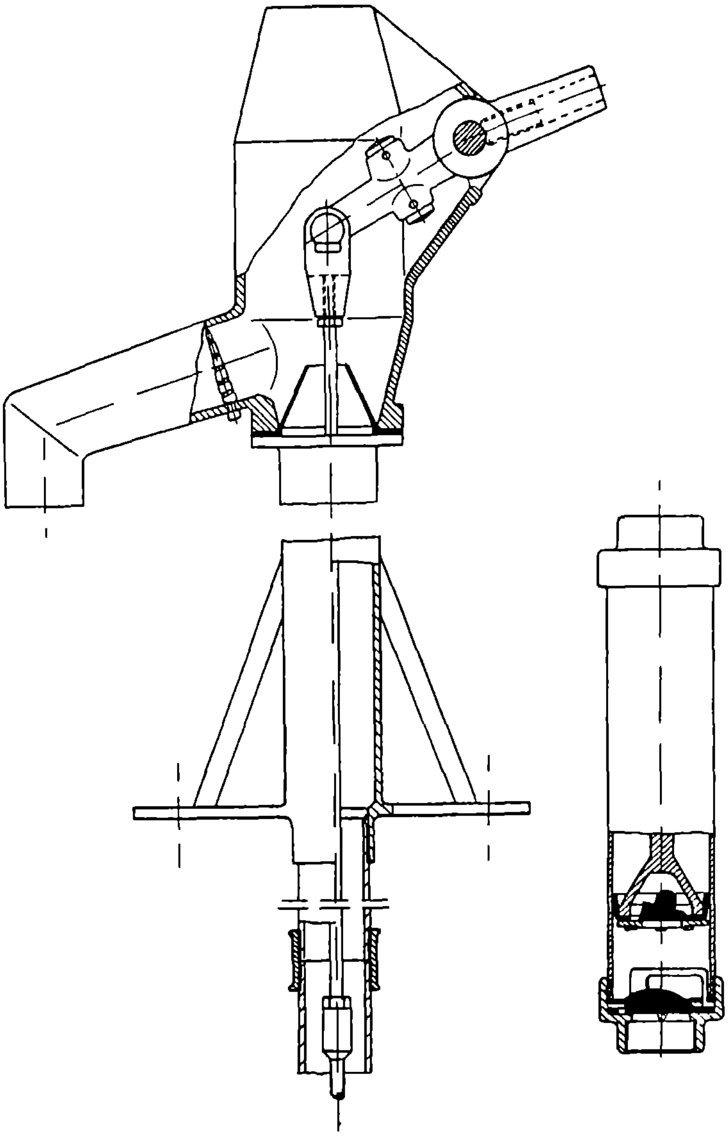


Figure 5.2 Nira Af-76 handpump

The toolset for the Nira Af-76 pump:

1 pc	11 mm spanner
1 pc	17 mm spanner
1 pc	19 mm spanner
1 pc	30 mm spanner
1 pc	14 " pipe wrench
1 pc	24 " pipe wrench
1 pc	36 " pipe wrench
1 pc	grip plier
1 pc	grease gun
1 pc	locally made drop pipe holder
1 pc	locally made piston rod holder
1 pc	locally made piston plate holder

5.2.4 Deep well pumps

The number of the deep boreholes equipped with handpumps was about 100 pcs at the end of 1986. The deepest hole was 60 m deep and the average depth was between 30 and 40 m. The deep well handpump must be capable of lifting water from 20 m to 70 m deep holes. The project chose the India Mk 2 handpump for its deep well installations which was at that time widely used and probably the best of all the alternatives.

The India Mk 2 has been developed since 1966 from the Jalna pump to the Sholapur pump which was constructed by a Swedish engineer Oscar Carlson in the Sholapur Mission in India. After an extensive test and development period carried out in co-operation with the Indian authorities, private companies and the UNICEF, the pump was formed and named the India Mk 2 handpump. Nowadays the pump is widely used and manufactured in many countries. Some years ago there were 22 registered manufacturers of the India Mk 2 pumps in India alone (Gray 1985).

The major design features are summarized below:

Head assembly:
- Sturdy mild steel box containing a handle pivot
- Simple inspection cover secured by a single bolt
- Heavy-duty handle stop permitting rough use
- Flange mounting to water tank

Handle assembly
- Solid bar handle to counterbalance pump rods
- Sealed ball bearings
- Chain linked for gravity return of piston
- Quadrant and chain to ensure connecting rod alignment
- Splash washer to help prevent wetting of chain

Water tank
- Angled spout making ingress of debris to water tank difficulty
- Riser pipe holder raised above the spout to prevent ingress of debris to cylinder
- Flange mounting to pedestal
- 6 " ID pipe pedestal fitting over bore well casing pipe
- Angle iron legs to ensure a firm bond to a concrete base
- Sanitary seal created between OD of well casing and ID of pedestal to prevent infiltration of polluted water to well
- Flange mounting providing for further head development or alternative mounting (e.g power pump)

Connecting rods
- Mild steel bright bar, electrogalvanized for surface protection
- Welded couplings to facilitate maintenance and accelerate installation
- 3 m lengths for ease of handling

Rising main pipe
- 32 mm ID medium grade galvanized pipe in 3 m lengths to facilitate installation and repair using hand tools

Cylinder assembly

- Cast iron case for low cost and to protect brass liner
- Brass liner with mirror finish to prolong leather bucket washer life
- Quality controlled chrome-tanned leather buckets
- Rubber seated valve poppets for effective sealing

(Arlosoroff et al 1984)

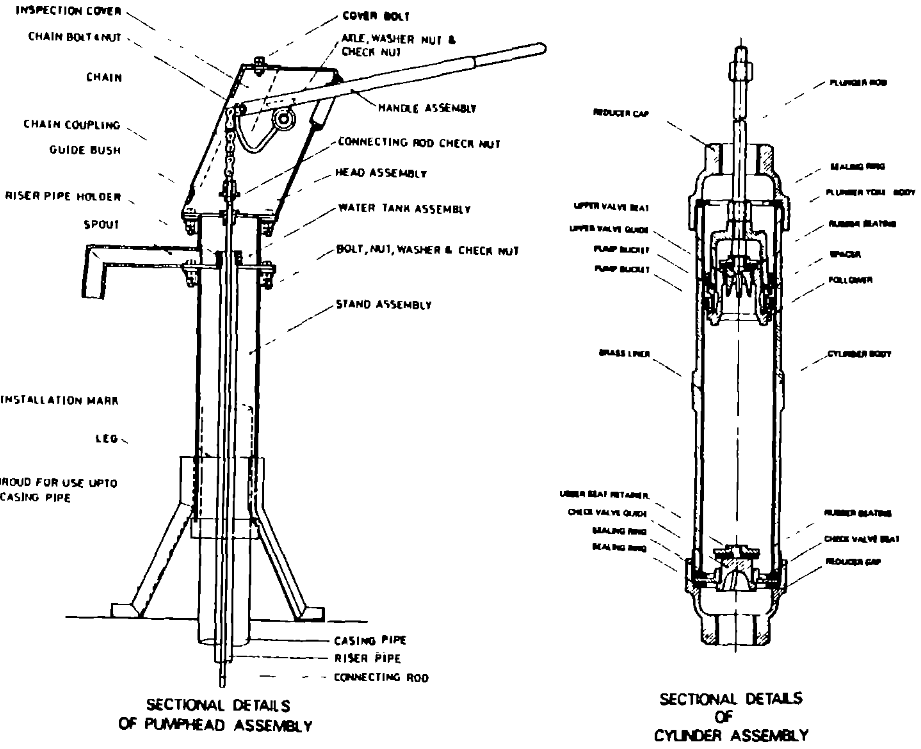


Figure 5.3 India Mk 2 handpump

The tools needed to maintain the India Mk 2 pump are listed below:

Standard tools:

- button die to suit M 12 * 1,75 threads
- die set for 32 / 40 mm N.B pipe
- 2 pcs pipe wrench
- 10 mm * 12 mm double ended spanner
- screw driver 300 mm long
- small hammer
- hack saw frame with spare blade
- pressure type oil can

- wire brush
- half round file
- punch 6 mm
- grease
- adjustable spanner

Special tools:
- self locking clamp
- tank pipe lifter
- coupling spanner
- handle axle punch
- connecting rod lifter
- crank spanner
- lifting spanner
- connecting rod vice
- chain coupler supporting tool
- bearing pressing tool
- tool box

In Mtwara-Lindi, the India Mk 2 pumps are installed in only two districts in a rather small area. The pumps are maintained by the district maintenance teams. The team inspects the pumps in the villages or receives information on breakdowns from the village well caretakers. The maintenance of the India Mk 2 pumps demands much skill and many tools so the village well caretaker cannot carry out the maintenance alone. In India where the pump was designed, installation and maintenance is not a problem but in Tanzania the pump is not suitable for village level maintenance.

The first India Mk 2 pumps were installed in Mtwara-Lindi in 1985. Installation and maintenance teams have been trained and equipped with the necessary tools.

At first the pedestal is cast in a concrete slab. After one week when the concrete is hard the pump can be installed. Proper tools facilitate the installation. All pipes and rods are of the same length. Poor installation often leads to breakdowns.

It is a demanding job to dismantle the pump. The weight of the rod and steel pipe full of water is sometimes over 100 kg. It is assumed that the lever mechanism, chain and cylinder assembly are the most commonly failing parts. The replacement of the ball bearings is done with special tools. The quality of the replaced bearing does not match those assembled in a factory.

The pumps for Mtwara-Lindi were bought from India. The quality of those pumps is high and the price reasonable. One complete pump with 30 m below ground assembly costs 250 USD FOB India. It is said that the price is not subsidized by the UNICEF or anyone else as is the case with the pumps sold in India for a domestic use which was in 1986 125 USD per one pump.

Among others the UNDP/World Bank program is testing plastic bearings, plastic riser pipes, removable footvalves and pistons through the riser pipe, hook rod connectors and rod hanger materials for India MK 2. Also other deep well pumps are being developed in the East-African countries. The most promising of those are the Maldev pump from Malawi and the Afridev pump redesigned from the Maldev pump by the UNDP/World Bank program staff. The Afridev and Maldev pumps have also been tested in the Mtwara-Lindi area.

The use of the India Mk 2 pump in East-Africa is not always recommended because of their own deep well pumps and pump development. It is also unwise to use pumps which are still prototypes and under development. Handpump well projects need pumps which have worked well and are also reliable in the field.

5.2.5 Centralized maintenance

After the well construction started in 1978 all the handpumps were maintained by the central maintenance organization within the project. Mobile maintenance teams travelled with cars carrying tools and spareparts with them. All the villages and wells were visited three or four times a year and required maintenance was carried out by the teams. The rate of the pumps in operation during the centralized maintenance system was high, 90 % of the pumps were in good condition. This was not only because the pumps were rather new but also because the maintenance was very effective.

The tasks of the maintenance organization were to maintain the pumps, to assemble and repair the pumps in the workshop, to train village well caretakers, to purchase spare parts and materials and to develop a maintenance system.

Within the centralized system, village well caretakers were carrying out the daily and weekly maintenance tasks such as cleaning the well site, checking the condition of the pump and the structure, greasing the pump, advising the villagers not to contaminate the well by washing themselves or clothes near the well, preventing abuse of the pump and informing the Maji organization or the project of the breakdowns.

The recycling of the old spare parts was very efficient because the maintenance team could bring the old and still repairable parts back to the workshop. The preventive maintenance also reduced the number of breakdowns.

5.2.6 Village level maintenance

In the year 1983 the creation of a three level maintenance system was planned. The maintenance should be based on village level activities, the central organization being there just to help in problematic situations. A following model was created:

1. In each village two people should act as village well caretakers who would be able to do all the day-to-day

maintenance and repair. They should have a toolset at their disposal and they should fetch the spareparts from the nearest sparepart store. They should also keep record of the condition of the pumps and the water situation in the wells.

2. District and divisional sparepart stores should provide spares for the villages. The storekeeper deals out the spares. The district handpump maintenance technicians help villages in difficult maintenance cases.

3. The overall sparepart consumption is followed from the regional headquarters. From there the spareparts are ordered, dealt out to the district stores and the whole system is monitored.

Regional maintenance center	Regional water engineer Central sparepart store Regional maintenance officer
District maintenance center	District water engineer District sparepart store District maintenance technician
Village well caretaker	Well caretaker under village leadership

(Finnwater 1986 a)

The wells are to be regarded as the property and under the responsibility of the village. Hence the village must accept a high degree of participation to promote the proper use and maintenance of the wells and handpumps. The water committee which is under the Village Government is to be elected in every village.

One or two village well caretakers carry out all the handpump maintenance for the shallow well pumps. The village decides about the well caretakers' compensation and the collection of money for the maintenance costs.

The importance of the preventive maintenance is well known. During the centralized system in Mtwara-Lindi preventive maintenance was efficient but in the village level system it exists less frequently. Preventive maintenance includes tightening bolts, nuts and joints, greasing bearings and replacing worn out parts. Many breakdowns could be avoided by preventive maintenance. If the worn out parts are to be replaced according to a defined schedule then the sparepart supply must be properly organized.

The required staff for the village level handpump maintenance is trained mainly by the project. One week training courses for 20 to 30 people at a time have been organized. The courses have had partly theoretical and partly in-service training.

There is no doubt that the rate of pumps in operation has been much lower with the village level than with the centralized system. The project had good facilities to run the centralized system but if it should be run by the local authorities it would be less efficient than the village level system. Evaluation of the village level maintenance system of handpump wells has been done since January 1984 for the villages where the maintenance has been handed over to the village government and village well caretakers. The results are shown in Table 5.4.

Table 5.4 The rate of the pumps repaired during the village level maintenance (Finnwater 1986 a)

Group	No. of the villages	percentage
1. All wells have been repaired by the VWCT	62	41%
2. More than 50% of the wells have been repaired	22	15%
3. Less than 50% of the wells have been repaired	12	8%
4. No wells have been repaired	55	36%

Reasons why the pumps are out of operation are the following:

1. The village well caretakers are not doing their duty.
They are not getting enough compensation from the villages either by payment or release from community duties. The well caretaker cannot technically repair the pump. One week of training is not always enough. If the pumps are repaired seldom the caretakers do not get experiences on that job. Continuous training is needed. The well caretaker might also be missing.

2. There was no toolset in the village.
The project has sold tools to the villages but all villages have not been eager to buy a set.

3. The spareparts are difficult to get.
The store is far away and the travel expenses have not been paid. The store has had no spares. The number of stores has increased continuously and there are now 14 sparepart stores in the area. Later if the spares are less expensive some spares can be kept in the villages also. If the old parts would be collected and repaired it would

help the availability of spares.

4. The well is not used due to several reasons.
The water is salty or has bad taste, the well is dry or far away from the village. There has not been any reason to repair the pump.

5.2.7 Spare part supply

Handpump spares should be available at a reasonable distance from each village which has a handpump. There are now 14 stores and each of them has a permanent storekeeper. From the main stores, the required spares are sent to the sub-stores. Storekeepers are keeping record of the sparepart consumption and where the spares have been issued. The store buildings are either old containers or store houses.

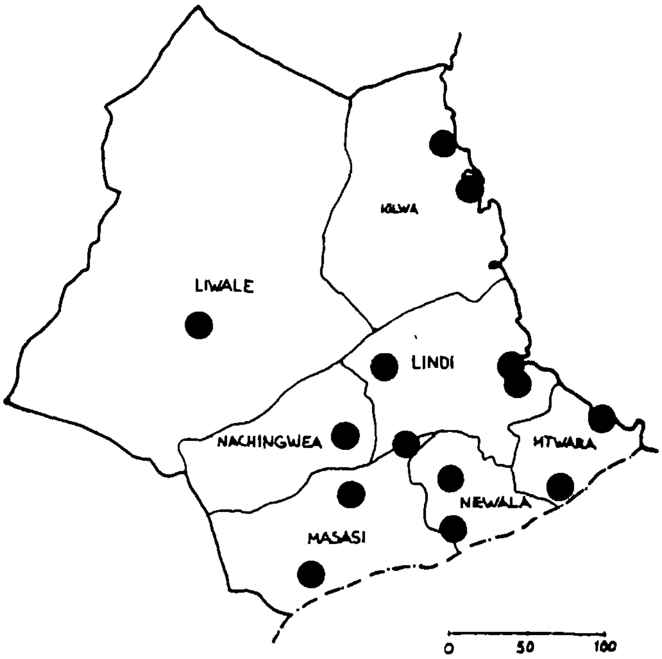


Figure 5.4 Handpump sparepart store distribution

The project has given spares free of charge to the villages. It has been suggested that the spares should be paid for by the consumers. The Government has not expressed its official policy on this issue. The money could be collected as taxes or as a payment for the spares. Whatever the case the projects must follow the principle. The collection of money for the spares has been attempt in some areas in Tanzania but with limited success.

5.3 Handpump development within the Project

5.3.1 Development by the project

The project does not have facilities or personnel for large scale handpump development. However, the handpump technology has interested the project much because its main products are handpump wells. The development work has concerned special subjects like the development of the direct action pumps or the Finnish made Nira pumps. There has been continuous co-operation between the project and the UNDP/World Bank handpump program because the Mtwara-Lindi area was one of its field trial areas.

One of the main outputs of the development work has been a prototype direct action handpump called Kate. It was made in the project's workshop from locally available materials. The project has tested and developed, together with the manufacturer, the Finnish made Nira Af-85 direct action handpump which has become the only pump installed in shallow wells. More details of the Nira Af-85 development are in Chapter 6. Altogether 18 different pump types have been installed in the project area as can be seen in Table 5.5.

Table 5.5 Pump types installed in the Mtwara-Lindi area before September 1986.

Type of the pump	No. of pumps installed	in operation
Nira Af-76	1700	1700
Nira Af-85	300	300
Nira Af-83	20	10
Nira Af-84	5	-
India Mk 2	70	70
SWN 81	19	19
Kangaro	6	2
Tara	2	-
Wavin	3	-
Maldev	10	10
Afridev	2	2
Kate	5	1
Blair	18	-
Shirazi	1	-
Tanda	3	-
PEK	2	2
Shinyanga	40	-
Mono	3	-
Total 18		

The first Nira pump models used in Mtwara-Lindi were designed for light use by one family in Finland. These pumps broke down in Tanzania after a few weeks of use. The manufacturer made a new robust handpump Nira Af-76 to be used in Tanzania and in similar conditions.

During the centralized maintenance system, the data on breakdowns, maintenance and sparepart consumption was collected efficiently. From the summarized maintenance reports it was easy to identify which parts needed to be redesigned.

5.3.2 The UNDP/World Bank handpump program

The Ministry of Water in Tanzania first expressed its interest in participation in the UNDP/WB Program in 1980. The discussion regarding the integration of the UNDP/World Bank field trials with the then current water supply project in Tanzania as held at the end of 1981 by the Tanzanian authorities, UNDP/WB staff and the donor agencies.

In the beginning the Mtwara-Lindi area was not considered to be suitable for the field trials because deep bore wells could not be found and a smooth communication system between the area and Dar Es Salaam would have been difficult to maintain.

However, the Mtwara-Lindi project had a continuous need for handpumps for new wells and Finnida and the project agreed to take and support the UNDP/WB program in the Mtwara-Lindi area. Later on the construction of bore wells began and the deep well pumps have been tested also.

The first handpump monitoring engineer was appointed in Mtwara in March 1983. The field trial in Mtwara-Lindi was concluded in August 1986.

The UNDP/WB input to this project included assistance by the UNDP/WB Regional Program Office in Nairobi in development of monitoring, liaison with other projects in Tanzania, procurement of the pumps and materials and overall supervision of the monitoring engineers who worked within the Mtwara-Lindi water project. Duties of the monitoring engineer was to install and monitor the pumps, to develop the monitoring system and to report to the project manager in Nairobi.

There have been continuously more than 100 pumps in the monitoring program. A total of 18 different types have been installed. Most of the pumps have been the Finnish made Nira pumps. The list of the pumps is in Table 5.5.

The pumps were visited monthly and special monitoring forms were filled. Breakdowns and the overall performance were recorded and broken pumps were repaired. The project had small scale co-operation with the University of Dar Es Salaam such as assisting with the monitoring and undertaking study projects on handpumps. The evaluation of the direct action pump designs for manufacture in Tanzania was of special interest.

The project has been a link between rural water supply projects in Tanzania transferring and introducing achievements and experiences on pump designs to the others.

6. Development of the Nira Af-85 direct action handpump

6.1 History of the pump

The development of the direct action handpumps in the Mtwara-Lindi Rural Water Supply Project began in 1983. The UNDP/ World Bank handpump testing program suggested that the project should design its own direct action handpump model taking into account the principles set for VLOM handpumps such as easy installation, maintenance and use and the possibility to manufacture it locally. A few prototypes were made in the project's workshop and they were tested in the field. The pump, called Kate (Figure 6.1), was found worthy of further development but the project alone had limited facilities for that.

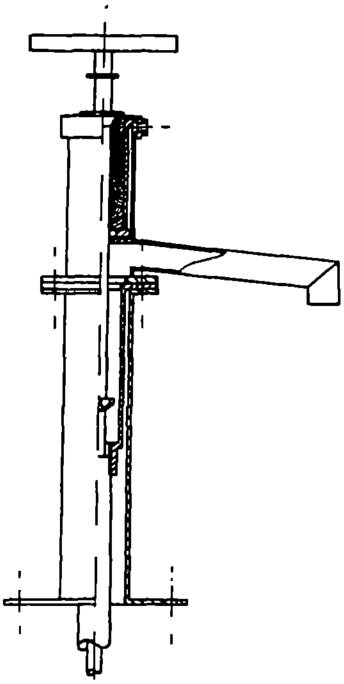


Figure 6.1 Kate, prototype direct action handpump

The Nira handpump manufacturer was asked to make own direct action handpump. The ideas and experiences gained from the project's prototype pumps were available for use by the manufacturer. The first 5 Nira Af-85 direct action handpumps were received by the project at the end of 1984. Since then these pumps have been tested and developed mainly in co-operation with the manufacturer, the Mtwara-Lindi water project, the UNDP/World Bank handpump program and the Consumers' Association Testing and Research Laboratory (CATR). Since 1986 Nira Af-85 pumps have been installed in China, Ethiopia, Ivory Coast, Kenya, Sri Lanka, The Sudan, Tanzania, Thailand, Malawi and Mozambique.

6.2 Manufacture

Vammalan Konepaja Inc. is a 68 years old engineering workshop in Finland. It had 55 employees and its turnover in 1986 was about 2 million USD of which 40 percent came from abroad.

At the beginning of the 1930s Vammalan Konepaja started to manufacture different types of handpumps for pumping water and oil. Since then they have produced about 400 000 NIRA handpumps. They are also producing water and drainage system components like waste-not-taps for urban and rural pipelines, submersible pumps, wood working machines and hospital equipment.

At the beginning of the 1970s Vammalan Konepaja started to design a sturdy and reliable handpump for village use in developing countries. In 1976 the first Nira Af-76 handpumps were delivered to Tanzania. Later on, a few improvements for Nira Af-76 were made and two other pumps were designed: Nira Af-85 for shallow wells and Nira Af-84 for deep wells (Suuriniemi 1986).

6.3 Description

There are two models of the Nira Af-85 pump. An A-model for the wells with a static water level less than 11 m and a B-model for wells less than 16 m deep. The only differences between the models are the measurements of some parts. The A-model could probably be discarded because the B-model can also be used in shallow well applications. The discharge of these two models is about the same and it is not sensible to have two similar pumps and their spares in stock.

List of the parts of the latest Nira Af-85 model:

Part name and number	Material
Handle (1)	-stainless steel
Shock absorber (2)	-natural rubber
Sleeve bearing (3)	-rubber and steel
Handle nipple (4)	-HDPE
Pump stand (5)	-mild steel
Allen screws, nuts (6)	-stainless steel
Base plate (7)	-mild steel
Pump rod plug (9)	-rubber
Plunger nipple (11)	-HDPE
Plunger valve (12)	-PUR
Bottom valve (12)	-PUR
Plunger body (13)	-HDPE
Plunger ring (14)	-HDPE
Bottom valve limiter (16)	-HDPE
Bottom valve body (17)	-HDPE
Pump rod (18)	-HDPE pipe
Pump rod nipple (19)	-HDPE
Riser pipe (20)	-HDPE pipe
Riser pipe coupling (21)	-HDPE

Toolset for Nira Af-85 pump:

2 pcs	belt spanner
1 pcs	10 mm allen key
1 pcs	19 mm spanner

The percentage price of the pump parts of 10,5 m installation are as follows:

- Pump head assembly	40 %
- Cylinder assembly	17 %
- Rising main assembly	43 %

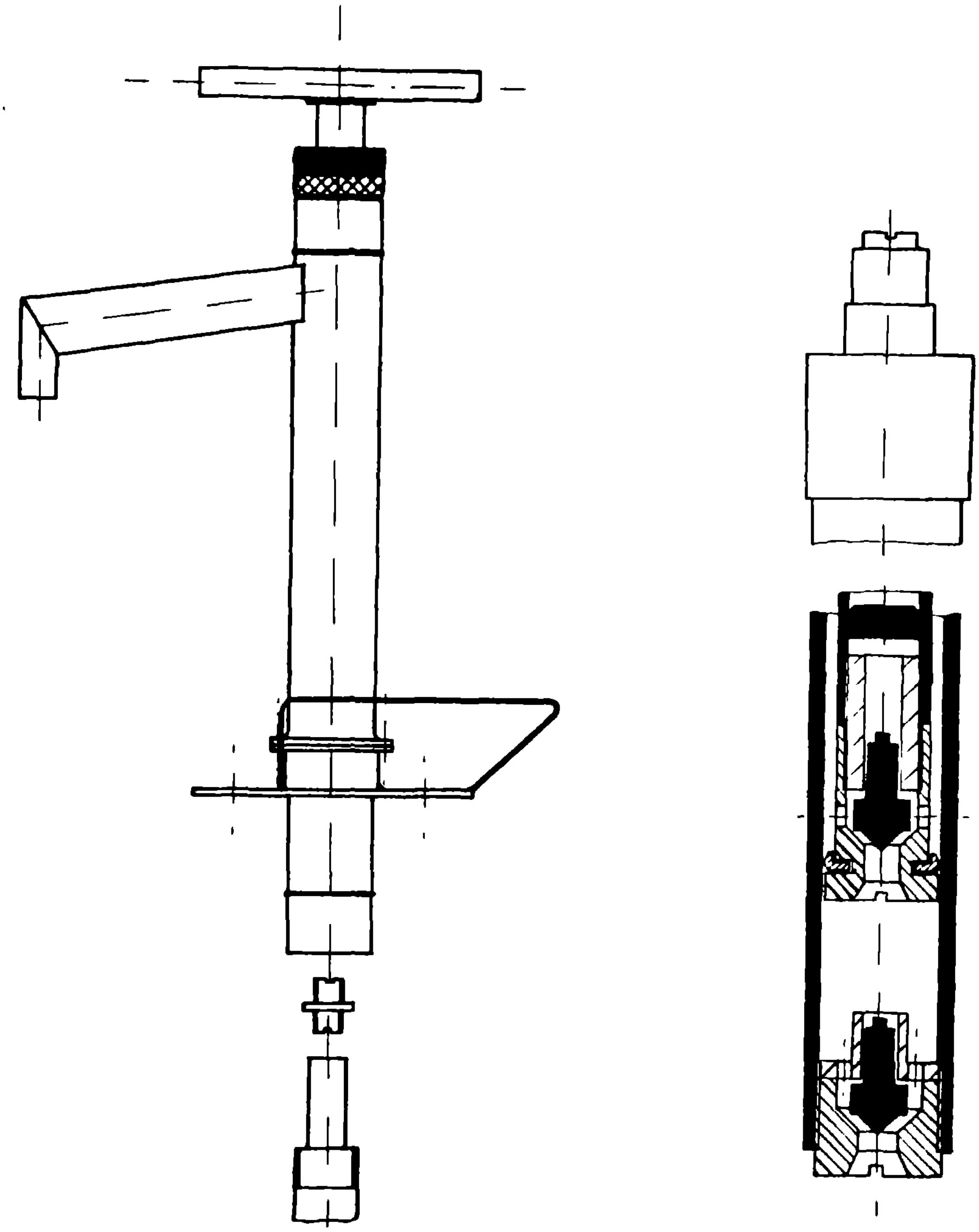


Figure 6.2 Nira Af-85 direct action handpump

6.4 Laboratory tests

The pump has been tested in laboratories by the manufacturer at the factory and by the Consumers' Association Testing and Research laboratory (CATR) in England as an assignment of the manufacturer. The goal has been to identify the characteristics of the pump, to test critical parts and new designs and to ensure the durability of the pump. The manufacturer has held meetings with CATR staff to be able to utilize the laboratory test results in their whole extent for further pump development.

At the factory the pumps were installed in a 62 meters deep so-called dry borehole with an adjustable water level and in a six meter high test rig. The same water was circulated. The endurance test was done both in the rig and in the borehole. The pump was operated by a pneumatic cylinder or by an electrical motor. The stroke length was about 300 mm and the number of the strokes about 60 per minute. The water used for the tests in 6 m rig was either clean or a quartz sand giesel gur mixture, grain size 75-500 μm mixture ratio 1 g / 1 liter of water which is similar to that used by the CATR laboratory.

One pump has been tested for 2800 hours in a test rig. This corresponds to 2 years use and equals about 6,7 million strokes. The main observations were:
-the sleeve bearing oval wear was 1,0 mm
-the plunger body was worn slightly
-the plunger and bottom valve body had an insignificant, small ring worn at the place where the valve touches the body
-the plunger ring had abrasion slots
-the valves had no wear
-the pump rods had place to place abrasion

The results of the endurance tests show that the pump is durable at least for a few years of use in laboratory conditions. The tests are continuing.

One target of the tests was to identify characteristics of the Nira Af-85 pump. During the tests various sizes of cylinders and pump rods at different depths were measured.

The characteristics from laboratory tests of a 75 mm cylinder with 50 mm pump rods which corresponds to the Nira Af-85 A shallow well pump, are presented in Table 6.1.

Table 6.1 Characteristics of Nira Af-85 A pump

Force up N	Force down N	Stroke length mm	Amount of strokes 1/min	Water level m	Amount of water 1/min
270	300	300	60	13,5	50
250	250	300	60	10,5	50
170	230	300	60	7,5	50
120	200	300	60	4,5	56

Table 6.2 Theoretical discharge of Nira Af-85 A and B pumps

Model A

	outside diameter	wall thickness	inside diameter	area
cylinder pipe	75,0 mm	8,4 mm	58,2 mm	2660 mm^2
pump rod	50,0 mm			1963 mm^2
space for water				697 mm^2

Discharge	per 1 cm	per 30 cm and 60 strokes
upward stroke	6,97 cm^3	12546 cm^3 = 12,5 l
downward stroke	19,63 cm^3	35334 cm^3 = 35,3 l
total stroke	26,60 cm^3	47880 cm^3 = 47,8 l

Model B

	outside diameter	wall thickness	inside diameter	area
cylinder pipe	63,0 mm	5,3 mm	52,4 mm	2156 mm^2
pump rod	40,0 mm			1257 mm^2
space for water				899 mm^2

Discharge	per 1 cm	per 30 cm and 60 strokes
upward stroke	8,99 cm^3	16182 cm^3 = 16,2 l
downward stroke	12,57 cm^3	22626 cm^3 = 22,6 l
total stroke	21,57 cm^3	38808 cm^3 = 38,8 l

In the CATR laboratory the pump was tested against the standard terms of reference developed in consultations with ODA (Overseas Development Agency) and the World Bank. The procedure of the CATR's tests is explained in Chapter 4.2.

Two reports have been published since the beginning of the tests in 1985. The first report summarizes the results before the endurance test and the final report has been published after the completion of the 4300 hour test.

The pump was received in good condition in CATR laboratory. The weights, dimensions, cylinder bores and ergonomical measurements were measured. The pump performance including volume flow, work input and efficiency was measured. The results are shown in Table 6.4.

According to the CATR, most of the pump parts could be manufactured in a number of developing countries by any well equipped general workshop. However, moulding polyurethane requires special machinery which is unlikely to be widely available in developing countries. The production requires steel fabrication, including stainless steel, general machining of steel and HDPE and moulding of polyurethane. The manufacturer's intention is that the HDPE bottom valve and piston would be injection moulded rather than machined.

The manufacturer has restricted the amount of threads cut on each pipe and internally chamfered the ends because over-tightening of joints caused internal restrictions in the bore through which the piston would not pass.

The light weight of the below ground assembly and the simplicity of its design means that only few tools and a modest degree of skill will be required to maintain the pump in working order.

The pump's resistance to contamination is good. The pump is adequately sealed at the well cover and at the point where the pump rod emerges from the pump stand.

There were suggestions for the improvement of the valve design. Subsequently the valve angle was increased from 60° to 90°. The valve with an integral retaining ring limiting the lift was changed for a new design in which the cruciform guide extends upwards rather than downwards and the lift is constrained by a strong external flange.

For the user trial in the CATR laboratory, the pump was set at a simulated depth of 10 meters. Several users complained that the foot rest was uncomfortable to use and they preferred to stand on the ground beside the pump. The foot plates should be eliminated. The smaller children found it difficult to achieve the necessary operating force on the upstroke but adults commented favorably on the rate of delivery from the pump. The manufacturer has later reduced the overall height of the pump stand to make it easier for small users to operate. The users were asked to fill a 10 liter container. The time required varied from 14 to 50 seconds and the number of strokes from 11 to 49. The average time was 27 seconds at 50 strokes per minute representing an average flow rate of 22 liters per minute (CATR 1986).

In the performance and endurance tests the cylinder was installed at a depth of 10,5 meters. The stroke, which was not controlled by external stops, was about 0,3 m. No leakage was observed for heads of 7 and 10 meters.

Table 6.3 The volume flow, work input and efficiency of the new Nira Af-85 A pump measured by CATR.

Head	7 meters				10 meters			
Oper. rate cycles/min	21	30	40	51	21	30	40	51
Volume per cycle lit.	0,75	0,85	0,95	0,88	0,81	0,78	0,84	0,85
Flow rate liters/min	15,4	25,8	36,3	45,1	16,7	23,6	33,8	43,1
Work input per cycle J	108	139	168	180	176	170	197	213
Work rate W	37	70	113	153	61	85	131	180
Efficiency percent	47	42	37	34	45	45	42	39

Table 6.5 Performance of the new pump and the pump after 4300 hours endurance test measured by CATR.

Head	10 meters New pump				10 meters After 4300 hours endurance test			
Oper. rate cycles/min	21	30	40	51	21	30	39	50
Volume per cycle lit.	0,81	0,78	0,84	0,85	0,46	0,64	0,79	0,91
Flow rate liters/min	16,7	23,6	33,8	43,1	9,8	18,8	31,3	45,7
Work input per cycle J	176	170	197	213	139	155	230	269
Work rate W	61	85	131	180	49	76	151	225
Efficiency percent	45	45	42	39	33	40	34	33

6.5 Field tests

The manufacturer has received field experiences of Nira Af-85 pumps mainly from the Mtwara-Lindi water project and from the UNDP/World Bank handpump testing program. In Mtwara-Lindi all the modifications have been monitored and the manufacturer has been informed about observations made in the field. The first Nira Af-85 pump were received in Mtwara-Lindi at the end of 1984. There were some 500 Nira Af-85 pumps installed by the end of 1986. Some of those were regularly visited, dismantled and parts were surveyed. The UNDP/World Bank program has some Nira Af-85 pumps in their field trials in Tanzania and Kenya.

The field tests in the Mtwara-Lindi area performed by the project included general observations, studying the most critical parts, making suggestions for redesign of the insufficient structures, improving the ergonomy and finding out which parts need more attention in further monitoring. All modifications and pumps of all ages have been visited in a few months period. Of the modifications the latest models have been inspected the most. Actual field conditions vary greatly from one place to another. The experiences gained in Mtwara-Lindi might not be relevant somewhere else.

According to the manufacturer the opinions of different countries differ mostly on how the pump should be fixed in the well cover, how big a bucket should fit under the spout and which aspects have to be considered if women are performing the maintenance.

The UNDP/WB handpump program used Nira Af-85 pumps in their field trials but not in the laboratory tests. The field trials have been done mainly in Tanzania and in Kenya.

6.6 Development of the pump design

6.6.1 General

Special conditions in Africa and in other developing countries have to be considered when the pump is designed. Demands are sometimes contradictory to each other and some designs are the result of compromises. Conditions vary greatly from country to country.

The pump has to be easy to install and maintain with only a few tools. The structure must provide protection against abuse and be durable even in heavy use. The price should be low. A combination of metals, plastics and wood is recommended. To be able to manufacture the pump locally high technology and special materials should be avoided.

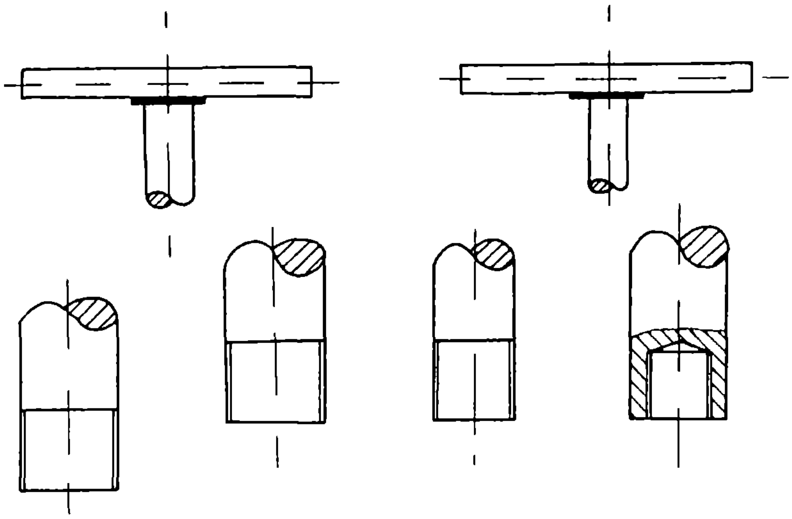
In the following chapter the experiences of the field trials in the Mtwara-Lindi area are explained.

6.6.2 Parts

Handle (1)

The handle is made of two stainless steel pipes which are welded together forming a T-bar handle. A pump rod is connected to the handle with a nipple. During the operation the handle is moved vertically through the sleeve bearing. The handle socket at the lower end and a rubber absorber at the top work as stroke limiters. Users may choose the most comfortable pumping position themselves between the lowest height of the handle from the foot board which is 67 cm and the highest height which is 105 cm. The handle and the pump rods rise by themselves because of floating rods. People use this as a sign that the pump is in good condition and there is water in the well. During the operation the rod must be pulled up faster than it would rise by itself, otherwise the water does not fill the riser pipe. To push the handle down the body weight is preferably used. When pumping the handle grip is kept at the stomach level or lower and the stroke length is rather short between 15 and 30 cm. The possible stroke length need not be longer than the average maximum stroke length.

Front and back movement during the operation causes friction between the handle and the sleeve bearing. The higher the handle is pulled the more it is bent and the greater the pressure between the bearing and the handle. This causes more friction, wear on both the handle and the bearing and decreased mechanical efficiency. If the bearing material is changed to a harder material, the handle wears faster. One way to reduce the wear is to lower the friction by using a more lubricative bearing material.



length	765 mm	540 mm	540 mm	540 mm
diameter	d 49 mm	d 49 mm	d 40 mm	d 49 mm
thread pitch	1/11 inch	1/8 inch	1/8 inch	1/8 inch

Figure 6.3 Nira Af-85 handle

There have been two different handle diameters, one for the A and one for the B model. Now the single handle diameter is reduced with two different nipples for the required rod diameters. The male threads have been changed to female threads as with pump rods. The lowest handle grip height has been lowered 25 cm. Slight wear has appeared on the side of the handle pipe. Now the handle pipe surface is polished to reduce the wear on the pipe and on the bearing. Particles stuck inside the bearing scratch the handle. A few dents on the handle have been caused during transportation due to improper treatment. If the handle has big dents it will not move freely through the bearing.

Shock absorber (2)

The shock absorber on the handle is made of natural rubber. There is a steel plate vulcanized inside it. The absorber makes the stroke end comfortable for the user.

The only reason to change the design has been to protect the absorber from being stolen. The plain rubber shock absorber disappeared easily even when a 1 mm steel wire was placed in a slot around it. The latest model is cemented to the handle and it has a steel plate vulcanized inside the rubber. People regard pumping more comfortable if the absorber is not missing.

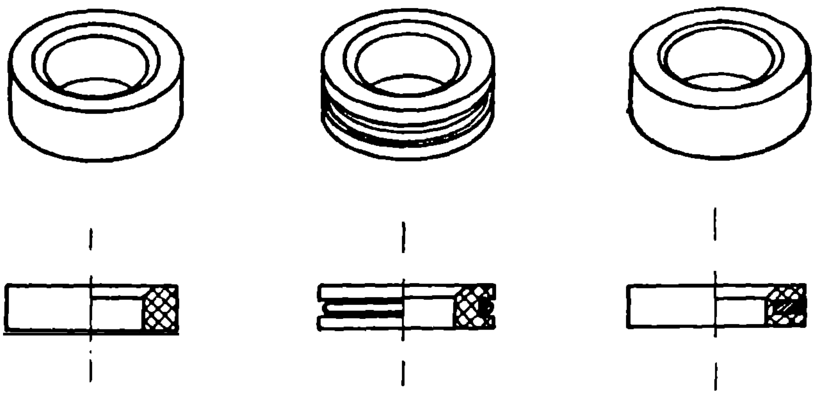


Figure 6.4 Nira Af-85 Shock absorber

Sleeve bearing (3)

The sleeve bearing is machined from a HDPE bar. The bearing is supporting the handle during handle movement. Water on the handle lubricates the bearing. The bearing is fixed with a thread joint in the pump stand.

If the handle is moved only up and down during the operation, the friction between the handle and the bearing is low. However, the handle is also moved back and forth and the friction causes wear on the bearing.

The top of the bearing was first conical towards the handle. The lubricating water and dust flowed back into the pump. The bearing was changed to be conical outward.

The face of the bearing was knurled and the height increased to enable better tightening with a belt spanner. If the threads are dirty the misthreading can happen if too much force is used.

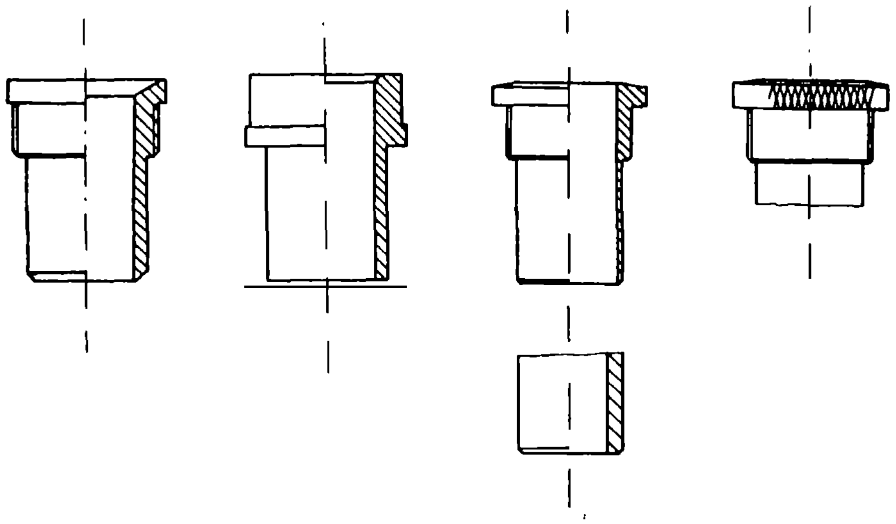


Figure 6.5 Nira Af-85 Sleeve bearing

The wear of different sleeve bearing models was not equal. This was strange because the materials should have been the same. One factor that affects the wear is the handle movement back and forth and the flexibility of the bearing. A bearing with thick walls keeps its shape during the operation and wears out much slower than a bearing with thin walls. The pump stand has been lowered and the handle is lifted higher during the operation than earlier. This results in bigger torque and more pressure between the bearing and the handle.

If the wall thickness at the lower end of the bearing is thin it might expand. There must be enough space between the bearing and the pump stand top threads in order to remove bearing.

Handle nipple (4)

The handle nipple is of HDPE material. It connects the handle with the first pump rod. The nipples are of two sizes to adapt the handle thread size to two different rod thread diameters. The nipple also works as a stroke limiter at the top of the stroke. It is easy to open and close the nipple with any tool using the slots which are made in the extensions of both ends.

Earlier the brass nipples similar to the pump rod nipples were used. The material was changed and male threads were changed to female threads. Because the lining compound is not readily available in Tanzania it is not likely to be used. Brass threads on stainless steel without the lining compound were easily stuck or the connection opened by itself during operation. How well the HDPE nipple works with steel threads without the lining compound has not yet been tested in field conditions.

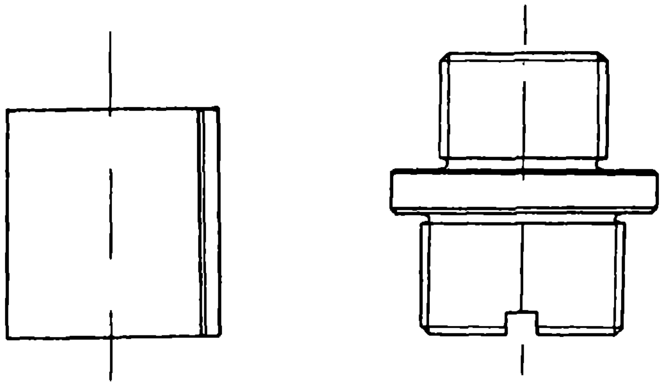


Figure 6.6 Nira Af-85 Handle nipple

Pump stand (5)

The pump stand is made of mild steel pipes and plates. It has a Rilsan coating. Both ends have threads; one for the sleeve bearing and the other for the riser pipe.

In the first model brass connectors were used to connect the riser and the bearing with the stand. These galvanic couples caused corrosion. The brass connector with the bearing was changed to a flange coupling and later to a thread joint without any connector. The riser pipe connection was also changed to a threaded joint.

The stand has been lowered 20 cm to reach a comfortable pumping height. The height cannot be reduced too much because the water container must fit under the discharge spout. The average maximum bucket height in the Mtwara-Lindi area is 34 cm which represents the commonly used ca 18 l volume galvanized steel bucket.

The Rilsan coating which has not influence on the pump function is firmly fixed on the stand surface. On the top of the spout the coating can be slightly removed if the steel bucket is lowered on it.

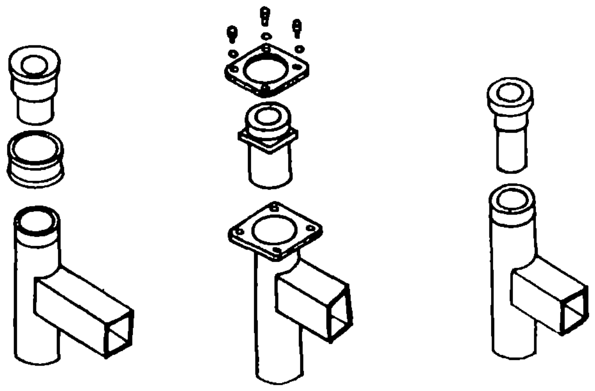


Figure 6.7 Nira Af-85 Pump stand

The extension of the pump stand below the base plate does not need to be much longer than the length of the threads but it must be remembered that the plunger may not touch the bottom valve.

For test purposes, one stand was lowered to about 30 cm high and the spout was extended 3 m away from the well cover. The well surroundings remained dry and the users could choose the most comfortable pumping position themselves.

Allen screws and nuts (6)

Stainless steel M12 allen screws are used to tighten the pump stand to the base plate and M12 nuts to tighten the base plate to the cover bolts. Mild steel cover bolts and nuts corroded easily. Now only stainless steel bolts and nuts are used. It is obvious that only well caretakers have allen screw spanners in the village and the screws are not opened by anyone else than the caretaker. If bolts and nuts are used two tools are needed.

Base plate (7)

The base plate is made of mild steel plates and it has a painted protective coat. It is installed on the well cover with four stainless steel M12 bolts which are cast in the concrete. There is a rubber sealing plate between the cover and the base plate.

There are a few reasons why the base plate should be there. The water container must fit under the discharge spout. In Mtwara-Lindi buckets are seldom more than 34 cm high but in some other countries the distance required between the cover and the outlet spout is longer. If the height of the pump stand is increased the pumping height is also increased. The user must then be lifted higher with foot boards. In most cases the cover is smooth and there is not any hole to lower the bucket. The pump is fixed to the cover with bolts which rise up from the concrete. If the bolts are under the foot boards the bolts do not hurt the users' feet. The cover bolts are in the corners of a 20 cm square. The base plate is always wet and the threads are in a corrosive atmosphere.

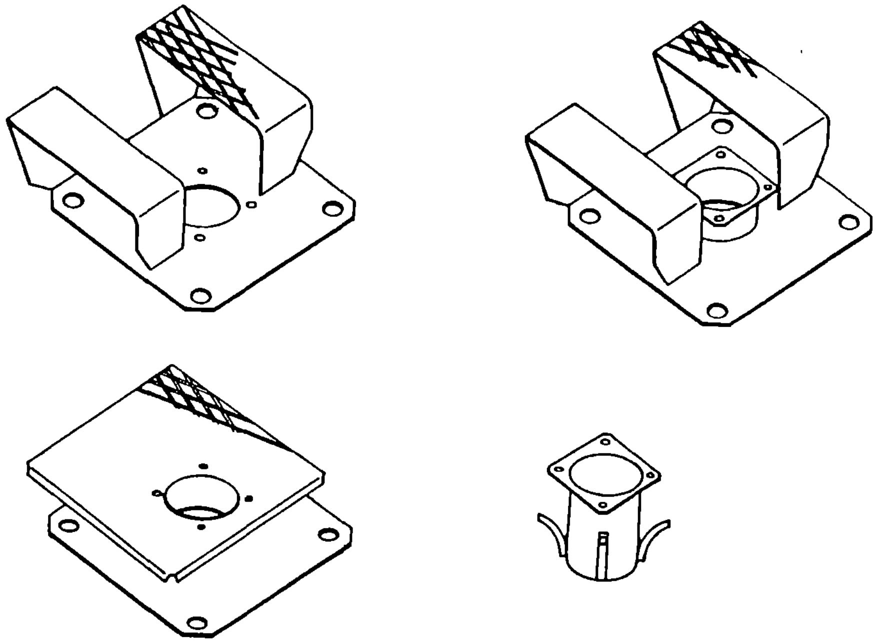


Figure 6.8 Nira Af-85 Base plate

In the first modification, a 4 cm high pedestal with a flange was added on the base plate. There were holes for the bolts and no threads. The pedestal prevented the water from flowing back into the well. The foot boards were still there.

In the next modification, a simple 6 inch pipe with anchor steel bars and a small flange on top of it was cast in the cover so that 4 cm was above the cover. It facilitated maintenance and the cover stayed clean. The water does not flow back into the well. The test period of this cast-in pedestal has been too short to report anything yet about its durability. If this pedestal is used 10 to 15 % of the pump price including cover bolts could be reduced. The increased pumping height of 12 cm can be lowered by shortening the pump stand and the spout end the same amount.

One structure has a big plate on the cover and a small flange on top of the few centimeters high pedestal. A foot board is fixed between the pump stand and the small flange.

Plunger nipple (11)

The plunger nipple is made of HDPE material. It has male threads and there is a hole through the nipple for the valve (12). It guides the valve movement and works as a limiter. The nipple is similar to the rod nipples except that there is a hole through it. Earlier brass nipples were used as rod and plunger nipples.

Plunger valve (12) and bottom valve (12)

The plunger valve and the foot valve are made of polyurethane plastic. These are interchangeable with each other. The valve was previously the most failure-prone part of the pump. There were different sizes of valves made of natural or nitrile rubber. The shape and the function was not correct because the valve was deforming, wearing out and splitting. In the original design, the valve lift was limited by an integral retaining ring on the cruciform lower part of the valve moulding. The valve had sometimes come out by itself which is hard to believe because it is difficult to remove even by hand.

The new valve design has been tested in the field only for a few months and no failures have been observed. In the laboratories the new design has been tested over 2000 hours which corresponds to 2 years of use. The wear observed is insignificant.

The missing plunger valve causes a slightly reduced discharge but the pump is still operational. If the foot valve is missing the pump is not operational because the plunger is not completely tight and the water column is going down.

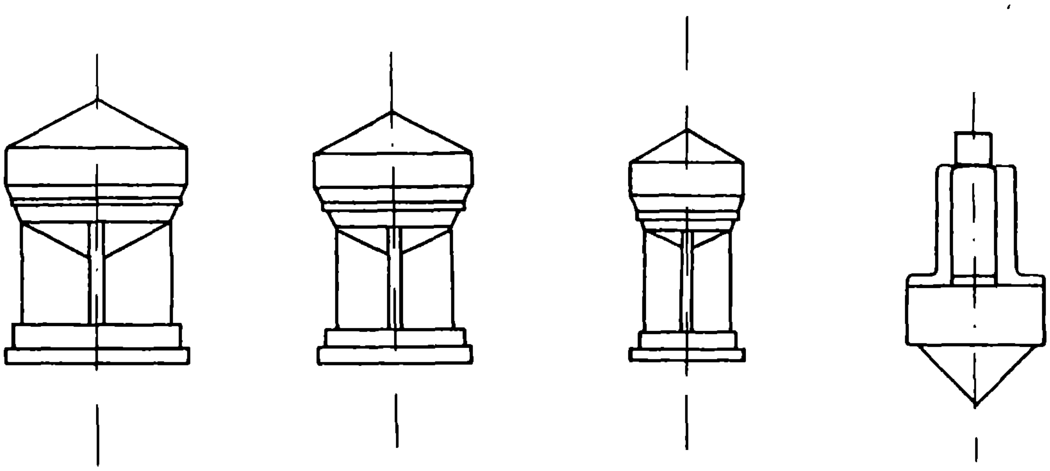


Figure 6.9 Nira Af-85 Valve a) original bottom valve, b) plunger valve and new bottom valve, c) B-model plunger valve, d) final plunger and bottom valve for both models

Plunger body (13)

The plunger body is machined from a solid HDPE material. It is joined to the pump rod with a HDPE plunger nipple. During a down stroke water is flowing through the plunger. The resistance of the flow over the plunger has been reduced by forming the flow channels and the plunger valve favorable to the flow. The pressure drop increases the needed downward stroke force.

During the upstroke the water column is lifted by the plunger. The valve is tight but the clearance between the body and the cylinder pipe lets the water flow beside the plunger. Faster speeds decrease the leakage but a deeper cylinder installation increases the leakage.

The whole plunger can be removed and the pump still delivers water if the pumping intensity is increased. This is due to the viscous friction, inertia and velocity of the mass of water between the pump rod and the riser pipe. The space between the rod and riser is 6 to 7 mm. The discharge of the pump without the plunger is low but the pump is easy to operate because there is no pressure drop over the plunger.

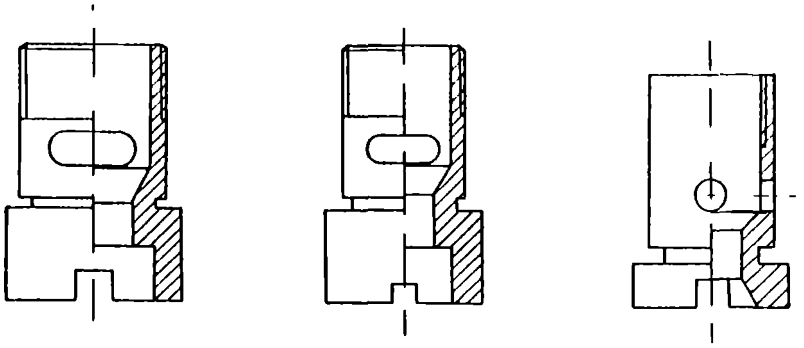


Figure 6.10 Nira Af-85 Plunger

Plunger ring (14)

The plunger ring is made of HDPE material. It seals the plunger and it is the part that wears insted of the plunger. It can freely move in a slot in the plunger body. A 10 degrees section of the ring perimeter has been cut and removed to help assemble the ring and let it expand and restrict in the cylinder.

Cylinder pipe (15)

The cylinder is made of HDPE pipe. The wall thickness is either bigger or the same as that of the riser pipes. The bigger inside diameter of the riser pipe helps the piston move through the riser during the assembly. Both ends are threaded, one with female threads for the foot valve and the other with male threads for the riser coupling. Both ends could have similar threads to allow the 1,5 m cylinder pipe to be turned upside down when it is worn out at the length where the plunger moves. However the cylinder might be mixed with riser pipes. If the riser is used as a cylinder then the clearance between the piston and the cylinder would be too large. If the same wall thicknesses for the cylinders and the risers and similar threads in both ends are used, the cylinder could be changed with any riser pipe sections. This would only be an advantage and would reduce the number of different parts.

Bottom valve body (17)

The bottom valve body is machined from HDPE material. It is connected to the cylinder with threads without any nipple. The valve is moving in the valve body. A limiter (16) controls the valve movement. There is a pressure drop over the valve body. This increases the force needed during the upward stroke.

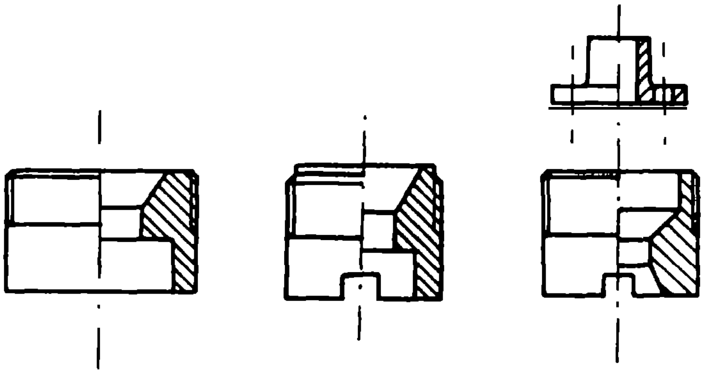


Figure 6.11 Nira Af-85 Bottom valve body

Pump rod (18) and rod nipple (19)

Pump rods are made of HDPE pipes. Dimensions are as follows:

	Nira Af-85 A	Nira Af-85 B
pressure class	PN 16	PN 16
outside diameter	40 mm	50 mm
wall thickness	5,8 mm	4,6 mm

The lengths of the rods are 0,5; 0,75; 1,0; 1,5; 2,0 and 3,0 meters. Transportation and treatment of the longer pipes is difficult. The best solution would be to avoid pipe units longer than 2 m and omit the lengths 0,5 and

1,0 m. Good variation of lengths could be combined from the rest of the unit pipe lengths. However, it would be more difficult for the villagers to count the lengths if the length 0,75 m is used instead of 0,5 and 1,0 m. Both ends have threads for the connecting nipple and the ends are plugged with rubber plugs to prevent the rod filling with water. Sometimes when the pressure passed through rod joints it pressed the plug deep inside the rod. It was only because lubrication was used during the assembly to put the plug into the rod. Now the rod and the plug are dry and it is firmly fixed into the rod. The nipples are machined from solid HDPE material. Both ends have slots to facilitate the opening of the nipple if required.

During more than two years of field trials none of the pump rods or riser pipes have been cut. This is an important factor if HDPE and other plastic pipe materials are compared. The HDPE pipes may stretch under high tension but in the Mtwara-Lindi areas the stretching was not observed.

Once a pump was found with the second lowest rod joint opened but it was still delivering water with a rather high efficiency.

The pump rods wear if the water contains sand or the rods are touching any corners like the top of the riser pipe.

Misthreading has been avoided by changing the size of threads from standard 1/11 inch pitch to 1/8 inch pitch with a thread angle of 55°. The misthreading was a bigger problem when the brass nipples with 1/11 inch pitch were used instead of HDPE nipples. The rods now have female threads and the nipples male threads.

The pump rod and the piston are extractable through the riser pipe and the pump stand as one piece. There is no need to open the rod joints. The flexible pipe bends but does not cut or break off when it is removed.

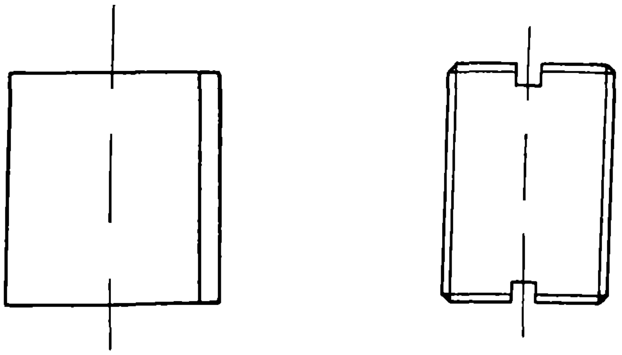


Figure 6.12 Nira Af-85 Rod nipple

Riser pipe (29) and riser coupling (21)

Riser pipes are made of HDPE pipes. Dimensions are as follows:

	Nira Af-85 A	Nira Af-85 B
pressure class	PN 10	PN 10
outside diameter	75 mm	63 mm
Wall thickness	8,4 mm	5,3 mm

The riser pipe lengths are the same as the rod lengths. The thread size has been changed from 1/11 inch pitch to 1/8 inch pitch. The couplings with female threads are made of HDPE pipe. The couplings were earlier made of brass.

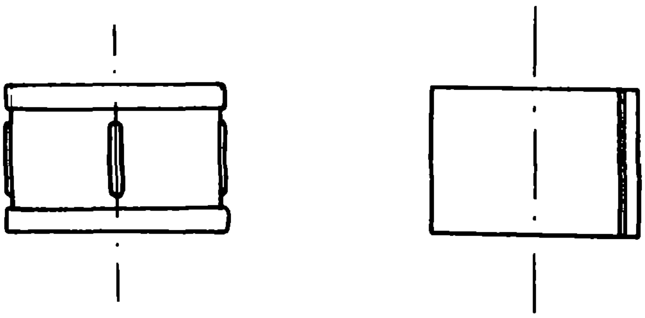


Figure 6.13 Riser pipe coupling

the pipe itself needs repair. All the couplings must be opened when the pipe is removed. Both ends have threads for riser couplings.

6.6.3 Development suggestions

The field tests of the pump should be continued in several countries to obtain experiences under different conditions. The manufacturer's responsibility is to assist and support field tests and develop the pump.

A few subjects need the greatest attention in the tests at present. The base plate should be removed and a substitute structure designed. The sleeve bearing and handle wear should be measured and, if necessary, the used material changed and a new design made. The suitability of HDPE nipples with or without lining compound should be tested. The ergonomy of the pump should be studied and the overall height of the pump defined. Earlier the poor valve design was the only real problem of the pump. Most probably the new valve design has solved this cause of failures. The wear along the whole length of the pipe and rod and at certain points over a long period should be measured. The recommended installation depth should be assessed according to the experiences and laboratory results.

Because the final design has now almost been reached, it is no longer necessary to add all the modifications into the production model before they have been tested and found to be real improvements.

Conclusions

In Tanzania several programs have been created to implement handpump well construction. Different types of handpumps have been installed in the wells, all of them more or less suitable for these conditions. Handpump development, testing and research have been carried out by national and international programs in Tanzania. This together with just recently initiated handpump standardization will hopefully result in pumps for two purposes to be standardized which could be manufactured locally. Most of the wells in Tanzania have shallow static water levels where direct action handpumps could be used. The direct action pumps have performed well in the tests and in use in Tanzania. The Government of Tanzania cannot afford to cover all the costs and they do not have facilities to maintain the wells and pumps. People in the villages are required to participate in well construction, carry out the pump maintenance and pay at least a part of the costs. Educational work in the villages is important to make people aware of things related to handpump wells and clean water. It takes years before people understand that the well belongs to them and they are responsible for its use and maintenance.

The Governments of Tanzania and Finland are in co-operation implementing rural water supply construction in two regions in south-east Tanzania. In this area Finnish handpumps have been tested and developed and the area has been one of the UNDP/World Bank handpump field test areas. The manufacturer of the Nira Af-85 direct action handpump in Finland has developed the pump with the assistance of the project. This has made it possible to consider the requirements set for handpumps in Tanzania. Nowadays Nira Af-85 is the only pump installed in shallow wells in the project area. Designs of a few parts have been changed during the development. The pump seems to be a real new generation handpump. This has also been admitted by other institutions who have tested and used the pump. The pump design allows it to be manufactured in developing countries like Tanzania locally.

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