REPORT NO. GEN 121

A TECHNICAL, ECONOMIC AND SOCIAL ANALYSIS OF ALTERNATIVE WATER PUMPING TECHNOLOGIES FOR UNDERDEVELOPED RURAL AREAS

K WISEMAN

&

A A EBERHARD

Energy Research Institute
University of Cape Town
Private Bag
Rondebosch 7700
South Africa

August 1987

A TECHNICAL, ECONOMIC AND SOCIAL ANALYSIS OF ALTERNATIVE WATER PUMPING TECHNOLOGIES FOR UNDERDEVELOPED RURAL AREAS

K WISEMAN

&

A A EBERHARD

1/2/86 - 31/1/87

PREPARED FOR THE FOUNDATION FOR RESEARCH DEVELOPMENT

BY

Energy Research Institute

University of Cape Town

This report was prepared as a result of work sponsored by the National Programme for Energy Research (NPER). The report has been submitted to, and reviewed and accepted by the NPER as part completion of the project requirements. However, the view or opinions of authors expressed herein do not necessarily confirm or reflect those of the NPER. Material in this report may be quoted provided the necessary acknowledgement is made.

CERTIFIED AN OFFICIAL FINAL REPORT

....

for NATIONAL PROGRAMME FOR ENERGY RESEARCH

Acknowledgements.

There are many people without whose help this project would not have been possible. In particular Dr Anton Eberhard deserves special thanks, since without his help the project would not have taken place. I would also like to express my gratitude to the following people and organisations, who listened, helped and contributed:

Climax Windmills (Pty) Ltd,

Mono Pumps (Africa) Pty Ltd,

Nimric Windmills,

KwaZulu Department of Agriculture and Forestry

South African Sugar Association,

Transkei Department of Agriculture and Forestry,

Transkei Appropriate Technology Unit, and in particular Mr Zipete and Mr Woolamindya,

Valley Trust, espeically Tim Mtembu and Dr Irwin Friedman,

World Vision,

Botswana Technology Centre, BTC, and Rural Industries Innovation Centre, RIIC.

the residents of Ndwebu, Pitoli, Mdonini, Eluphepheni, Impaphala (Mr & Mrs Mtshali), Mbongolwana, Mntengwane, Esiqungeni and Upper Mnafu in KwaZulu, and the residents of Tabase, Xhwili, Ambrose (espeically Mr Joller), Mndini and Luyengweni (espeically Mr Monakali and Mr Government) in Transkei.

Executive Summary

The provision of clean potable supplies of water is one of the most critical problems in underdeveloped rural areas. In many areas the only sources of water are springs, which provide an inadequate quantity of poor quality water and are often a considerable distance from the homestead. One solution is the use of groundwater, which is less susceptible to the effects of drought and faecal contamination. Groundwater extraction, however, requires the use of energy-consuming water lifting devices in areas where modern energy sources, such as electricity, are not usually available. In this report the technical, economic and social considerations relevant to the use of water lifting technologies in underdeveloped rural areas are reviewed.

The amount of water used per capita per day in underdeveloped rural areas has been found to vary according to the time and effort required to collect it (Eberhard, 1986; Mara, 1982; Rosenhall & Hansen, 1979). Where only surface water sources are available, per capita water use is between 5 and 15 litres per day; where water from standpipes is available 20 to 40 litres per person per day may be used, depending on the standpipe density; and where water from a single household tap is available 50 to 100 litres per person per day may be used. These figures may be compared to the daily per capita water use in the United Kingdom, which is about 185 litres, or that of the USA, which is about 300 litres (Dunn; 1978 p85).

In underdeveloped areas of South Africa the most common source of water are unprotected springs, that is springs that are not protected from faecal contamination, or other surface bodies of water. Stone (1984b p6) found that 90% of the population in the Chalumna/Hamburg area of Ciskei obtain their daily water needs from unprotected surface sources. The average amount of water used per household per day was found to be 75 litres, and the average time taken to collect water was found to be 100 minutes.

In addition to the problem of the amount of water available there are often problems with the quality of water. Unprotected springs are shared with other water users, such as livestock and cattle, as well as other water uses, such as bathing and washing. As a result many rural communities suffer from water borne diseases, such as cholera and typhoid, as well as a host of other diseases associated with poor quality water supplies.

The problems of providing an adequate and reliable supply of clean water exist throughout the underdeveloped world, and a considerable amount of effort has recently been made to solve those problems. Water supply schemes in Bangladesh, Sri Lanka, India, Ethiopia, Kenya, Tanzania and Malawi were reviewed, with particular attention to the technologies that have been chosen and the organisational and planning methodologies that have been applied. It was found that in all the above countries three technologies are widely accepted: spring protection, handpumps, and, to a lesser extent, windpumps.

It was also seen that these technologies are often designed to facilitate at least a partial level of village maintenance, and often a high level of local construction. In this respect it is interesting to note that the primary motivation for village maintenance is a reduction of the reliance on Government service institutions.

The review also showed that it is now a widely accepted practice to select, or encourage the village to select, a person to be responsible for the servicing and 'first line' maintenance of a village water supply. This often takes place in conjuction with a village contribution to the construction of the water supply project. The review showed that the concepts of village maintenance and participation have been widely accepted as essential prerequisites for successfull water supply developments in underdeveloped rural areas.

Spring protection is a technique for improving the reliability of spring water supplies, as well as increasing the amount of water that is available and the quality of that water. The technique has been favoured by many independent water supply planners, such as aid agencies, since it is inexpensive, technologically simple and is suitable for the involvement of the benefitting community, both in terms of the materials used and the labour necessary.

In many situations, however, spring protection may not be a suitable option, either due to the susceptibility of the spring to drought or dry periods, or due to unsuitable topography. In other cases the surface water potential may have been reduced as a result of land mismanagement, overcrowding or overgrazing. One solution in such cases is to use water from underground sources.

There are five methods commonly used to gain access to underground water sources: driven tube wells, bored tube wells, jetted tube wells, hand dug wells and mechanically drilled boreholes. In South Africa mechanically drilled boreholes are the most commonly used. It is estimated that during the recent years of severe drought a total of some

100 000 boreholes have been drilled annually, at an estimated cost of over R100 000 000 (Borehole Water Journal; 1986 p4).

In Transkei, approximately 1 300 boreholes have been drilled for supplying village domestic water. Similarly, in KwaZulu between 200 and 250 are drilled annually for village water schemes. The average cost of Transkei boreholes, which are accepted down to 120 metres, is between R4 000 and R5 000 (Shaker; 1986 Pers Comm).

Water Lifting Technologies.

In this report the technical considerations of the energy source used, the volume of water required and the servicing and maintenance requirements of pumps in the field have been reviewed, together with an economic assessment of the cost of pumped water. Pumped water costs in $c/m^3.m$ (cents/volume volume rate times head) were calculated for heads of 30 and 60 metres, and flow rates of 5, 10, 30 and 50 m^3/day, using 1986 retail prices. Village case studies were conducted of handpump, windpump and spring protection schemes in order to identify the social considerations that influence the long term success or failure of a water supply scheme.

Handpumps. Handpumps are utilised for village water supplies throughout Africa and Asia. In South Africa handpumps are widely used by water supply planners: in KwaZulu, between 200 and 250 handpumps are installed yearly by the KwaZulu Department of Agriculture and Forestry, and a further 100 to 150 by the KwaZulu Water Development Fund.

Two types of handpump are commonly used: piston-cylinder pumps and rotary positive displacement pumps. There are three main manufacturers of piston-cylinder handpumps in South Africa: Climax, National and Nimric. The three manufacturers follow a similar handpump design, consisting of a lever, moving in a vertical plane, connected to pump rods that drive the cylinder in the piston (although Climax also manufacture a wheel type handpump using a gear system to produce the required reciprocating movement).

The most common causes of failure of these reciprocating handpumps are breakages above ground level of the handle, either through wear or misuse, and failure below ground level of leather piston seals or the footvalve seal. Replacing the failed components in the piston-cylinder requires lifting the pump rod, rising main and cylinder to the surface using a block and tackle or crane. Such repairs are generally time consuming and expensive, and require experienced labour.

An example of a reciprocating handpump designed and built for rural water supplies in Southern Africa is the Blair pump. Designed by the Blair Research laboratory in Zimbabwe, the pump differs from the usual piston-cylinder designs as two of the most troublesome components- a lever type handle and water tight seals- have been eliminated. The result is a pump that looks like a walking stick with a curved handle, since the handle doubles as a spout. Although the results of field trials are not yet available, the Blair pump has been tested successfully under laboratory conditions.

In South Africa the manufacturers of piston-cylinder handpumps are competing with Mono Pumps (Africa) Pty Ltd, who manufacture the rotary positive displacement Mono Direct Drive handpump. The Mono handpump is at present widely used by Transkei and KwaZulu water supply planners, as well as the KwaZulu Water Development Fund and the Lesotho Government.

Below ground the Mono handpump consists of a helical rotor element, which works on the Archimedes screw principle, inside a moulded rubber-polymer stator. The rotor is driven by a vertical drive shaft that is fixed directly to the pump handle on the surface. An advantage of this design is that water is produced at the surface at every turn of the handle, whereas reciprocating handpumps require a certain amount of pumping before water is produced. Secondly, the torque produced at the surface is independent of the head, such that, when operating normally, the pump can be used by women and children without undue effort. A disadvantage of the design is that the output is considerably less than a reciprocating pump: in a 30 metre borehole the Nimric reciprocating handpump will produce 1635 litres/hour at 30 strokes/minute. The Mono handpump over this head will produce about 540 litres/hour (both figures from manufacturers data).

A further disadvantage of the Mono design is that it is more expensive than reciprocating type handpumps. A complete Mono Direct Drive unit for a 30 metre installation costs about R1045, whereas a Nimric lever handpump would cost about R630. The pumped water cost for the base case analysis (H=30 metres, Q=30 m^3/day) was found to be 0.84 c/m^3.m for the Mono pump, and 0.68 c/m^3.m for the Nimric handpump. Seven Mono Direct Drive installations would be required to produce 30 m^3/day, compared to six Nimric or five Climax Lever pumps.

The Mono handpump is a 'no maintenance' design that has been considerably refined and improved by its' manufacturers over the years. In the field, however, there is still no guarantee that the pump will produce water. 24 Mono handpump installations were visited during the course of the project. Of these 15 were found to be working adequately, 7 were working but with serious problems, and 2 were not working at all. All the working installations were found to suffer from problems of inadequate output with respect to the number of people served, resulting in queues and the continued use of surface water sources, and over 50% were found to suffer from inadequate borehole yields, such that the pump dried up during busy periods.

Pedal Pumps. Pedal powered pump units are commercially manufactured in South Africa by Mono Pumps (Africa) Pty Ltd. The pump unit was designed initially for a water supply project undertaken in KwaZulu by the Development Committee of the Red Cross, in conjunction with the Faculty of Engineering of the University of the Witwatersrand.

The pedal unit consists of a triangular framework constructed of 40 mm square tubing. A standard crank and axle arrangement drives an adapted version of the Mono Direct Drive handpump. The complete pedal pump unit retails for R1350, of which R580 is for the pump section. The pumped water cost of the pedal pump in the base case of the economic analysis was found to be 1.49 $c/m^3.m$. As such it is more expensive than handpumps, windpumps and diesel pumps. However, pedal pumps may be regarded as an experimental technology since they have not yet been widely used or tested in the field.

Wind Pumps. Wind pumps have been widely adopted in the developing World for rural water supplies, although not as widely as handpumps. In Southern Africa wind pumps have been used in Botswana, where a windmill was specifically designed for use in remote rural areas, as well as in Bophutatswana, Transkei, and to a lesser extent in KwaZulu.

The windmills produced by four manufacturers were investigated during the project and included in the economic analysis. Southern Cross, Nimric and Climax windmills each produce windmills utilising piston-cylinders, and incorporating a variety of reefing, braking and transmission systems. In addition, Climax produce a 'rotary' windmill that drives a rotor stator pump of the type produced by Mono Pumps. A similar windmill is produced by Midkaap Engineering (the M&S Rotor Windpump). The capital costs of these windmills vary a great deal, according to the size of the windmill and the type of transmission system used on the windmill head. A Climax windmill of 3 metres rotor diameter costs about R3 000, whereas the M&S Rotor, with a diameter of 5.5 metres costs approximately R8 000. Southern Cross manufacture the largest range of windmills, from 2.5 metres to 7.5 metres diameter, the latter costing in excess of R15 000.

In the base case of the economic analysis it was found that the Nimric windmill offered the least expensive option of all the technologies included. The pumped water cost from the Nimric windmill was 0.29 $c/m^3.m$, compared to 0.33 and

0.60 $c/m^3.m$ for the Southern Cross and M&S Rotor windmills respectively. The M&S Rotor windmill was found to be very competitive at higher heads and flow rates. At H=60 metres, and Q=30 m^3/day, the pumped water cost of the M&S Rotor was found to be 0.35 $c/m^3.m$, compared to 0.38 and 0.51 $c/m^3.m$ for Climax and Southern Cross windmills respectively.

The greatest problems associated with the application of windpumps in rural areas are of reliability and maintenance. Discussions with windmill servicing co-ordinators, agricultural extension officers and windmill manufacturers revealed the three most common causes of windmill breakdown to be: rotor failure in high winds, transmission system failure at the windmill head and piston-cylinder failure, often due to the cylinder being pumped dry.

The common causes of piston-cylinder failure in windpumping systems are the same as for piston-cylinder handpumps, such as worne valves, leather washers or seals, but with the added problem that the windmill will pump water whenever the wind blows, irrespective of the borehole yield.

Windpumps have been widely adopted for village water supplies in Transkei. Each scheme consists of a windmill, reservoir and water reticulation network to standpipes, and costs, on average a total of R120 000. 1300 such schemes are reported to have been built in Transkei, of which it was estimated that between 800 and 900 were operating in April, 1986. In 1985, a total of R750 000 was allocated to the maintenance of Transkei's windmill water supply schemes (Shaker; 1986 Pers Comm).

Diesel Pumps. The use of diesel powered water lifting systems is widespread throughout the developed agricultural sector of South Africa. They are also often selected by rural communities for village water supplies. Unfortunately, diesel systems operating in underdeveloped rural areas suffer from frequent breakdowns and the collection of regular contributions to buy diesel is a difficult process.

Feachem *et al* (1978 p30) investigated six diesel powered water lifting systems in their extensive analysis of rural water supplies in Lesotho. Their conclusion was that: "The only rural communities for which they (diesel pumps) might be suitable would be those adjacent to missions or other institutions with the financial, technical and manpower resources to take full responsibility for their operation and maintenance."

In the economic analysis diesel powered water lifting systems were found to be competitive with other technologies at higher heads and flow rates. In the base case the pumped water cost was found to be 0.69 $c/m^3.m$, compared to 0.29 for Nimric windmills, 0.72 for Climax windmills and 0.56 for the

Climax Lever handpump. At a head of 60 metres and output of 30 m^3/day, the pumped water cost for a diesel system was found to be 0.27 c/m^3.m, compared to 0.38 for Climax windmills.

Biogas Pumps. Biogas pumps are still in an experimental stage despite the fact that they use widely available diesel technologies. The use and operation of biogas digester units is difficult from logistical and organisational viewpoints: a trained operator is required to input the correct materials for the digestion process and the daily involvement of the community is needed to provide the materials. In addition the primary energy source needed- cattle dung and vegetable waste- is often burnt or used as fertiliser, and so may not be available for use in the digestion process. Further research into the use and operation of biogas units is justified, however, as they can provide a free and sustainable energy source in a rural environment.

Animal Pumps. Animal pumps have been traditionally used in other parts of the developing world, but have yet to make a substantial impact in Southern Africa. Apart from the design and testing of an animal pump by the Rural Industries Innovation Centre in Botswana, no other example of the use of animal power for water lifting was found. As with biogas pumps, insufficient output and cost data was available for the inclusion of animal pumps in the economic analysis.

The social factors of utilising animal power within a South African context need carefull consideration. Cattle are held as a form of wealth and prestige in many African societies, and their use for providing communal water supplies may require that some of these traditional values are given up.

Solar Pumps. Solar power has been the focus of a considerable amount of research in recent years. It may be utilised in two ways: Firstly, solar thermal devices utilise the heat generated by sunlight. Such devices are capable of lifting small quantities of water over low heads, and are not suitable for community water supplies. Secondly, there are solar photovoltaic devices that convert solar energy to electricity.

The technology used to convert light to electricity is possibly the most elegant of all the power producing technologies- there are no moving parts, no high temperature working fluids and hence negligible wear and maintenance requirements. Hence it is generally regarded as being suitable for remote applications where servicing facilities are not readily available. However, although the servicing requirements of photovoltaic system are minor, a simple fault such as a loose electrical connection could cause the system to fail, and it is unlikely that a villager would be able to effect a repair.

The high cost of PV panels has restricted their use so far. The cost of PV cells is falling rapidly, however, and with the introduction of the next generation of thin film modules the potential exists for photovoltaics to become more cost effective. In the economic analysis solar photovoltaic systems were included twice: firstly using the present cost of panels (R780 for 41 Wp), and secondly assuming a 50% reduction in panel costs. In the base case the cost of solar powered pumped water was found to be 1.98 c/m^3.m, or 1.03 c/m^3.m with a 50% reduction in panel costs. It is worth noting that the PV systems were sized according to an average irradiance of 377 W/m2 over 7.7 hours for a site near Durban in June. These figures should be regarded as pessimistic, such that the system will pump more water than is required during the summer months. In addition, many sites in South Africa receive solar radiation far in excess of this "worst case" figure.

<u>Hydraulic Rams.</u> Hydraulic rams, or hydrams, have been used in many parts of the world for rural water supplies. They have the advantages of a technically simple operating design that uses a free energy source- the momentum of free flowing water. Unfortunately, it is the unreliability of that energy source that has restricted the use of hydrams in Southern Africa's underdeveloped rural areas. A further disadvantage is that hydrams do not necessarily provide good quality water. Since stream water is used to 'drive' the hydram, a water purification unit may be necessary in order to provide good quality water.

Case Studies.

Village case studies were conducted in Transkei and KwaZulu of the three most commonly used water supply technologies- Mono Direct Drive handpumps, reciprocating windmills and spring protection schemes. A total of 24 handpump installations, three windpump installations and two spring protection schemes were visited. The objective of the village case studies was to evaluate the water supply schemes in terms of their ability to provide an adequate, reliable supply of water, and to identify factors in the planning, implementation and maintenance of the schemes that facilitate a successfull water supply development.

The village case studies in KwaZulu provided a usefull insight into the operation of the Mono Direct Drive handpump in the field. 40% of the installations visited were either not supplying water or were operating with some mechanical

or other difficulty. The three main problems were found to be:
i) Inadequate borehole yields. Over 50% of the installations visited were found to dry up during busy periods.
ii) Strenuous or difficult operation. The operation of the pump was observed to be abnormally difficult at about 20% of the installations visited.
iii) Queueing. Problems of queueing were found to exist at all of the installations visited. It is the KwaZulu Government's policy to install only one handpump per village, regardless of whether 20 or 200 families are to be served (Berridge; 1986 Pers Comm). As a result the output of the pump is insufficient to meet villagers' needs, and the collection of water from surface sources may continue.

Villages having windpumped water supplies were investigated in Transkei. The case studies, although not statistically representative, succeeded in identifying the main causes of windmill failure and how these are related to windmill technology and the methodology of the water supply planner. The three most common causes of windmill failure were found to be:
i) Rotor failure in high winds. Both Climax and Southern Cross windmills are fitted with automatic and manual furling systems to protect the windmill in periods of high winds. However, it was observed that the manual system was disconnected and the villagers were discouraged from touching the windmill. As a result the windmills are inadequately protected from the effects of high winds.
ii) Failure of transmission system (gearbox). Windmill gearboxes require regular lubrication and inspection, and such servicing is often not available in remote rural areas.
iii) Failure of piston-cylinder seals or washers. This is a common and well known problem with reciprocating pumps. In some developed agricultural areas farmers have reported that it is necessary to renew leather seals as often as once every six months.

In general, the village case studies showed that water supply schemes that are planned, implemented and maintained by central Government departments are often inadequate to meet village water requirements, often break down and that such breakdowns are often not reported. Even the 'no maintenance' Mono handpump is subject to failure due to inadequate borehole yields, and a high percentage of inadequately operating pumps had not been reported.

It is concluded that the involvement of the community in the planning, operation and maintenance of water supply schemes is required if the schemes are to provide an adequate and reliable supply of water. The degree of involvement of the community necessary depends upon the type of technology to be used and the resources of the water supply planner. For example, the training of a villager to service a windmill and furl the sails in periods of high winds would help to improve the reliability of windpump water supplies. In the case of the Mono Direct Drive handpump there is little scope for village level servicing or maintenance. However, the establishment of a quick and reliable communication link between the village and the District or Regional maintenance services would improve the reliability of such water supplies.

At present water supply schemes in rural areas are the domain and responsibility mainly of central Government institutions. There have been some attempts to involve communities, but these appear to be uncoordinated and to have utilised oversimplified concepts of community 'ownership' and maintenance. The technologies necessary to solve the water problem in underdeveloped rural areas do exist, but the *long term* successfull application of water lifting technologies is dependent upon the involvement of communities in the planning, implementation and maintenance of their schemes.

A Technical, Economic and Social Assessment of Water Lifting Technologies for Rural Water Supply in Underdeveloped Areas of Southern Africa

6. Appendices

List of Tables.

List of Figures.

List of Graphs.

Chapter One.

Introduction.

The provision of clean, potable supplies of water is one of the most critical problems in underdeveloped rural areas. The only available water sources are often unprotected springs, ponds, lakes or rivers. These sources may be a considerable distance from the homestead and are often shared with other water users, such as livestock and cattle, and other water uses, such as bathing and washing. As a result many rural African communities suffer from water borne diseases such as cholera and typhoid, as well as a host of other diseases associated with poor quality water supplies.

The collection of water from these traditional sources is an arduous task for a rural woman, who may frequently have to walk distances of up to two kilometres carrying a 25 litre container of water for use in the household. Two or three collection journeys are commonly required per day, such that a considerable amount of time and energy is spent fulfilling this basic human need.

In recent years increasingly large sums of money have been allocated by Government departments and independent aid organisations to the improvement of village water supplies. In many cases a simple spring protection scheme coupled with a gravity supply to standpipes is a suitable first step in improving the quality and quantity of water available and partially reducing the burden of water collection. However, in many other situations the only available water source is underground, requiring some form of water lifting technology for its' extraction. Many different technologies have been used for this purpose, including diesel pumps, various types of handpumps, windpumps, solar pumps and hydraulic rams.

However, these groundwater supplies have often proved to be unreliable due to breakdowns of the water lifting technologies. The difficult and expensive process of repairing rural water supplies is aggravated by such problems as poor communication between villages and centrally administered water authorities, poor access to villages and shortages of spare parts and skilled labour.

At present it can also been seen that agencies administering water supply improvement schemes commonly have inadequate or non-existant monitoring procedures, such that the causes of water supply failure are not identified.

There have been no systematic studies of the most commonly used sources of water or water supply technologies utilised in underdeveloped areas of South Africa. Indeed, the problems of rural water supply have only begun to be addressed within the last ten to fifteen years. In that time it is likely that the three problem areas of rural water supply- quantity, quality and distance- have been aggravated by such policies as influx control, the Group Areas Act, forced removals, relocation and the Homelands policy, which have all tended to increase the population density in rural areas. These, in conjunction with a high rate of population growth, have resulted in traditional water sources being unable to meet the needs and requirements of todays rural population.

Within the context of the complex physical, social and historical causes of rural water problems, a one year research project can have only limited objectives. It can seek to either investigate fully a single narrow aspect of the broader problem, for example, to investigate the reliability of various water pumps in a laboratory, or it can seek tc collect information on a wider range of topics, in order to analyse, interpret and present an overview of that information. Whilst such an approach may not statistically confirm or refute an hypothesis or specific relationship, it is capable of identifying more complex interrelationships, so providing a usefull insight or deeper understanding of the problems inhibiting succesfull water supply development.

The succesfull use of groundwater sources for domestic water supply in underdeveloped rural areas depends upon a number of factors. The chosen water lifting technology should provide water at the required rate and quality, have initial capital costs within the budget of the implementing organisation, have servicing and maintenance requirements that can readily and reliably be met by that organisation, and be acceptable to the user community. Hence, it can be seen that the considerations relevant to the succesfull selection and application of a water lifting technology can be grouped into three broad categories: technical, economic and social.

The technical, economic and social considerations relevant to the selection of water lifting technologies are not mutually exclusive- rather, they are dependent and interdependent. The failure of water supply planners to fully address any one of the three broad categories is likely to result in the failure of the water supply scheme to provide an adequate, reliable supply of water.

The primary technical considerations for water lifting technology selection are those of the volume of water required and the head over which water is to be lifted. It is necessary to know the amount of water required daily, including an allowance for peak periods, and the depth of the well or borehole that is to be used. Carefull consideration must also be given to the source of energy that is to be used, which must be available, reliable and sustainable over long periods in the village.

When selecting the technology and energy source that are to be used, equal consideration must be given to the servicing requirements of moving parts and the amount, frequency and difficulty of likely corrective maintenance procedures. In many instances these considerations have been given insufficient attention, resulting in the failure of the water supply at the first component breakdown. The considerations of servicing and maintenance are not only technical, but are also strongly related to the social aspects of water supply schemes (Berold; 1981, Huisman *et al*; 1981, Feachem *et al*; 1978, Pacey; 1978).

The economic considerations of rural water lifting technologies are primarily considerations that have to be addressed by water supply planners. They include the capital and installation costs of the technology, the expected usefull lifetime of the installation and the costs of servicing and maintenance in the field.

Water supply planners in Southern Africa are most commonly Government or aid organisations, administering as many as two or three hundred new schemes in a year. The economic implications of technology selection may then extend beyond the administering agency, up to the level of the national economy, as the selection of indigenous technologies will provide employment, often be cheaper than imported technologies and encourage investment and technological innovation. Rural water supply agencies have in some cases sought to design and manufacture technologies adapted to local conditions. For example, in India the India Mark II handpump was designed as a modification of existing technologies to facilitate village level operation and maintenance. The design was not patented in order to encourage local and small scale manufacturing (Fricke; 1984 p1).

The implementing "agency", however, may occasionally be the user community itself. In that case the sole economic consideration taken into account may be capital cost. Many communities in Southern Africa have purchased diesel powered borehole pumps, as they are cheap and readily available. Unfortunately, these diesel supplies often fail due to inadequate servicing or maintenance, or at best pump water intermittently, due to problems of collecting regular cash contributions for repairs or to purchase diesel (Feachem *et al*; 1978 p30).

The social considerations of water lifting technology applications in underdeveloped rural areas are interdependent with the technical and economic considerations. The success of Malawi's rural water supply schemes, for example, is the result of the selection of a simple, low cost technology in conjunction with a high level of community participation and involvement at every stage of the water supply schemes (Liebenow; 1984, Charnock; 1983, Robertson; 1980, Munyimbili; 1980).

A water lifting technology selected for use in an underdeveloped rural area should compliment the existing levels of social organisation and education. In effect this means that the choice of water lifting technology should be made in conjunction with, or at least should take into account, the user community.

Some social considerations relate directly to the design of the technology itself. For example, Mono Pumps (Africa) Pty Ltd, who manufacture the widely used Mono Direct Drive handpump, redesigned the handle of the pump in order that rural women would have less difficulty operating it with a correct posture.

Conversely, social aspects of the water supply *scheme* require carefull consideration, such as the involvement of the community in the planning process, in order that the completed scheme is correctly used and does not suffer from breakdowns caused by pilferage or misuse.

In terms of the objectives of this project it was decided to follow the holistic approach described above. By collating information related to the technical, economic and social factors influencing the success or failure of water lifting technologies in Southern Africa it has been possible to identify technologies and planning and implementation methodologies that are suitable for use by Government and aid organisations to provide adequate and reliable water supplies. The objectives of the project were:

i) To review the the domestic water use and requirements of underdeveloped rural areas in Southern Africa, in terms of the volume of water used per person per day and the distance walked and time spent in collection.

ii) To review the water lifting technologies available to meet those requirements in terms of the relevant technical, economic and social considerations.

iii) To identify the water lifting technologies most commonly used in Southern Africa by Government and aid organisations for the provision of water supplies in underdeveloped rural areas, and the methods of planning, implementation and maintenance that are applied.

iv) To investigate the success of the above technologies and implementation methodologies in terms of the user's perception of the water supply scheme, its ability to increase the volume and quality of water available, and the scheme's overall adequacy and reliability, by the use of village case studies.

v) To identify whether a correlation exists between the type and level of community participation utilised in the water supply scheme (planning, implementation and maintenance) and the success of the scheme in terms of the above considerations.

vi) To use the above information and case study results to identify those water lifting technologies, planning and implementation methodologies, community responsibilities and maintenance programs that are capable of providing adequate and reliable supplies of water in underdeveloped rural areas.

Chapter Two.

Literature Review.

2.1 Rural Water : Collection and Use

The amount of water used daily by rural households has been found to vary in proportion to the amount of water available and the time and effort required to collect it.

In many areas typical water sources are unprotected springs (that is, springs whose water is not protected against contamination by other water users, such as livestock) as well as ponds, lakes or rivers. The collection of water from these sources is an arduous task for rural women, who carry their water in 20 or 25 litre containers from the source to their homes. In many cases, including Transkei in particular, the water source is at the foot of the hill onwhich the village is situated, such that it is a long and laborious uphill climb carrying water. For these reasons, the per capita water use is often below 10 litres per day, and there are considerable health and social problems caused by the use of polluted water. These will be discussed in Section 2.3 (Water and Health).

Eberhard (1986 p69) conducted surveys of rural water collection and use in underdeveloped areas of South Africa and its Homelands. It was found that the average quantity of water consumed in the study villages was about 15 litres per person per day. The results of this survey are shown in Table 2.1 below.

Table 2.1 Average Quantities of Water Currently Consumed.

	Mean Amount of Water collected per day (litres) Per household	Per capita	Mean no. of collection trips
Lujiko	74	16.0	3
Manzimahle	70	16.3	3
Clarkebury	74	13.0	3
Nkanga	110	13.1	3
Cottondale	87	14.1	3
Mokumuru	81	15.5	3

Source: Eberhard; 1986 p69.

Stone (1984b p6) conducted a similar survey of water sources and domestic water use in the Chalumna/Hamburg area of Ciskei. This area contains 19 villages with a combined total of over 3000 dwellings. The population is in the order of 25 000 over an area of about 240 km^2.

It was found that 90% of the population collect their water from unprotected surface sources. No protected surface sources were found. A few dwellings (less than 2%) were found to have functional rain tanks. Some boreholes were found, but it was estimated that less than 2% of domestic water consumed was from a borehole source (there is a high degree of mineralisation of groundwater in the area, making boreholes an unpopular source).

The average daily household water use was found to be 75 litres per day, requiring at least three journeys to collect water. The average distance to water was 850 metres, and the average time taken for a one-way journey to the source was 16 minutes. Hence water collection requires, on average, at least 100 minutes per day.

Stone (1984a p4) also investigated the water consumption in black townships in the former Albany region of the East Cape

Administration Board. These areas are commonly served by municipal standpipes, but, as can be seen in Table 2.2, the number of people served by each standpipe varies considerably. As a result the water consumption also varies considerably from area to area.

Table 2.2 Township Water Consumption in the East Cape.

TOWN	POPULATION	PEOPLE/TAP	WATER CONSUMPTION LITRES PER PERSON PER DAY
Cradock	14 000	100	35
Kenton-on-Sea	1 576	775	5
Cookhouse	3 900	5	32
Fort Beaufort	15 000	272	10
Somerset East	6 650	12	20

Source : Stone; 1984a p4.

These figures serve to illustrate that the provision of clean reliable water from standpipes will only increase per capita water consumption to the extent that the water is available for collection. It can be seen that the amount of water used is strongly influenced by the difficulty with which it is obtained. It should be noted that in these townships the cost of water in financial terms is not a consideration for the users - hence the variation in consumption is directly related to the human cost of water collection.

The provision of standpipes in rural villages usually represents a reduction of the human cost associated with water collection, and the per capita water consumption can be expected to rise.

Table 2.3 below shows the average amount of water used with respect to the supply service level. These figures can be compared to the daily per capita water consumption in the

United Kingdom, which is about 185 litres per person per day, or that of the U.S.A. which is about 300 litres (Dunn; 1978 p85).

Table 2.3 Rural Water Use with respect to Supply Service Level.

WATER SUPPLY SERVICE LEVEL	TYPICAL WATER CONSUMPTION (LITRES/PERSON/DAY)
Surface Water	5 - 15 (depending on distance)
Standpipes	20-40 (depending on standpipe density)
Yard taps	50-100
Multiple in-house taps	>100

Sources: Eberhard (1986 p69), Mara (1982 p16), Rosenhall & Hansen (1979 p77).

In addition to the quantity, the manner in which water is used can be seen to vary with the level of water supply service. Eberhard (1986 p71) found that in villages where water is collected from a surface source, (such that about 15 litres per person per day is used), about a third was used for cooking, 15% for drinking, 15% for washing dishes and about 40% for bathing. It was also found that bathing and dishwater are often recycled.

Feachem *et al* (1978 p107), in their extensive investigation of rural water supplies in Lesotho, found that individuals with household connections used a great deal more water and for different purposes. A trader's household in the mountains of Lesotho was found to use over 90 litres per person per day; of this, 10% was for general domestic use, 10% for brewing, 39% for clothes washing and 41% for washing his cars.

2.2 Water: Needs and Requirements

Water is a basic human need in all societies. It is essential for life, for industry and for agriculture. In developed parts of the World, including 'white' South Africa, water is generally available with the turn of a tap, and its' cost is well within reach of the user.

In underdeveloped areas there is little chance of reticulated water to individual households on a widespread basis. Hence it is necessary to provide or help establish a supply which is sufficient to fulfill basic needs and other requirements in terms of quality, quantity and reliability.

The minimum daily water requirement of an average adult is between 1.8 and 3 litres per day. Of this about 60% is usually obtained from food and 40% from drinks. This is the minimum amount of water which will sustain life. In addition to the minimum need, water is required for other daily functions, such as cooking and washing (Dunn; 1978 p83).

As was shown in the previous section, the amount of water used by a rural household is a function of the availability of water and the time and effort involved in its' collection.

The quantity of water required by a rural household is dependent upon the amounts necessary for activities such as cooking, washing, bathing, irrigation and stock watering. The largest requirements are for agriculture, for crop watering, direct irrigation or stock watering. If borehole or spring water is to be used for these purposes it is necessary to evaluate the amount required and ensure there is sufficient available.

In many cases, however, water supplies are designed solely for domestic use. Here it is difficult to quantify the amount of water that is required due to variations in demand between households and, as shown in Section 2.1, water uses that are not strictly necessary.

The level of water supply provision must be determined such that it is able to meet all the domestic requirements present and, if possible, the agricultural requirements also. However, the design parameter of Malawi's gravity fed rural water supplies was set at 27 litres per person per day. This figure was calculated according to the existing population levels and the food production capacity of the soil, which determines the maximum population capacity of the land. The design parameter does not include an allowance for agricultural water use (Robertson; 1980 p208).

The International Drinking Water Supply and Sanitation Decade has an objective of every person having access to clean drinking water and organised sanitation. The supply level which is thought to meet this objective is 50 litres per person per day, within 200 metres of the household. As such this level of water availability is considered sufficient to meet rural domestic requirements (Kenna & Gillet; 1985 p39).

However, any water supply that increases the amount of water available and reduces the time required to collect water will have the effect of increasing the daily water use of the community. As will be shown in Section 2.3, there are considerable health benefits associated with an increase in per capita water use, as well as the reduction in the time spent fulfilling this basic human need.

2.3 Water and Health.

The types and incidence of diseases associated with contaminated water supplies are well known. In general, such diseases can be grouped into four main types, distinguished by their associated disease vectors (Bradley; 1977):

i) Water borne diseases are those spread by infected water, such as cholera and typhoid. The incidence of such diseases can be reduced by 90% and 80% respectively through the elimination of the micro-organisms by chemical treatment. Otherwise it is necessary to use an uninfected water source that has been protected against sources of contamination, such as through faeces and urine.

ii) Water washed diseases such as trachoma, scabies, dysentry and gastro-enteritus are caused by inadequate water supplies for general hygiene. The incidence of these diseases can be reduced by up to 50% by improving the availability of water.

iii) Water based diseases, such as bilharzia, which are dependent on organisms present in water for their transmission. The incidence of these diseases can be reduced by up to 60% by protecting users from exposure to the vector organism. This may be done through micro-biological treatment of the water or education of the rural population.

iv) Finally, there are water related insect vectors which cause disease, such as maleria transmitted by mosquitoes.

The improvement of village water supplies can have substantial health benefits for rural populations. In particular, the high incidence of infant mortality frequently found in underdeveloped rural areas is often associated with poor quality water and water related hygiene, such that many children die from the effects of diarrhoea. Improvements in the quality and amount of water available can reduce the incidence of the above diseases which have plagued rural communities for many years.

It should be noted that the health benefits of an improved water supply will be limited by the extent to which such infections are as a result of water borne organisms. For example, Feachem *et al* (1978 p160) investigated the incidence of water related diseases in Lesotho, and concluded that "...there is no difference in the incidence of reported water-related disease between villages with and without piped water supplies". In addition, the incidence of diarrhoeal infections was found to be at a maximum in the wet season.

In this case several factors other than contaminated water supplies were found that were capable of causing diarrhoeal infections. In particular Feachem *et al* identified the higher survival rate of pathogens in the warm, moist climate of the wet season, the poorer nutritional status commonly encountered in Lesotho villages during the summer, and poor standards of domestic hygiene.

It can be seen, then, that although poor quality water is a widespread cause of disease and infant mortality, an improved water supply can only provide a marginal reduction to the incidence of intestinal infections. In order to improve substantially the health conditions in underdeveloped rural areas it is necessary that improvements in the water supply be accompanied by improvements in excreta disposal facilities and general domestic hygiene practices. Such improvements can only be achieved if there are considerable educational as well as infrastructural inputs to a village.

2.4 A Review of International Water Supply Schemes

The problems of water supply in remote rural areas (and also in densely populated peri-urban areas) exist throughout Southern Africa and in many other underdeveloped areas of the world. The Governments of countries with such problems have adopted a variety of technological and organisational methods of providing water. It is therefore of some interest to review the various solutions that are implemented and, if possible, make some assessment of their success or failure.

In the following pages the rural water supply methodologies of Bangladesh, Sri Lanka and India are reviewed briefly, and Ethiopia, Kenya, Tanzania and Malawi are reviewed in more detail. In each instance it was attempted to collate information on the technologies chosen, the provision of maintenance, the type and level of community participation and the cost of each scheme.

This task proved difficult to complete for two reasons. Firstly, there is a paucity of published material on rural water supplies, and secondly, published material that is available is frequently written by Government representatives. As such it tends to be high on rhetoric and general principles and low on field studies or objective data.

Hence, in each case reviewed below the nature of the source of data is included wherever possible, in order that the reader may assess independently the objectivity of the information.

2.4.1 Bangladesh

Rural areas of Bangladesh suffer problems of contaminated water and difficulties of collection. However, it is fortunate to have sand and silt to great depths and a water table that is generally 5 to 6 metres below the surface.

Agarwal (1981 p74) reports that the Bangladeshi government, in conjunction with UNICEF, have implemented a widespread rural water project, using a tube well and handpump designed to suit the country's subsoil.

The tube-well sinking technique that is used was first developed in Calcutta in the 1940's. A four or five man team can construct a 30 metre deep tube well in 8 to 10 hours, including assembly of the handpump. No drilling equipment is used except galvanised iron pipes, a simple bamboo scaffold and a chain wrench to tighten threaded joints. PVC tubing is used inside the well.

The handpump used was specifically designed by UNICEF for use in Bangladesh and is manufactured locally using imported pig iron. 50 000 such pumps were reported to be manufactured annually. Unfortunately, the make of pump used was not recorded in the paper under review.

Initially there were serious maintenance problems associated with the pump, but they were solved through simplification of the technology and increased efforts to involve the beneficiary community. For each installation, a community member is appointed as caretaker and provided with tools and spare parts. If a more difficult pump repair is needed the caretaker can call on one of the 100 000 Government trained 'village mechanics'.

Agarwal (1981 p75) reported that nearly 50 000 tube wells were being installed every year, each serving about 180 people. In this way the number of people per tubewell dropped from 385 in 1971 to 162 in 1980.

In these schemes UNICEF pays for the pump and tubing, the government pays half of the labour cost and the community pays the rest, equivalent to about one-third of the total cost.

In the above-mentioned paper, it was claimed by Mr M A Hussain, the Chief Engineer of the Department of Public Health Engineering, that Bangladesh had (in 1981) 540 000 rural tubewells and that 70% of the rural population had 'reasonable access' to water within 150 to 200 metres of their homes.

2.4.2 Sri Lanka

Rainfall in Sri Lanka, although of an adequate quantity, is concentrated in a short season, with the result that agriculture is restricted to one crop a year. This has serious implications for the rural population, as there are about 1.4 million farms each of less than 1,2 hectares in Sri Lanka.

The rural population usually uses engine pumps, of which some 500 000 are presently in use (Consultancy Services:Wind Energy:Developing Countries (CWD); 1983 p1). The pumps are used during the dry season of May to October, lifting an average of $50m^3$/day over a head of 7 metres.

In 1977 the Sri Lanka Government and CWD set up the Wind Energy Utilisation Project. By 1983 some 200 windpumps were in operation and it was predicted that 10 000 would be in use within the next decade.

CWD designed a six bladed windmill of three metres diameter, with a 9 metre tower and a suction pump. It was built entirely of locally available steel and PVC components and incorporates an automatic furling mechanism.

The cost of the windmill was set such that a farmer could purchase a complete unit at the same price as a diesel driven pump. It was later found necessary to redesign the pump to 2 metres diameter, which was capable of irrigating between 1/4 and 1/2 hectare - sufficient to keep a family employed during the dry season.

The number of windmills in use is increasing, and it is estimated that if the target figure of 10 000 is reached, Sri Lanka will have reduced the annual amount spent on imported fuel by 20%.

A handpump project has also been undertaken in Sri Lanka, in conjunction with UNICEF (Boyagoda; 1984 p100). The objective of this project was to improve the traditional domestic water sources, which are dug wells, tanks, rivers and springs.

In a pilot project in 1979, 200 test wells were dug in the hard rock areas of the dry zone of Sri Lanka. The results were favourable and UNICEF extended their assistance to further drilling and the installation of handpumps. By the end of 1983, about 1400 deep wells had been drilled in hard rock and supplied with India Mark II handpumps. The wells are between 36 and 75 metres deep, with casing down to an average of 15 metres, as the water table is an average 5 to 15 metres deep. Each pump lifts water over an average of 30 metres.

The Mark II handpumps are supplied with spare parts required for maintenance over a 5 year period. The installed cost of each pump was US $500, and the total cost of drilling a 5" (130 mm) borehole to a depth of 75 metres was about US $600.

Boyagoda reports that it was observed that a well used pump required the replacement of the bucket washers on average every six months. This was found to be a disadvantage of the pump since lifting the suction pipe and cylinder to the surface required skilled workers with the appropriate tools.

This problem was overcome, however, by using 75 mm PVC riser pipes instead of the usual $1^{1}/_{4}$", which enabled the piston to be lifted or lowered with a limited number of tools.

Maintenance of Sri Lanka's handpumps is carried out by caretakers appointed from the community. These are given a two day training course by the Government. If the caretaker is unable to repair a breakdown, a Government pump mechanic is available from the district office.

K B Boyagoda is a Project Engineer of the National Water Supply and Drainage Board.

2.4.3 India

The provision of water in rural areas of India is well documented. In particular, Pacey (1978 p27) has reviewed the technological and organisational approach that was recently applied successfully by the Indian government.

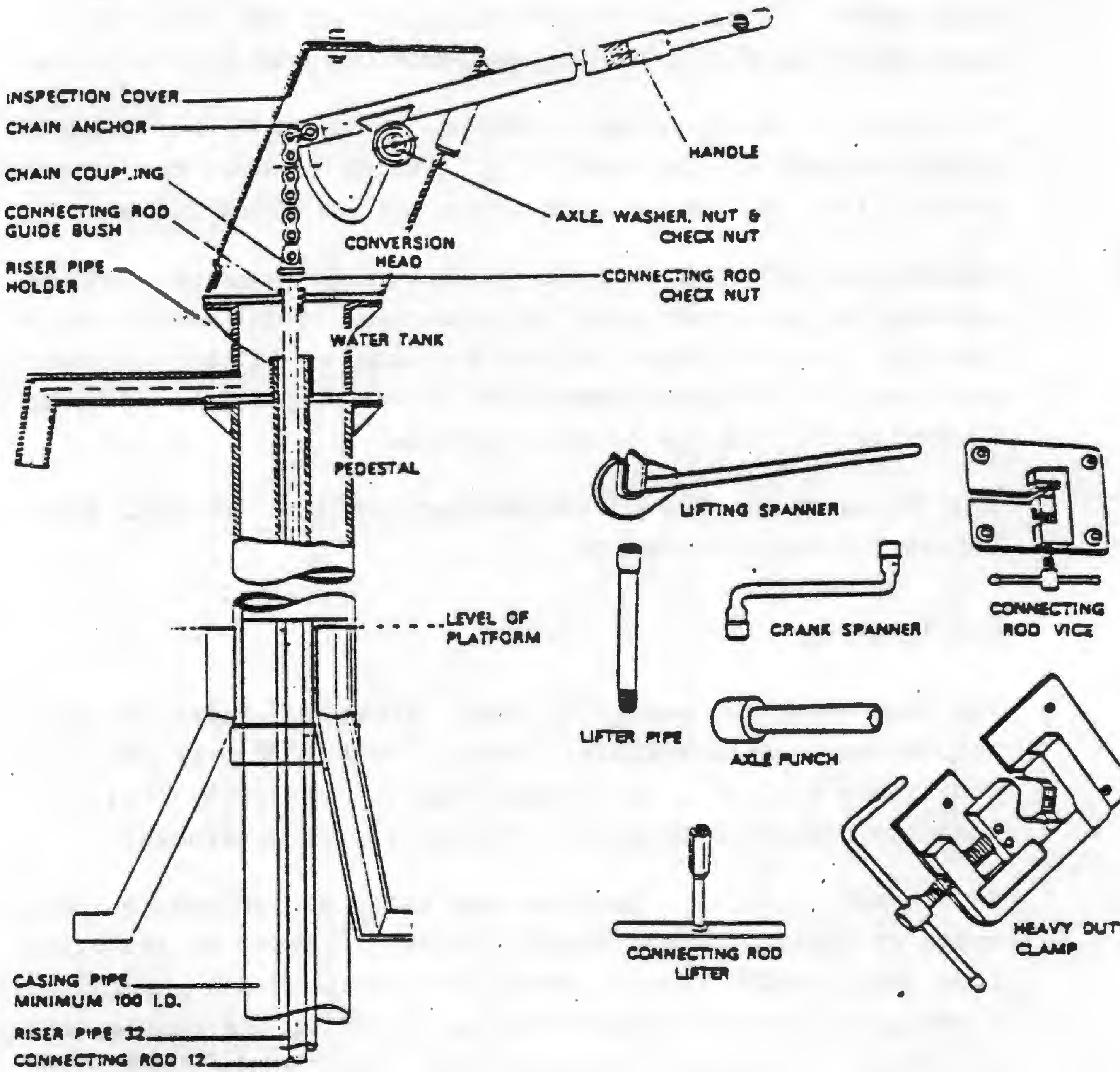
In the early 1970's a handpump was designed for use in rural areas of India, called the India Mark II. Based on the Jalna type pump, which used a lever arm handle and a length of motorcycle chain to connect the pump rod to the handle, the new pump was similar, with a steel body, roller chain and sealed gears and bearings.

The India Mark II went into production in Madras in 1976. Two years later, 20 000 had been built and a large proportion of them installed in the Indian State of Tamil Nadu. They were installed on new and existing boreholes, replacing older types of pumps. In this way the India Mark

Figure 2.1

India Mark II Handpump and Toolkit.

Source: Fricke; 1984 p4.



SPECIFICATIONS

Particulars	Unit	Amount
Operational depth	metre	25-80
Cylinder I.D.	mm	63.5
Stroke	mm	100
Strokes per minute	nos.	40-50
Discharge per stroke	Litres	0.32
(doesnot vary with depth)	Imp. gallons	0.07
Discharge per hour	litres	800-1000
	Imp. gallons	170-210

II became the only type of deep well hand-pump in use over large areas, so that the provision of maintenance could be based on a standardised set of spare parts.

Fricke (1984 p1) reports that, as of December 1984, over 600 000 India Mark II handpumps had been installed in Indian towns and villages. Each installation serves an average 200 to 250 people, corresponding to over 60 million villagers being affected by this innovation in India alone.

The India Mark II handpump was designed specifically to facilitate village level operation and maintenance. The pumps were given to communities on the condition that they make a commitment to maintenance and future costs that would arise. A maintenance system was initiated called the "three tier system". In this system maintenance is provided at village, sub-district and district levels.

At the village level a handpump caretaker is selected from the community and given a brief but intense course by the District Development Officers on health education and elementary handpump repairs. The caretaker is then given a set of tools and a diploma as formal recognition of his/her new responsibilities. The special tool kit for the India Mark II pump, and the pump itself, are shown in Figure 2.1.

The second tier of the system involves Government mechanics, who are supplied with a set of tools and a bicycle or motorbike. The mechanics make regular rounds to each of the 50 or so handpump installations assigned to them.

At the third tier maintenance teams are established, with about one mobile team for every 500 pumps. Either the mechanics or the caretakers can inform the maintenance teams if a repair beyond their capability is required.

This maintenance system has been criticised (see Roy; 1984, and rebuttal by Gray; 1984) on the grounds that it is still inadequate to deal with improvements in the pump technology and keep up with the rate of pump failures. However, it is reported that further modifications of the pump design, as well as experiments with locally self-reliant maintenance ("one tiered systems") are occuring in various parts of India to deal with these issues.

In Tamil Nadu there were 15 200 deepwell hand pumps in 1977. Complaints of breakdown were reported at an average rate of 660 per week, and were dealt with, on average, within 7 days (Pacey; 1978 p8).

2.4.4 Ethiopia

In rural parts of Ethiopia the consumption of water was estimated in 1981 to be at a level barely exceeding 10 litres per capita per day. Haile (1980 p91), the Head of the Public Relations Service of the Ethiopian Water Resources Authority, (EWRA), outlined the technologies and methods that were being implemented at that time to improve rural water supply. The EWRA design standard for rural water consumption was set at 20 litres per capita per day.

EWRA has a policy of developing springs where they are available. Where they are not, shallow well handpumps are used. The wells are dug and a handpump fitted by EWRA work crews. Mammo (1980 p18) reports that over two-thirds of the hand dug wells that have been installed are in the Central Region of Ethiopia. Several handpump makes are used, both imported and locally manufactured. The imported pumps used include the Consallen, which is a piston-cylinder pump constructed largely of steel. Several problems are associated with this pump, including heavy action, failure of the PVC riser pipe and leakage from the foot valve. The Mono Type 3 imported pump is also used; its only maintenance problem is oil loss from the gearbox.

The locally produced handpumps that are used are the Boswell piston cylinder handpump and EWRA/IDRC designed handpumps. The Boswell handpump incorporates leather cup seals and a galvanised steel cylinder, and has the facility to withdraw the footvalve without lifting the riser pipe. The problems encountered with this pump are the wearing away of handle stops and expansion of the seals with use which causes a heavy pump action.

There are three types of the locally designed EWRA/IDRC pumps commonly used - type BP, type C and Type D. The BP type is a piston cylinder pump, suitable for heads from 20 to 40 metres, and the type C and D are inertia pumps. There have been several problems with the designs of these pumps and also problems of obtaining steel for use in the pump housing. The type C and D pumps are not widely used, as they require a spring for their operation which is not readily available in Ethiopia.

Servicing and maintenance of the handpumps is done by a community person who has been trained by the Government. The community is responsible for the salary of the pump attendant and for the purchase of lubricants.

The community is also encouraged to participate in the construction of the water supply, the level of participation being determined by the sophistication of the technology. For example, a high level of community participation is expected in a spring protection scheme.

EWRA also has a policy of encouraging the establishment of village water committees as subcommittees to the rural development committee of local peasants' associations. In this respect the Government has trained "community participation promoters" (Haile; 1980 p91).

Some problems of user education have been experienced, as despite EWRA projects being free to the community it has been found that consumers will usually only use them after nearer sources have dried up.

Haile reported that "in some places people use poor quality water from ponds and unimproved shallow wells (which are those built by local craftsmen and considered by EWRA to be unsuitable for improvement) even though an extra ten minute walk could take them to an improved water source". For this reason the Government set up a water education project in primary schools, with an emphasis on creating an awareness of the benefits of clean water for women and children. In addition a broader education effort was attempted through "a weekly health programme transmitted through the radio voice of revolutionary Ethiopia".

The paper reviewed here was written, as stated above, by the Head of the EWRA Public Relations Service in 1980. At that time it was estimated that only 4% of Ethiopia's rural population (which constitutes 90% of the country's total population of 30 million) had access to improved water supplies.

2.4.5 Kenya

It is the Kenyan Government's policy to provide piped water to every household by the year 2 000. This is being attempted through National water projects and community water projects. The aim of the latter is to encourage contributions by Aid donors. The Kenyan Government has a difficult task, though, as two-thirds of the country's 570 000 km^2 is arid or semi arid with sparse pastoral communities and large livestock and game populations.

Getechah (1980 p85), a Staff Development Officer of the Directorate of Personnel Management, reported two water projects that had been successfully implemented.

(i) The Karweti Water Project in the Kiambu District of Central Province. This was a community project in which a committee was elected after motivation by women in the village for clean water. The committee consisted of nine people, including four women. The principle posts of Chairman and Secretary were given to men, despite the initial motivation being from women. The committee collected cash contributions to buy and install a diesel pump, and then continued to collect monthly contributions for diesel and to pay for a pump attendant. It is interesting to note that the topography of this region of Kenya is steep and hilly, which would appear to indicate a potential for spring development rather than the expensive diesel equipment.

(ii) The Kihara Project, in the Kiambu District. In this case the women of the village wanted to install a rainwater collection facility and approached the Government for financial assistance. They were recommended to use a pump.

As in the Karweti Project, a nine member committee was elected, including four women, three of whom held the posts of Chairman, Secretary and Treasurer. The committee raised money by household contributions and organised the digging of trenches and laying down of pipes. This work was carried out mainly by the women of the area. The type of pump used was unfortunately not included in the report.

According to the Ministry of Water Development in Kenya, the above projects are typical in that most water projects are started independently by the community on a self-help basis. Also, most of the work and organisation is carried out by women. This is partly due to many men being away working in the cities, and partly due to colonial experiences of forced communal labour. The latter has resulted in many men considering communal work as degrading, an attitude which has reduced the self-help labour contribution of men to a minimum. Getechah (1980 p85) reports that women contribute the bulk of labour and non-technical work, including digging trenches and carrying building materials, whereas men contribute mostly to the more "technical" tasks of management and maintenance.

Pump attendants (male) are trained by the Government, at a rate of 150 per year. More difficult maintenance tasks are carried out by the Ministry of Water Development, whose provincial and district offices are equipped with full maintenance facilities.

The role of education and training in rural development appears to have been fully recognised by the Kenyan Government. Shikwe (1980 p115) wrote: "...the achievement of national development is not conditioned by the endowment of natural resources and capital only. The availability of manpower with appropriate skills and attitudes to exploit and convert these resources effectively for the national benefit is an imperative condition .... training should be viewed as the development of the most important national resource, the human resource".

2.4.6 Tanzania

A good example of the methodology and technology used in the provision of rural water in Tanzania is given by Kashoro (1980 p26). Although he is a Government representative (Project Manager (Shallow Wells) of the Ministry of Water, Energy and Minerals) the paper includes field data and as such may be regarded as a good indicator of their water supply strategy.

The paper describes the Shinyanga shallow wells project, which was initiated in October 1974 and completed in June 1978. Shinyanga is one of the 20 regions in Tanzania south of Lake Victoria. It has an area of about 50 000 km^2 and a population of 1 325 000 in 684 villages. The region has a semi-arid tropical climate, with an annual rainfall of 700 to 1 000 mm, falling between October and May.

The Shinyanga shallow wells project was effectively a collaboration between the Government of Tanzania and the Kingdom of the Netherlands. A total of 994 wells were constructed, serving 300 000 people in 297 villages. The villages were chosen according to their need.

An aerial and hydrological survey was carried out in each village, followed by a ground survey to identify possible shallow well sites based on accessibility, soil suitability and population. Having identified potential well sites a further survey was carried out to determine the quality and quantity of water available at each site. The surveys were done with the assistance of a mechanical drill where hard material was encountered. Having found the aquifer, its thickness was measured and a pump test carried out to determine its yield. Water samples were taken for quality tests. It was found that high fluoride and salt contents were the main hazards to potability of the water.

Three methods were used to construct the wells: hand-dug wells, hand-drilled wells and mechanically-drilled wells, according to the hardness of the strata being penetrated.

Hand-dug Wells

These were dug with a hoe or pick-axe. They could reach a depth of 10 metres in sand, loam or other loose materials, but became very expensive at depths greater than 10 metres. Once the aquifer was reached the well was lined with concrete rings and covered with a concrete cover. It was found that one well sinker with four self-help labourers could dig two seven metre deep wells per month. This method was used in preference where it was considered important to leave some knowledge of well construction techniques in the village.

Hand-drilled Wells

These were constructed with a 25 metre auger turned by two self-help labourers. At the required depth the well was lined with slotted 15 cm diameter PVC casing and gravel filter packing was applied to the outside of the pipe.

This was found to be the cheapest method of well drilling, but was only suitable in soft strata suitable for the auger. Two wells per week could be drilled by one foreman with eight self-help labourers.

Mechanically Drilled Wells

Where neither of the above techniques was practical due to hard strata a percussion rig was used. The borehole was cased and lined in the same manner as the hand-drilled wells. It was found that one foreman with four rig-crew and three labourers could produce one well per week.

Mechanically drilled wells were used where it was practical to produce the well in a short-time. A disadvantage of this method was that it did not involve the community or leave any drilling expertise in the village.

Two types of pump were used in the wells: the Shinyanga pump and the Kangaroo pump. The Shinyanga pump is a modified version of the UNICEF and Uganda pumps, and consists of a pump stand, a wooden upright and handle, the rising main and pump rod and a piston-cylinder. With the exception of the piston-cylinder, all the pump parts were fabricated in Shinyanga workshops.

The Kangaroo pump is a minimum maintenance pump which omits any hinge points that require lubrication. The head of the pump incorporates a spring which is compressed by pushing on a foot plate. The spring is released and the recoil produces the pumping stroke. The Kangaroo pump can operate in a depth of 6 metres with a 4" cylinder, 10 metres with a 3" cylinder and 20 metres with a 2" cylinder.

In the Shinyanga project the completed wells were handed over, with a certificate of ownership, to the village chairman. Two villagers were then chosen and trained to maintain the well. In cases where maintenance is required which is beyond the capability of the pump caretaker, he can fill in a form detailing the repair required which is then sent to the district maintenance officer.

Kashoro (1980 p28) reviewed some problems associated with this maintenance procedure. Firstly, it was found that some of the villages did not understand the system, or in particular how to contact the district maintenance officer. Secondly, due to a lack of transportation and an increasing number of breakdowns, the district maintenance officer was increasingly unable to cope with all the requests for repair that he received. It was proposed to alleviate the pressure on the district maintenance officer by establishing maintenance officers at the divisional level.

It was found that the Shinyanga pump had a normal maintenance free period of 2 years, and the pump was well looked after by the women and children as they understood that a breakdown meant a long walk for unclean water.

2.4.7 Malawi

A relatively large volume of work has been published on the methods used to provide clean water in rural areas of Malawi. This is at least partly because the gravity-fed water supplies that have been used there represent a considerable success story in the field of rural water supply. It has utilised both the natural resources available and the help of the benefiting communities to their full potential. (Liebenow; 1984 a,b, Charnock; 1983, Munyimbili; 1980, Munthali & Kamwanja; 1980, Robertson; 1980). The gravity fed system serves the needs of an estimated 420 000 people in 13 districts of the Northern, Central and Southern regions of Malawi, and was expected to serve an additional 303 000 by 1985 (Liebenow; 1984a p20).

Credit for the success of the scheme, apart from the thousands of Malawians who helped, is given to a British expatriate, Mr L H Robertson. It was he who realised that the 60 inches of rainfall falling on the high lands of Mount Mulanje was enough to provide water all year. He set an objective of piping pure mountain water by gravity from the mountain to villages on the plain below.

The design criteria were set at 27 litres per person per day, with one public standpipe per 160 people, and a design flow of 0.075 litres per second at each tap when all the taps were open. These criteria were based on the existing population, the food production capacity of the soil and the estimated maximum population which the land could support.

Aerial photographs were used to establish village layouts and 1:50 000 ordinance maps were used to align the pipes. For each scheme, asbestos piping was used from the mountain source - high in forest reserves and hence unpolluted - to 50 000 gallon storage tanks. Sedimentation tanks are used to remove natural debris and sediment. Asbestos was used as it is resistant to corrosion and strong enough to withstand the weight of the three feet of sand and stone under which it was laid.

Plastic piping was then used in a branching network from the storage tanks to the standpipes. The pipe sizes used varied from 12 mm to 90 mm of PVC to the larger 100 mm to 250 mm asbestos pipes. In some of the larger projects the main pipe feeds a number of separate tanks which in turn feed branched pipelines to scattered villages on the plain.

A feature of the gravity-fed supplies was the high level of community involvement and responsibility, and the role of government workers as technical supervisors. The high level of community support was gained through a successful demonstration project at Chingale, which convinced people on the plain that water could flow for long distances without the help of a pump. In addition, water committees were elected at village meetings, with the responsibilities of organising the large amount of labour required, overseeing the construction of the tap and apron with a soakaway pit, and for maintaining the tap and ensuring the cleanliness of the tap surroundings. The commitment of the water committees was essential, as in some areas, such as at Mulanje, the water was to be up to 2 years in arriving.

Villagers were responsible for digging trenches for the pipes along the planned route under the supervision of a

Government trained Technical Assistant. These were the vital link between project and the people. They were given in-service training such that they were proficient and respected (aided by the perk of using a Government motorcycle) and highly motivated towards the success of their project.

The motivation of the villagers was further maintained as the work progressed downwards from the mountain. At the end of each day's pipe laying the water was turned on, for the dual purpose of flushing out the pipes and graphically demonstrating that the water was that much closer to the village.

Each village served by a single source was expected to give a weeks work, in rotation, to excavating the trenches and branch lines. The progress was planned with enough flexibility to allow for variations in the amount of volunteer labour available due to agricultural demands.

Once installed, the water committee was responsible for enforcing certain regulations on the collection and use of water. The committee (composed of women from the village) ensures that the tap is not left running, that people do not leave water standing that might become a breeding ground for mosquitoes and that the cement slab around the tap is kept clean. In addition, women are not allowed to wash clothes near the tap and must carry all their water away with them. This has the effect of maintaining water consumption within the design criteria.

It has been estimated that the cost of the entire gravity fed system (up to 1984) was roughly $10 per person (Liebenow; 1984a p22). Robertson attributes the success of the project to the success of the initial demonstration project and "ten years of patient understanding and persistent hard work" from field staff (Robertson; 1980 p10).

The Malawi Shallow Wells Program.

In addition to the gravity supply schemes, which are obviously not practical in all parts of Malawi, there is a shallow wells program which is designed to "assist villages in obtaining their own protected wells, which can provide a plentiful supply of disease-free water" (Nkana; 1980 p30). According to Nkana, who is the Wells Program Officer of the Department of Lands, Valuation and Water (DLVW), the areas suitable for shallow wells, mainly in the high plateau areas and in the dambo areas of the Central Region, rarely overlap with those suitable for gravity-fed water schemes. In this way, most of Malawi's rural population can be served by one or other of the two systems.

The shallow wells project started with a pilot project in 1975 in the District of Lilongwe in which 30 wells were completed. The pilot project was considered a success and expanded into other districts such that by 1979 five hundred wells had been constructed and fitted with pumps. The wells are shallow, averaging 6 metres in depth, and a PVC pump is used.

The community infrastructure and high level of self help used was organised along the same lines as the gravity-fed schemes. In this case the project assistants, who are trained and employed by the Government, would take village leaders on a tour of completed wells and wells under construction. The leaders were then able to discuss the costs and relative merits of the scheme with other village leaders already in the program. A village meeting would then be held, in which the project assistant would explain the project to the entire community and, with the help of the village leaders, obtain popular support for it. A working committee would then be elected and made responsible for tools and materials.

An interesting method of achieving further community involvement was the establishment of program subcentres within communities that possessed strong program leadership. The subcentres were used to establish a complete system of protected wells in the surrounding area, acting as a precedent to spread the program from one village to the next.

The wells were constructed with materials supplied by the community, including bricks, sand and gravel, in a hole of one metre diameter and six metres deep. The project assistant was responsible for delivering the pump and assisting the village committee with its installation.

The village committees were then responsible for maintaining the well and through training by the project assistant are able to complete most repairs to the pump. Unfortunately, the precise make of handpump used was not included in this paper. As with the gravity-fed standpipes, the committee enforces certain rules with regard to activities near the well - most commonly preventing contamination by washing or bathing.

2.4.8 Summary.

Although the above review of worldwide efforts to improve rural water supplies in underdeveloped areas is by no means comprehensive, it is possible to identify some common trends and lessons that have been learnt elsewhere.

The first point of interest is that the technologies that are being applied do not vary a great deal from country to country. It can be seen that in all the above reviews three technologies are widely accepted: spring protection, handpumps, and, to a lesser extent, windpumps.

Secondly, these technologies are often designed to facilitate at least a partial level of village maintenance, and often a high level of local construction. In this respect it is interesting to note that the primary motivation for village maintenance is a reduction of the reliance on Government service institutions. The most successful of these modified technologies appears to be the India Mark II handpump, which is often delivered to a village with enough spare parts for up to five years of maintenance. Further innovations include the design of piston-cylinders that allow the seals and washers to be renewed without lifting the rising main to the surface.

Thirdly, it is now a widely accepted practice to select, or encourage the village to select, a person to be responsible for the servicing and 'first line' maintenance of a spring protection or handpump. This often takes place in conjuction with a village contribution to the construction of the water supply project.

From the above review it can be seen that the concepts of village maintenance and participation have been widely accepted as essential prerequisites for succesful water supply developments in underdeveloped rural areas.

Chapter Three

Assessment of Available Water Supply Technologies in Southern Africa.

3.1 Water Source Selection and Development.

As stated in Chapter 1, typical water sources in underdeveloped rural areas are unprotected springs, ponds, lakes or rivers.

The first step in improving water supplies from such surface sources is to protect the source against contamination by other water users. This may be done by erecting a fence around the source to exclude water users or activities that are likely to contaminate the water, such as cattle, sheep and goats. Activities that should be excluded include washing clothes, swimming and bathing.

The protection of large bodies of surface water against contamination is an extremely difficult task. In such a case it may be preferable to use some form of water purification to provide water of acceptable quality. The design and use of water purification plants is beyond the scope of this report.

The protection of springs against contamination is relatively simple, and spring protection techniques are widely used in Southern Africa by development and aid organisations, such as World Vision, Valley Trust, and the Transkei Appropriate Technology Unit, (TATU).

3.1.1 Spring protection

Spring water is the result of the seepage of rainwater into underground aquafers. The aquafer may slope in a particular direction and intersect the side of a hill or mountain, at which point a spring will occur. The point at which water from the aquafer intersects the land surface is called the "eye" of the spring.

The methods of spring protection that are commonly used in South Africa involve capping the eye of the spring and directing the water to a reservoir. The successful implementation of such schemes is a result not only of the relatively simple technology and materials that are used, but also of the philosophies of participation and community-level maintenance that are applied by the development organisations listed above. Hence, in this section the social implementation strategy as well as the techniques and materials used are reviewed.

Spring protection techniques in South Africa are well standardised within the development organisations that use them. Several criteria for selection are applied to a spring before it is selected for protection:

(i) It must be a perennial water source, ie flowing all year round. The Transkei Appropriate Technology Unit (TATU) recommend that it has a flow rate of at least 3 to 5 litres per minute during the dry season (TATU; p2).

(ii) The eye of the spring should be above the village to be served. Unfortunately, this selection criteria cannot be applied in many areas where villages are located at the top of mountains or hills.

(iii) The spring should preferably be located within 500 metres of the village centre.

(iv) The eye of the spring should be situated such that it is possible for water to flow into the reservoir tank under gravity.

(v) The eye should be situated such that it can be sealed and protected from surface run-off water, which would otherwise contaminate the spring water.

Having selected a suitable spring a procedure is followed which usually consists of six components:

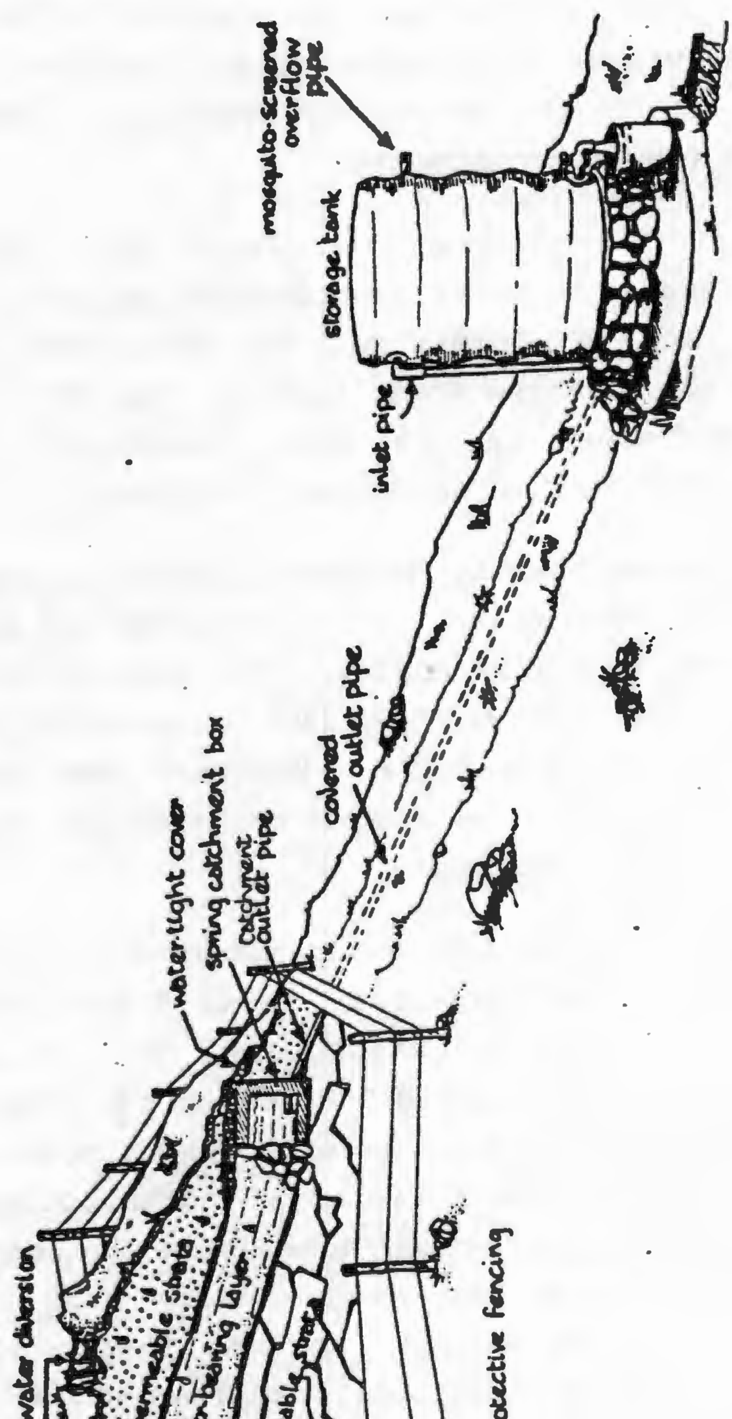
1. A water tight box is constructed around the eye of the spring. This involves clearing the eye and installing a filter, retaining wall and removable cover.
2. A water collection pipe is connected to the spring box.
3. A water reservoir tank is constructed at some point below the eye of the spring. This is connected to the spring by the collection pipe such that all the water from the eye is diverted to the reservoir. One or more standpipes may be connected to the reservoir.
4. An overflow pipe is connected to the reservoir. The water from this pipe may be diverted for cattle watering or garden irrigation.
5. A system of ditches is constructed above the eye of the spring to prevent surface run-off water from polluting the spring.
6. A fence is constructed around the spring, outside the run-off ditches, to exclude animals and animal waste which might pollute the spring water.

Figure 3.1 shows a standard spring development as used by TATU. It should be noted, however, that it is not possible to systematise the methods of spring protection as there exists a complex variety of spring sites and situations, and a variety of community needs to be served by the protection scheme.In the TATU approach to spring protection the community involved is required to elect a water committee which is then responsible for collecting a financial

Figure 3.1

Standard Spring Development.

Source: TATU; p4.



contribution for the purchase of raw materials, as well as organising the labour input for the digging of trenches. In addition, one person is selected by the community to observe the spring protection and learn the necessary servicing and maintenance techniques. The input from TATU is only to deliver materials that are not available within the village, design the spring protection and provide the necessary technical supervision for construction. TATU will not begin the project until the community has fulfilled its own financial and labour commitments.

Similar social organisation techniques are used by the Valley Trust, where a Water Association is formed prior to construction and a Committee and Maintenance Officer elected. Both organisations justify the high level of community involvement as creating a democratic structure which may lead to further development projects.

The simplest water supply projects administered by TATU involve a spring protection, about 10 metres of pipeline, a 4 400 litre tank and a standpipe. The cost of this system is about R700, of which R150 to R200 is usually contributed by the community for materials. However, the cost of each scheme is dependent on the length of pipeline required and the number of reservoirs used.

The above example represents a minimum cost: larger schemes involve up to 5 km of pipeline, seven 4 400 litre ferro-cement water tanks and ten standpipes. The cost of such a scheme is in the region of R10 000, of which about R2 600 would be contributed by the community (TATU Progress Report; 1986 p18). The household financial contribution to TATU administered spring protection schemes varies according to the number of persons who are actually able to make a financial contribution at all, and the length of pipeline required. Usually the donations vary from R3 per person up to a maximum of about R12. The number of people served by each scheme is typically between 80 and 200. As already stated, TATU require that the money is collected and the labour input organised before the project is commenced.

3.1.2 Groundwater Sources

Many areas in South Africa do not have surface or spring water sources that are suitable for protection or development as described above. This may be due to unsuitable topography or, often, to an insufficient annual rainfall. In other cases the surface water potential may be reduced as a result of land mismanagement, overcrowding or overgrazing (Muller; 1984 p19).

In such a case one solution is to utilise water from underground sources. These consist essentially of water that has infiltrated the underlying strata. The depth at which water may be found varies considerably, from 2 or 3 metres up to 120 metres or deeper, depending on the nature and porosity of the rocks and soil.

Several methods are available for extracting water from below ground sources, but each requires that some form of tube or well be constructed to reach the source. In general there are five main methods of constructing wells to extract groundwater. They are: driven tube wells, bored tube wells, jetted tube wells, hand dug wells and boreholes.

Driven tube wells

In areas where ground conditions are suitable, this is the easiest type of well to install. It is constructed by pushing a special point, called a 'well point', into the ground. The well point is usually a 30 to 50 mm diameter cylindrical tube with a point at the lower end and holes or slits in the sides through which water can filter. They are made usually of brass or steel, but both materials have a limited useful lifetime.

The well point is driven into the ground by twisting it, or hitting the top with a heavy object, or sometimes by forcing water down the pipe. As it is driven down further lengths of steel pipe are attached to the top.

When choosing a well point care should be taken to ensure that the pump cylinder to be used within the tube will fit inside, as most cylinders have a diameter of at least 50 mm.

Driven tube wells can generally not be sunk more than 10 to 15 metres, and cannot penetrate heavy clay soils or rock. An advantage of a driven tube well is that it can be removed and re-used if insufficient water is found or if a temporary water supply is required.

Bored tube wells

This is another simple type of tube well, which can be constructed by hand using simple tools and materials. The first section of the hole is usually made with a hand auger which is used to remove soil and stones. Once water is reached, and the soil becomes too loose to lift with an auger, a spiral or fan auger may be used. As the hole deepens it is cased with steel or PVC tubing. Once it is completed a narrower tube is inserted and the original casing removed.

Bored tube wells can be sunk to a depth of about 25 metres in a couple of days. The process is relatively simple, but labour intensive, and as such is suitable for rural communities with technical supervision.

Jetted Tube Wells

This method can be used to sink wells up to 80 metres deep. It involves pumping water down a hole to loosen soil and thus allow a pipe to be forced into the hole.

The simplest method of jetting is known as the 'sludger' method and does not require a pump. Initially, a one metre deep hole is drilled by hand, filled with water and a sharpened piece of steel pipe inserted. A scaffolding is built next to the hole and a lever fixed to it with one end attached to the steel pipe. An operator standing on the scaffold lifts and drops the pipe using the lever. At the same time he places one hand over the pipe and uses it as a valve. As the pipe rises his hand is held firmly over the end, until he lets go as the pipe begins to fall. The up and down process is repeated, lifting water up the pipe which brings soil with it. As soil is removed from the bottom of the hole, the pipe sinks further and further lengths of steel are added at the top. Throughout the process the hole is kept filled with water.

This method of jetting is suitable only for fine loose soils, such as sand or silt, and only to a depth of about 10 metres. Other jetting methods are used, but they all require special pumping equipment.

Hand Dug Wells

If a tube well is not suitable or satisfactory it is possible to dig a well by hand. This is often the case where water has been found to be present, but only seeps slowly into a tube well.

In effect, a hand dug well is simply a wide tube well that allows water to seep in more quickly due to its greater below ground surface area. A further advantage of hand dug wells is that they have a greater storage capacity.

Unfortunately, digging a well by hand is a difficult process, and as Cairncross and Feachem (1978, p17) state "can be a dangerous business for the workmen". Some technical supervision is usually regarded as necessary for wells over 5 metres deep. Indeed, in areas where there is no previous experience of hand-dug wells it is usually recommended that some other form of well or tube be used instead.

Digging a well by hand requires a great deal of effort; usually about 5 man days per metre of depth. The risk of pollution of had dug wells is also greater, for they are exposed to contamination from surface run-off, sillage and discarded rubbish as well as the common risks of groundwater contamination and seepage due to incorrect siting.

Boreholes

This is the most expensive form of groundwater access, as a specialised drilling rig is required. These are usually hired from private contractors or supplied by the Government. A further cost may be incurred in gaining access to remote rural areas.

There are two types of borehole drilling rigs: percussion rigs, which work by repeatedly dropping a heavy weight down the hole, and rotary rigs, which drill by rotating a sharp bit. The latter are much faster and can drill through harder rock.

Boreholes can be drilled to great depths, often in excess of 100 metres, but even they are not guaranteed to find water. In general it is advisable to investigate the groundwater potential of an area before hiring a drilling rig. This may be done either by employing a hydrogeologist, or by looking at other wells or boreholes in the area, or even by using a water diviner.

In South Africa it is estimated that during the recent years of severe drought a total of some 100 000 boreholes have been drilled annually, at an estimated cost to the hirers of over R100 000 000 (Borehole Water Journal; April 1986 p4).

In Transkei approximately 1 300 boreholes have been drilled for use in supplying village domestic water. Similarly, in KwaZulu between 200 and 250 are drilled annually for village water supply schemes. The average cost of Transkei's boreholes, which are accepted to a depth of 120 metres, is between R4 000 and R5 000 (Shaker; 1986 Pers Comm). However, it must be noted that the Transkei Government owns its own borehole drilling rig, which was donated by World Vision.

3.2 Water Lifting Technologies

It is at the level of groundwater extraction for rural water supply development that the use of appropriate technologies for water lifting becomes important. A reliable pump connected to a reservoir tank can dramatically ease the burden of water collection, reduce the effects of dry periods or drought and even be extended for reticulated water supplies to houses or field irrigation systems.

The assessment of individual water lifting technologies requires a holistic approach to the technical, economic and social condiderations described in Chapter 1. In this Section, the technical and social aspects of each water lifting technology are reviewed, using reliable field data wherever possible. The technologies are compared financially, using a Nett Present Value method, in Section 3.3.

The pumps have been grouped according their energy source. For each energy source, the power potential and principles of operation of various types of pump available are described, together with the pumping capacity and capital costs. The two most commonly used water lifting devices, handpumps and wind pumps, are discussed first, followed by the less frequently used technologies: diesel, biogas, animal and solar powered pumps, and hydraulic ram pumps.

3.2.1 Hand Pumps

Handpumps are utilised for village water supplies throughout Africa, Asia and the Near East. Feachem et al (1978 p37), in their extensive study of rural water problems in Lesotho found that, in villages where pumping is unavoidable, handpumps offered the best solution for three reasons. First, handpumps have few moving parts and so are easier to maintain than, say, windpumps or diesel pumps. Second, handpumps use the free, renewable energy source of human power, and third, if several are installed in a village, then one can break down without jeopardising the entire village water supply.

Table 3.1 shows the typical adult power output for effort over different periods of time using different muscle groups. Given the human power available, the amount of water lifted then depends on the pump efficiency. This can range from 25% for a traditional form of pump, to 60% for a modern design.

Table 3.1 Typical Adult Power Output.

Muscle group(s) involved	Sustained effort (up to 6/7 hrs)	10 to 15 minutes	Few minutes
Mainly arms and shoulders:	30W	50W	70W
All body:	40 to 50 W	70W	100W
Pedalling:	75W	180W	300W

Source: Kennedy and Roberts; 1985 p3.

Handpumps were found to be widely adopted by water supply planners in Southern Africa. For example, between 200 and 250 handpumps are installed yearly by the KwaZulu Department of Agriculture and Forestry, and a further 100 to 150 by the KwaZulu Water Development Fund. The Transkei Department of Agriculture and Forestry installs about 50 handpumps per year (Shaker; 1986 Pers Comm). Before looking at the types of handpumps that are most commonly used in Southern Africa, it is relevant to discuss the design factors which influence the success or failure of a handpump water supply:

* Engineering and Design. These should preferably be as simple as possible, using standardised parts and materials.

* Servicing and maintenance. Although village installations are usually maintained by regional service teams, a pump requiring simple skills can increase the amount of village level maintenance, thus saving transport and manpower costs and increasing the level of village responsibility for the pump. The present practice in Transkei and KwaZulu is to use centrally administered maintenance teams.

* Reliability may be increased by reducing the number of moving parts and using materials resistant to wear.

* Performance. The output from the pump must be such that the operators- women and children- can fulfill their water needs. This implies both a high volumetric and mechanical efficiency, as well as sufficient borehole yield. The performance should decrease as little as possible with worn parts.

* Strength and durability. The pump should not be susceptible to pilferage (usually of exposed nuts and bolts) or damage through negligence or malicious actions.

* Corrosion resistance. The lifetime of many pump components (especially borehole cylinders, casings, rods, washers, valves and seals) is determined by the "aggressive" nature of the water (i.e. water content of corrosive compounds or sand particles). A choice of materials resistant to these water properties will increase the lifetime of the unit and reduce the below-ground maintenance requirements.

The design of a handpump for use in a village environment should incorporate as many of the above attributes as possible. Unfortunately, materials that are strong and corrosion resistant tend to be more expensive, so a handpump manufacturer is forced to find a compromise design, trading-off the benefits of expensive materials against the cost of the finished product.

In Southern Africa the handpumps most commonly used can be divided into two categories: piston-cylinder pumps and rotary positive displacement pumps.

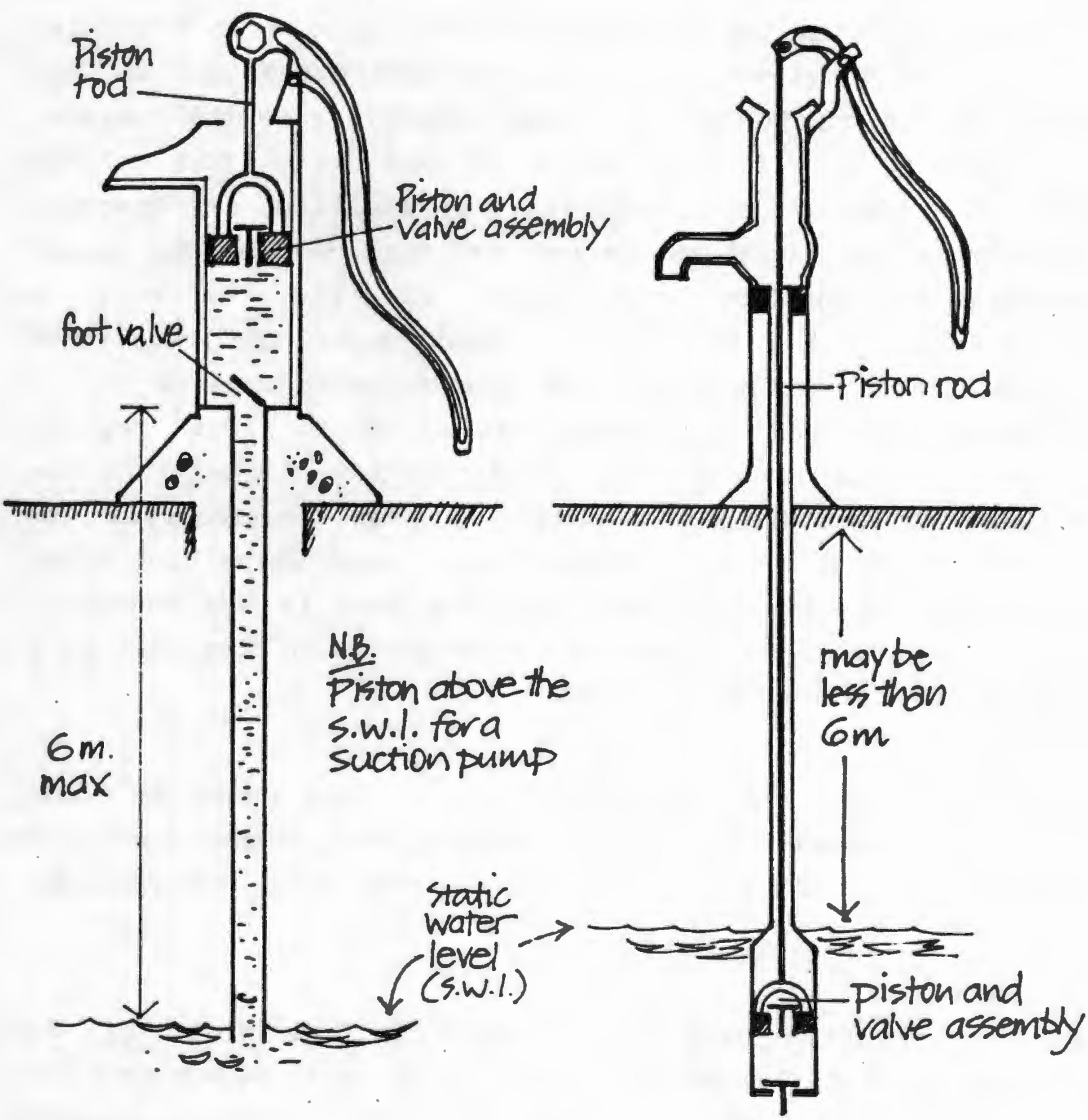
3.2.1.1 Piston-cylinder Handpumps

Within this category two distinct types can be identified, characterised by the position of the piston with respect to the water level. The principles of operation are common to each type. Essentially, piston-cylinder pumps consist of a long handle moving in a vertical plane, which moves a vertical rod connected to a piston with a flap valve and a foot valve. In a suction pump the piston is situated above the water level so that water is 'sucked' up the borehole by a vacuum effect. The limit of lift for a suction pump is about 6 metres, determined by the effectiveness of the seals in a vacuum. In a 'lift' type piston cylinder pump the cylinder is situated below the water level. Here an upward movement of the piston rod lifts the piston, creating a

Figure 3.2

Typical Suction and Lift Piston-Cylinder Handpumps

Source: Kennedy & Rogers; 1985 p31.



partial vacuum and allowing water to flow in through the foot valve.

Typical suction and lift pumps are shown schematically in Figure 3.2.

Lift pumps (usually referred to as reciprocating pumps due to the motion of the piston rod) can operate in boreholes deeper than 6 metres. However, the effort required to lift water may be considerable in deep boreholes, as the operator is required to lift the weight of the piston rod and the mass of water in the rising main. In addition, the operator must pump for a given period of time before any water reaches the surface. The effort required for this is determined by the mechanical advantage of the lever-type handle. For shallow pumps a mechanical advantage of 4:1 is adequate, whereas for deep wells up to 10:1 may be necessary. Unfortunately a longer handle can restrict the stature or posture of the user. Near Hammanskraal the author observed a Nimric reciprocating pump whose handle had been considerably extended. In this case it was necessary for the operator to climb onto a boulder and literally hang on the lever to bring it down.

There are three main manufacturers of lift pumps in South Africa: National, Nimric and Climax. The output and load tables of pumps produced by each are shown in Appendix 6.4.1.

Nimric handpumps have been tested in the field by the KwaZulu Water Development Fund and the Department of Agriculture and Forestry, along with others models produced by National and Mono. As will be seen in Chapter 4, the preferred model by both organisations is now the Mono Direct Drive handpump, which is discussed fully in Section 3.2.1.2.

It was found that the reciprocating type pumps suffered from pilferage and the generally turbid water caused leather seals and washers to wear quickly. It was also found that the design of the handles on these pumps allowed children to swing on them, causing considerable damage. Nimric has since begun to spot weld the bolts and other fittings on their handpumps, which are now under test by the Department of Agriculture and Forestry.

Climax manufacture two distinct types of reciprocating handpumps- a lever type handpump, similar in appearance to that produced by Nimric, and a wheel type handpump, called the Climax No 104. The 104 is available in single or double wheel models. The moving parts run in self aligning sealed-for-life bearings, although grease nipples are provided. The body barrel is of medium quality SABS tube with a crankcase of high quality cast iron. It is claimed that this handpump can operate for 12 to 15 years if it is properly handled.

A similar reliability is claimed for the Climax Lever type handpump, although it has only been on the market for three years. At the time the Climax manufacturing works were visited it was reported by Mr Paddy Cavanagh, the Managing Director, that they had yet to sell a spare part for the Lever handpump. It was also reported that a total of 600 handpumps were sold in 1985, with a large proportion to Bophutatswana and Zululand.

The most common causes of failure of reciprocating handpumps are breakages above ground level of the handle through wear or misuse, or failure below ground level of leather piston seals or the foot valve seal. Repairs of above ground components are much simpler than those below ground. Changing failed leather washers in the cylinder requires lifting the pump rod, rising main and cylinder to the surface using a block and tackle or crane. The usual procedure is to lift a complete section of the rising main clear of the well, clamp the next section below it and lower the whole assembly so that it hangs on the clamp. The top section, which is usually six metres long, then stands clear of the borehole and can be unscrewed. This is a long and expensive process requiring experienced labour.

In order to reduce the difficulty of repairing the pump cylinder it is common to install a piston with a diameter slightly smaller than the rising main. This allows the piston to be pulled up through the rising main by lifting the pump rods only. Alternatively, cylinders have been designed that allow the footvalve to be removed without lifting the cylinder to the surface. Figure 3.3 shows a borehole cylinder of this kind. In this example the loop on top of the footvalve can be caught from the surface and used to pull it out. On other types the pump rod is disconnected from the drive at the surface, allowing the piston to be lowered on to the footvalve, which has a threaded spigot on top of it which screws on to the piston when the rods are twisted. In this way both the footvalve and piston can be drawn up to the surface together. Since failure of leather seals in the piston or the footvalve are common causes of pump failure, such a system can greatly reduce the difficulty of maintenance.

An example of a suction pump used and designed in Southern Africa is the Blair pump. This was designed by the Blair Research Laboratory in Zimbabwe to be a locally manufactured product requiring minimum maintenance. The Blair pump differs from the standard format of a piston-cylinder pump as two of the most troublesome components - a lever-type handle and water-tight seals - have been eliminated. The result is that the pump looks like a walking stick with a

Figure 3.3

Borehole Cylinder with Extractable Footvalve.

Source: Fraenkel; 1986 p28.

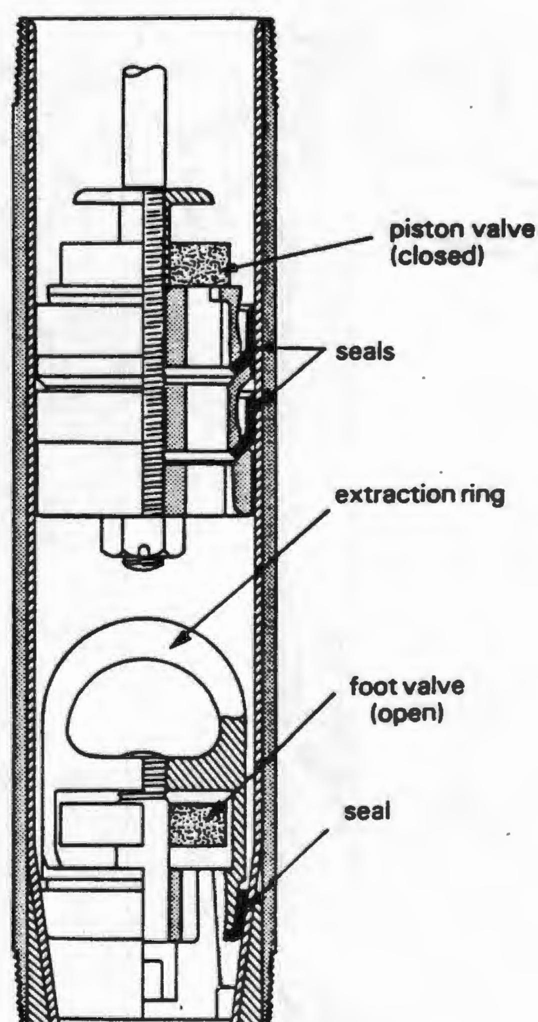
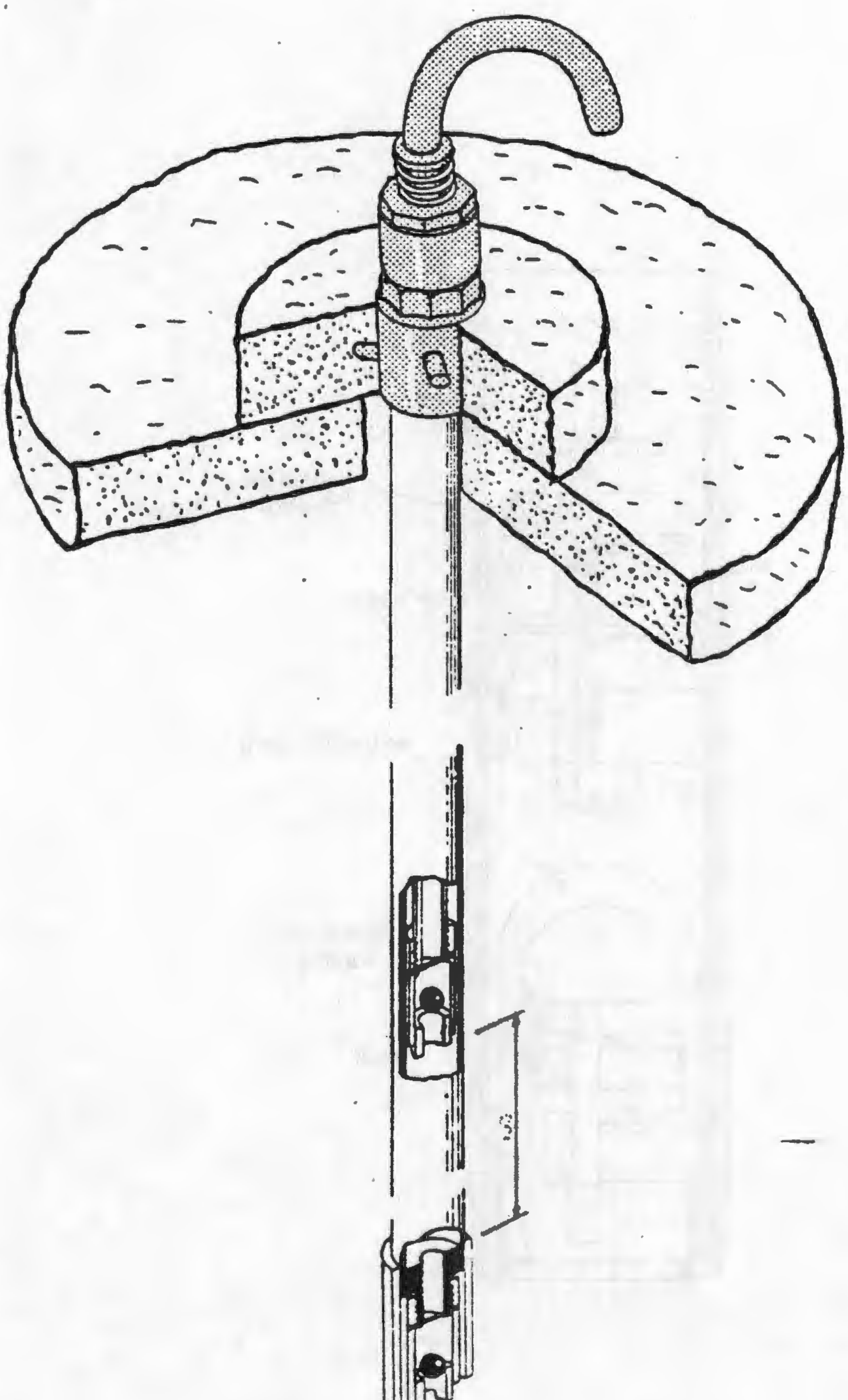


Figure 3.4

The Blair Handpump.

Source: Prodorite (Pvt) Ltd, Zimbabwe.



curved handle. The pump is operated by grasping the handle and moving it up and down (the handle doubles as a spout), see Figure 3.4. Below ground (but adjacent to the pump head as described) is a stationary cylinder with a piston attached to a pushrod fixed to the galvanised iron handle.

This has the advantage of protecting as many moving parts as possible from the elements and the effects of misuse or abuse.

Blair pumps are now mass produced in Zimbabwe by Prodorite (Pvt) Ltd. Kennedy & Rogers (1985, p35) report that a test rig was set up at the factory and used continually for three months (equivalent to six million strokes). After this the working parts were claimed to show no detectable wear. Other tests were conducted using water to which soil had been added . In this case minimum wear was detected after 5.5 million strokes. Unfortunately no results of field trials are available at the present time.

The National Building Research Institute is planning to test the Blair pump, along with other pump designs, in the manner of the Consumer Association tests which have taken place in Britain.

Reciprocating piston-cylinder pumps are generally inexpensive in South Africa. For example, a Nimric handpump costs R160 for the above ground hardware, plus about R110 for the pump cylinder. In addition are costs of borehole casing (about R55 per 3.66 metre lengths of 150 mm diameter), rising main (R12 per metre of 50 mm diameter pipe) and the pump rod. Hence a complete installation in a 30 metre deep borehole would cost approximately R630, excluding drilling and casing the borehole. The latter costs cannot be ignored, as they may be from R2000 to R4000, depending on the site, geology and accessibility .

Typical cost and output figures for the Climax and Nimric handpumps, as well as the Mono Direct Drive handpump, are shown in Table 3.2, at the end of Section 3.2.4.2.

3.2.1.2 Rotary Positive Displacement Handpumps

In Southern Africa one company name has become synonymous with rotary action, positive displacement pumps - Mono.

Mono handpumps have been used extensively in recent years in Lesotho, Zambia, Botswana and all of South Africa's "Homelands". The pumps are manufactured in South Africa by Mono Pumps (Africa) Pty Ltd., whose approach to pump design for use in underdeveloped areas is towards a "no maintenance" concept. This has resulted in a strong design with a minimum number of moving parts- the Mono Direct Drive.

The below ground pump unit consists of a helical rotor element, which works on the archimedes screw principle, inside a moulded rubber-polymer stator. The rotor is driven by a vertical drive shaft situated inside the rising main column, which is fixed directly to the handle. The operator turns the handle in a horizontal plane, rotating the shaft and rotor such that water is lifted with every turn of the handle. A footvalve is fitted below the rotor, so that the water does not fall back when the pump is not in use. In this system every rotation of the handle produces water from the spout. A schematic cross section illustrating the Archimedian screw principle of the Mono pump is shown in Figure 3.5

Mr Stan Payne, the Research and Development Director of Mono Pumps (Africa) Pty Ltd, has documented the development and refinement of the Mono handpump since their first hand operated borehole pump was produced nearly twenty tears ago (Payne; 1986 p7). The first design utilised the positive displacement helical rotary principle in conjunction with a speed increasing right angled drive discharge head, incorporating a 3:1 greased bevel gear and pinion ratio. However, the capital cost of this design was high and it required skilled maintenance staff.

The design went through various modifications and an oil filled gearbox was added. A disadvantage of this design was that the oil seals and bushes tended to wear, allowing the lubricant to leak out, which gave the water an unpleasant flavour until the gearbox ran dry.

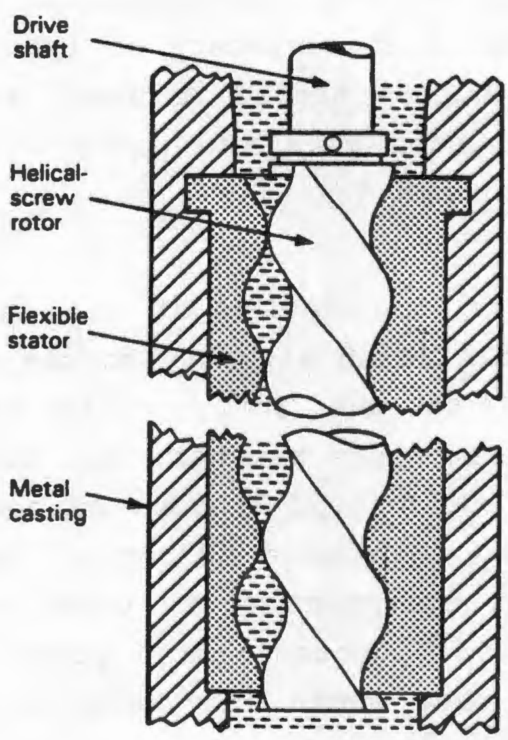
This problem resulted in the design of the Direct Drive head, which has the handle fixed directly to the pump shaft, giving a direct drive to the rotor. This head, which incorporates a pin and ramp type ratchet, was tested by the Consumer Association of the United Kingdom on behalf of the World Bank. It was found to meet a number of the criteria considered essential for equipment to be used in the Third World: it was tamper proof, contamination proof, safe, and socially acceptable in that women and children could draw water without undue difficulty.

Certain design modifications were suggested by the Consumer Association, pertaining to the foot valve, the ratchet and the handle which incorporated expensive ball bearings. These suggestions were taken up and further improvements were made to the head, resulting in the Mono Type 5 Direct Drive handpump. In this model the pin and ramp type ratchet has

Figure 3.5

Schematic Cross Section of a Mono Pump.

Source: Fraenkel; 1986 p41.



been replaced by a "unique" ball and track system (Payne; 1986 p9).

The Direct Drive handpump has been extensively sold in Southern Africa. For example, it is one of two pumps specified for village water supplies in Lesotho, and is presently the most widely adopted throughout the Homeland rural areas of South Africa.

Recently, Mono have turned their attention to the form of the stator itself. A self compensating stator is now used, which allows the torque to be directly proportional to the head developed, such that the starting torque is zero and the running torque increases as the pressure increases.

Mono have also given considerable attention to the materials used in the pump. The rotor is of machine turned brass, which is then chrome plated. Natural rubber is not used in the stator as it tends to absorb water and become distorted. Instead a nitirile elastomer is used, which is phosphotised and bonded to the steel tube housing.

The rotor-stator design is a mechanically simple device, but requires a considerable amount of engineering expertise to manufacture. The end result is a pump which has eliminated many, if not all, of the troublesome components of piston-cylinder pumps. There are no pins, no bushes, no leather seals, no gearbox and the very minimum of moving parts.

In the field, however, there is no guarantee that a Mono pump will supply water. In June 1986 the author visited four villages which had Mono pump installations, accompanied by extension officers of the KwaZulu Department of Agriculture and Forestry. These villages contained a total of 24 Mono pumps. Of these, 15 were found to be working adequately, 7 were working but with serious problems, and 2 not working at all. Of the 7 working inadequately, two produced dirty or discoloured water, three operated with a minimal output and heavy action, one suffered from inadequate borehole yield and one had a faulty foot valve. Of the two not working, one had a 'lost' handle and one a suspected broken shaft. Hence half of the 'failures' can be traced to mechanical faults and half to inadequate boreholes. The results of the village case studies are presented in Chapter 4.

Conversely, some pumps were found to have operated successfully for up to four years, being used by as many as 60 families, without a breakdown. Conversation with field officers, extension officers and community representatives showed the average lifetime to be 2 years before a breakdown.

The fine engineering and high quality materials used in Mono pumps makes them more expensive than piston-cylinder pumps. The above ground pump unit costs about R270, and the 'cylinder' about R325. Rising main and shaft costs about R45 per 3 metre length. Hence a complete installation for use in a 30 metre borehole costs about R1045. This can be compared to the Nimric piston-cylinder handpump which would cost about R630. The output from each pump varies considerably also: In a 30 metre borehole the Nimric pump will produce 1635 litres/hour (at 30 strokes/minute). The Mono pump over this head would produce about 540 l/hr (both figures are from manufacturers data). At higher depths the Mono output, however, does not decrease as rapidly as a piston cylinder pump, and the effort required does not increase as markedly either.

The Mono handpump represents the application of high technology and engineering to produce a simple, maintenance free pump. Its successful use in the field, however, is still subject to external factors, such as correct borehole depth and yield, correct installation and siting and, to a lesser extent, correct application and use by the community.

<u>Table 3.2 Comparison of Mono, Nimric and Climax Handpumps.</u>

Source: Manufafacturer's Data

	Mono Direct Drive	Climax Lever	Climax "104"	Nimric Lever
Pump type	Rotary, positive displacement	Reciprocating	Reciprocating (wheel handle)	Reciprocating
Unit cost (above ground)	R270	R165	R700	R160
Cost: 30 metre installation (*)	R1045	R585	R1134	R580
Output	540 l/hr	840 l/hr (@ 30 strokes per minute)	540 l/hr (@ 20 revs. per minute)	1635 l/hr (@ 30 strokes per minute)
Cost: 60 metre installation	R1575	R951	R1486	R946
Output	360 l/hr	522 l/hr (@ 30 strokes per minute)	204 l/hr (@ 20 revs. per minute)	740 l/hr (@ 30 strokes per minute)

*: cost excludes borehole and casing.

3.2.2 Foot Pumps

The human power potential has already been discussed in Section 3.2.1. In that case the prime mover was the arms and shoulders of the pump operator. Recently, however, pumps have been designed, and are now commercially manufactured in South Africa, which utilise the power of the lower part of the body- pedal power.

Rod, Marcus & Kitsoff (1983 p1) have reported the development of a foot powered pedal pump by the Development Committee of the S A Red Cross Society in conjunction with the Faculty of Engineering of the University of the Witwatersrand.

The KwaZulu Water Project, for which the foot pump was designed, was sited near a village in the Enseleni District of KwaZulu. The objectives of the project were to set up an irrigation scheme for communal gardens and to provide a supply of drinking water for the community. A further objective was the transportability of the technical solutions produced. The project was seen as a pilot scheme and the methods of irrigation and purification used had to be applicable to similar situations in Africa. This objective was achieved and, as will be discussed later, the pedal powered pump is now in commercial production.

The area in KwaZulu under consideration was found to have a limited perennial source of water with restricted accessibility. Leg power was chosen to lift water as it was regarded as the most efficient form of human power available. A bicycle type design was considered, but rejected after field trials as the design was not suitable for extensive operation under adverse conditions, the seat was too small for the average farmer and the parts were found to be subject to an excessive amount of pilferage.

It was decided, instead, to abandon the bicycle arrangement and design a purpose built pedal pump. The design was based on guidelines of the ergonomics of lengthy pedalling sessions, robustness, ease of manufacture, use of standard materials and ease of installation. The final design, shown in Figure 3.6, incorporated a bench rather than a saddle, allowing women, men and children to use the pump without any adjustment to the seat.

The pedal unit consists of a triangular framework constructed of 40 mm square tubing, facilitating a high strength to weight ratio and rigidity. The pump is driven by a standard crank and axle arrangement. The primary sprocket drives a transfer shaft by means of a non-standard length of chain. The drive ratio can then be changed by changing the sprockets, which are standard bicycle types. Various drive ratios were tested and a ratio of 1:3.8 was found to be the most satisfactory.

The pedal pump drives an adapted version of the Mono Direct Drive handpump. At the time the report was written, the pump had been in use for over a year. Two adjustments had been made to the design whilst in use: a system to prevent removal (theft) of the chain had been fitted and the transfer shaft had been omitted.

This form of the pump, but with a standard bicycle seat, is now manufactured by Mono Pumps (Africa) Pty Ltd. The retail cost of a complete unit is R1350 (September, 1986), of which R580 is for the pump section and the remainder for the pedal section. Mono Pumps have stated that they are prepared to make the design drawings available to any persons interested in fabricating the pedal section.

The output of the pedal pump as reported by Rod, Marcus & Kitshoff is shown in Figure 3.7. The pedal pump and performance curves produced by Mono are shown in Appendix 6.4.2.

Figure 3.6

Design of the Mono Pedal Pump.

Source: Rod, Marcus & Kitshoff; 1983.

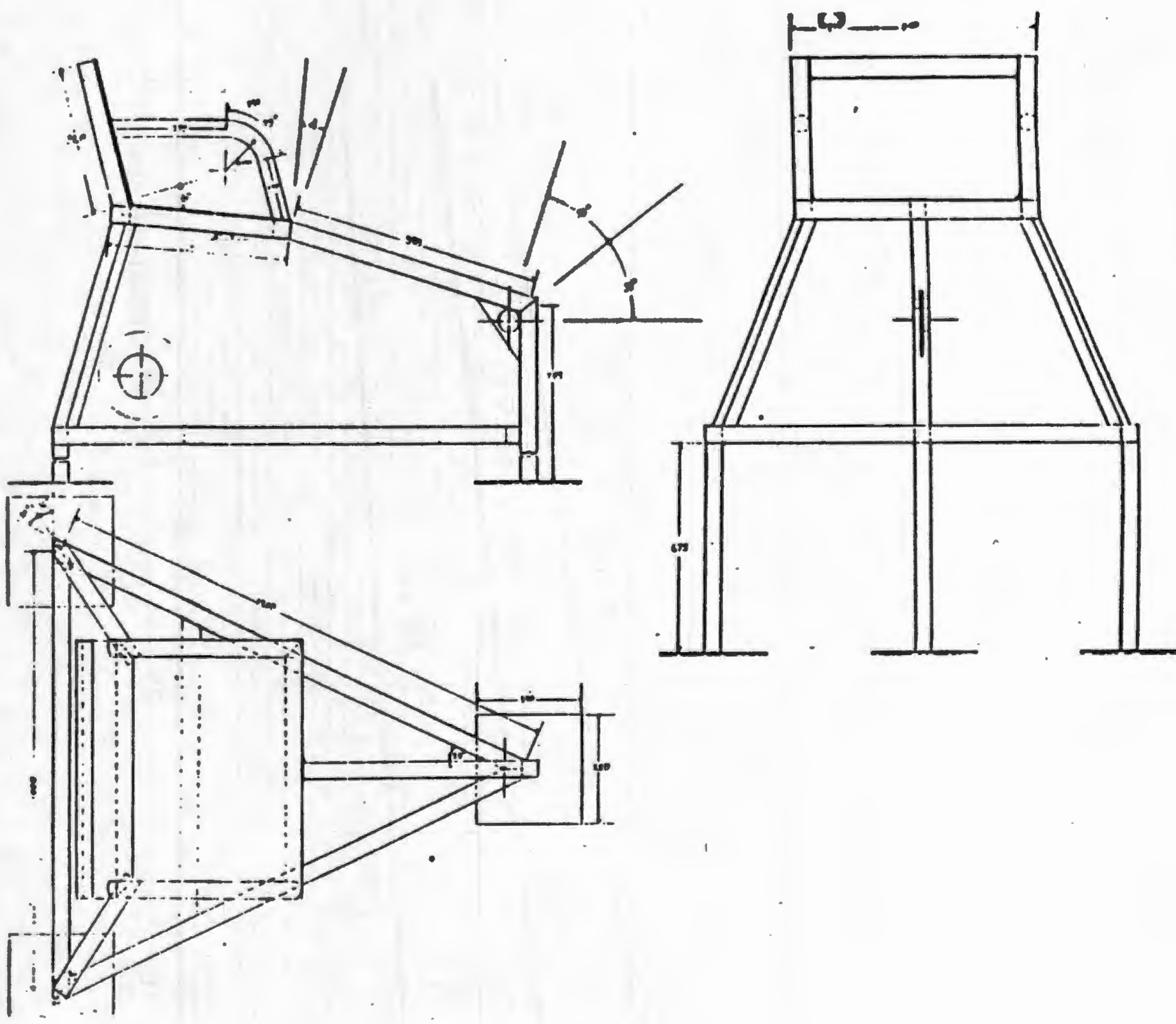
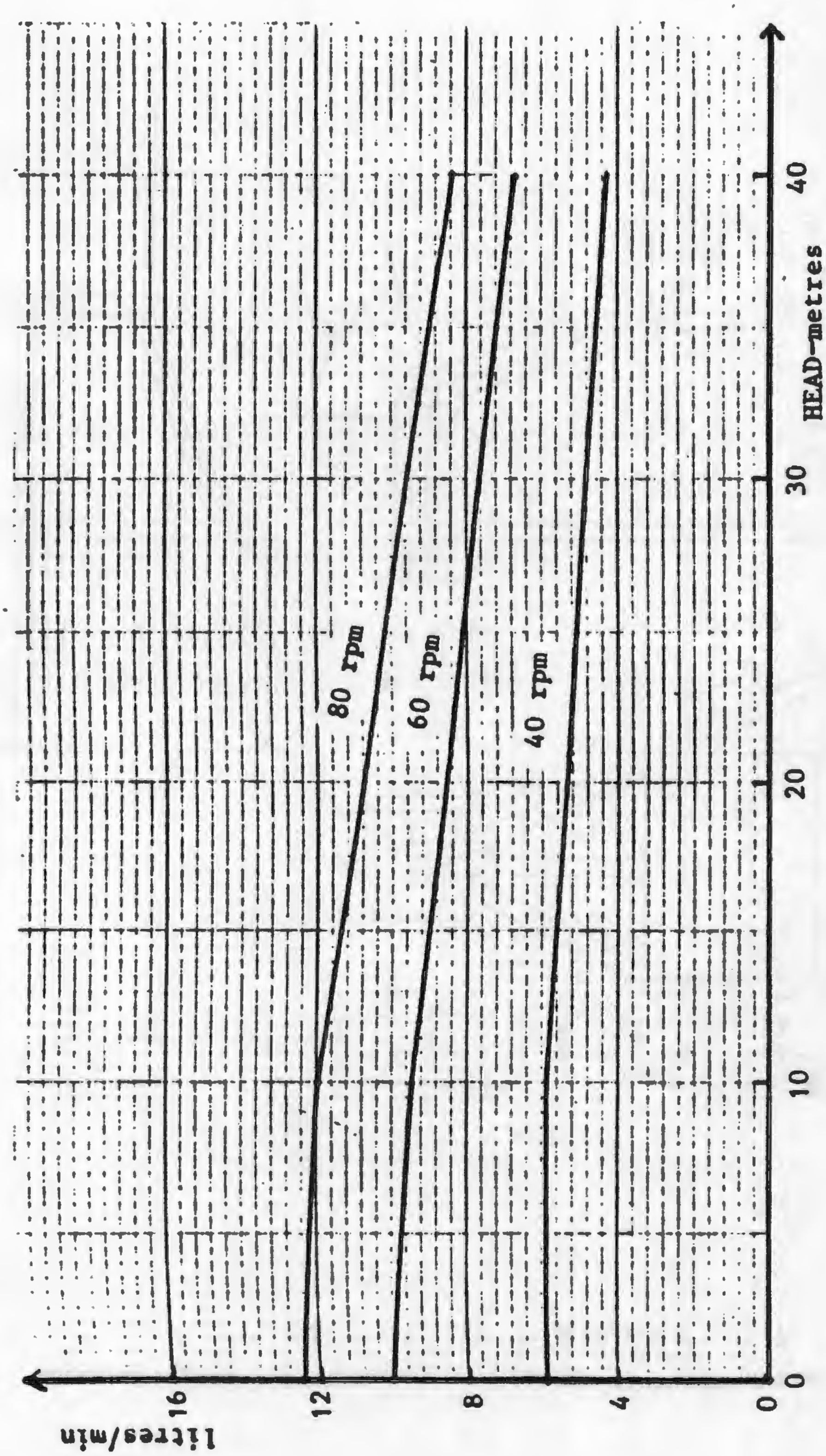


Figure 3.7

Measured Footpump Performance.

Source: Rod, Marcus & Kitshoff; 1983.



3.2.3 Windpumps

The harnessing of wind energy has an extremely long history, with many previous civilisations realising the potential of the free energy source. Today wind energy is converted to useful energy in two ways. Firstly, the wind may be used to drive a turbine to generate electricity. Secondly, the wind may be used to drive a pump or other device utilising mechanical energy. The use of wind powered water lifting systems is widespread in Southern Africa, both in the developed and underdeveloped agricultural sectors. The Government of Transkei alone has purchased over 1000 windmills in recent years for use in supplying the domestic water requirements of its villages.

A wind powered water lifting system can be reduced to five functional components, each of which must be chosen and sized correctly to match the other components and the prevalent wind regime. The components are :

* the rotor, which converts the wind's kinetic energy to rotational energy on a horizontal axis.

* the transmission, which converts the rotational motion of the rotor to a reciprocating movement.

* the storm control device, for furling the windmill in high winds to prevent damage.

* the pump unit, usually a piston-cylinder, which converts the mechanical energy of the transmission to hydraulic energy.

* the reservoir, in which is stored the water output before use or distribution.

In order that each of these components functions adequately it is necessary to have a certain amount of information about the site at which the windpump is located.

Firstly, knowledge of the site's wind regime is required. It is necessary to know the average wind speed, the speed distribution over time, the longest calm period that can be expected, and the highest speed. Unfortunately, wind data are not readily available in developing countries. Secondly, it is necessary to know the borehole yield and total head over which water is to be lifted (i.e. pump cylinder to reservoir inlet). Thirdly, it is necessary to know the required water output.

Using the wind data, the windmill characteristics and the pump characteristics, it is then possible to match rotor, pump and wind regime such that each is used to its full potential.

In Botswana, the Rural Industries Innovation Centre (RIIC) designed and developed a wind pump to suit Botswana's wind regime, the widely used Mono pump and a Government requirement of a minimum pumping rate of 7.5 m^3/day from a 100 metre head. Due to their collaboration with the Intermediate Technology Development Group (ITDG) they were able to use the 'Kijito' chassis, which had already been developed in Kenya. This was converted to rotary drive, and from available data RIIC calculated the optimum rotor speed at the minimum wind speed and the necessary step up ratio from rotor to pump. That step up ratio indicated the use of a low solidity rotor, moving faster in low wind speeds, with the advantages of low weight, torque and cost. The step up ratio was also used to calculate a furling speed which corresponded to the pump's maximum speed. In addition, RIIC designed a device to keep the rotor turning at low windspeeds and so overcome start-up torque problems (Ewens; 1985 p41).

The RIIC windmill shows that, given the constraints of low wind speeds, deep boreholes and limited technological resources, it is possible for a developing country to initiate, design and manufacture a well-adapted, indigenous technology.

The greatest problems associated with the application of windpumps in underdeveloped rural areas are of reliability and maintenance. If a breakage or failure occurs in any one of the five functional components the system will cease to provide water. Discussions with windmill servicing co-ordinators, agricultural extension officers and windmill manufacturers in South Africa revealed the three most common causes of windmill breakdowns to be, inter alia: i) rotor failure in high winds, ii) transmission system failure at windmill head, and iii) piston-cylinder failure, often due to being pumped dry.

The three largest windmill manufacturers in South Africa, Climax (including Stewarts and Lloyds), Nimric and Southern Cross, have each adopted a combination of reefing, braking and transmission systems which they believe to be the most reliable and cost effective.

Table 3.3 below shows the different systems utilised by each of the three manufacturers for a 12 foot diameter windmill. The prices refer to the cost of windmill head with a 9 metre tower.

Table 3.3: Some Characteristics of Windmills Available in South Africa

	Climax	Nimric	Southern Cross
Reefing speed km/hr	30-50 adjustable	25 adjustable	32 non-adjustable gravity system
Brake	by wind only	by wind only	geared winch and cable to reefing chains
Transmission	gearbox in oil bath	rubber coupling between shaft and pump rods	gearbox
Price (Head and 9 metre tower)	R3325	R2123	R3325

Source : Manufacturer's Data. (Manufacturers output figures and other technical specifications of these and other windmills available in South Africa are given in Appendix 6.2.3).

Probably the single largest manufacturer of windmills in South Africa is Climax, which is part of the Stewarts & Lloyds trading group. Climax are reported to sell apptoximately 1250 windmills per annum, about 5% of which go to the Homelands for water supply (Cavanagh; 1986 Pers Comm). As part of the their windmill services, Climax conduct product seminars aimed at improving servicing and maintenance by purchasers. These are conducted through their network of distributers in conjunction with Stewart & Lloyds on a direct dealing basis. The seminars are often conducted on site, and cover windmill erection, servicing requirements, maintenance and 'trouble shooting'.

Climax windmills are manufactured at their extensive engineering works in Vereeniging. The head and gearbox are made in their own foundry, and all steel parts are hot-dipped galvanised to SA specifications. The windmill sails, pump rods, and pump casings are manufactured of galvanised mild steel, and brass cylinders are usually used.

From the above table of windmills manufactured in South Africa it can be seen that Nimric are substantially cheaper than Climax or Southern Cross. Nimric windmills are of the reciprocating type, similar to the others on the market except that the design incorporates a flexible rubber coupling in place of a gearbox. The coupling converts the rotary action of the rotor shaft to the required reciprocating action of the pump rods. It was estimated by Mr Jim Kennedy of Nimric that the rubber coupling could withstand seven or eight years of operation before it was in need of replacement. An advantage of the coupling was reported to be the short stroke of the pump rods, which allows the windmill to start in low wind speeds.

Another feature of the Nimric windmill is the provision of two grease cups near the base of the main mast, one of which is for the thrust bearings and the other for the Vestomite shaft. Nimric also supply windmills to the Homelands and, although accurate figures were not available, over 50 units are estimated to have been supplied to Bophutatswana in 1985.

The common causes of piston cylinder failure in wind pumping systems are the same as for piston-cylinder handpumps, such as worn valves, leather washers or seals, but with the added problem that the windmill will pump whenever the wind blows - irrespective of the state of the borehole yield. It is worth noting in this respect that some rotary windmills are now available in South Africa. For example, Climax produce a rotary action windmill utilising the widely available Mono Pump. This is available in 15 or 18 feet diameters, and incorporates a pinion on the vertical axis to produce the rotary motion of the pump shaft. The cost of the Climax Direct Drive windmill with a 9 metre tower is R6553. It was estimated by Mr Paddy Cavanagh, Managing Director of Climax, that 50 rotary windmills were sold in 1985, compared to their total annual sales of approximately 1250 units. The central placement of rotary windmills over the borehole is more critical than for reciprocating windmills.

Rotary windmills are also manufactured in South Africa by Midkaap Engineering of Middelburg. The M&S Rotary Windpump, designed by Mr A L Schoombee of Midkaap, also utilises the rotary action positive displacement Mono Pump. A step up ratio of 5 to 1 is used from the rotor to the pump. An M&S Rotary Windpump of 5.5 metres diameter on a 9 metre tower costs R7911. Although no field data on the use of rotary action windpumps was found, it is expected that they would be more reliable than equivalent reciprocating types, as they do not incorporate any of the leather valves, seals or washers associated with borehole cylinders. The manufacturers output figures of the M&S Rotary Windpump are presented in Appendix 6.4.3.

The widespread use of windpowered water systems in Transkei, whilst obviously ambitious, can serve to illustrate the problems that occur when windmill technology is applied in a

Third World context. The first point that arises is the high capital cost of each scheme, which consists of the windmill and pump, a reservoir (sited at the highest point of the village) and water reticulation network to standpipes, amounting to an average of R120 000 per installation (Shaker; 1986 Pers Comm). Then there are the maintenance costs involved. In 1985, R750 000 was allocated to water supply maintenance services. Of this, R350 000 was spent on spare parts. Of the 1300 windmills installed, comprising 60% Southern Cross and 40% Climax, it was estimated that 800 to 900 were in working order (Shaker; 1986 Pers Comm). The average operational period before the first breakdown was reported to be three months. The main problems encountered by the maintenance services were a lack of experienced maintenance staff, technical difficulty of replacing failed gearboxes, pump washers and seals, and a time delay in obtaining spare parts. In addition, it was found that a considerable time delay existed between the breakdown and a report of the breakdown reaching the relevant Government Department (there is no community involvement in the windmill schemes, in construction, servicing or maintenance).

Windpumps have also been used for village water supplies in Lesotho (Feachem et al; 1978 p32). The practice there was to select a windpump which could pump the maximum yield of the borehole or spring from which it was drawing water, based on the assumption that it would pump for eight hours per day, as quoted by the manufacturer. However, it was found that windpumps chosen and sized in this way were of inadequate capacity. The validity of the assumption of eight hours pumping per day was checked against wind velocity observations made by the Hydrological Survey of Lesotho at a flat exposed lowland site near Maseru. It was found that, for a pump with a cut in speed of about 8 km/hour and reefing speed of 40 km/hour, the average pumping time per day was only about four hours when averaged over a year, and only over eight hours per day for four months of the year.

One conclusion that can be derived from the above is that the application of windmills on a large scale for water supply requires a high degree of infrastructural support and organisation, at village, district and central Government levels and a considerable amount of site evaluation prior to installation. The high quality windmills manufactured in South Africa have long been and continue to be used successfully in the developed agricultural sector, however, infrastsructural and technical problems have limited their success in the underdeveloped sector.

3.2.4 Diesel Pumps

The use of diesel powered internal combustion piston engines to power water lifting devices is widespread throughout the developed agricultural sector of South Africa. The reasons for its popularity are its compact size, high power to weight ratio and instant start up ability. In addition, the technology involved is relatively familiar in modern agriculture and parts and servicing facilities are readily available.

In underdeveloped rural areas, however, the use of diesel powered water lifting systems is subject to several disadvantages, the most common of which are the difficulty of obtaining diesel, its high cost and the problems of making regular cash collections to buy fuel.

Diesel powered compression ignition systems operate by igniting the fuel by a heating effect caused when a volume of air is quickly compressed. Diesel engines are heavy and robust in construction to allow the high pressures needed to cause compression ignition. A compression metering system and injection pump are also required in order to force the right quantity of fuel into the cylinder at the right moment. These components are manufactured to a high precision and so tend to be expensive. They also depend on clean fuel and careful maintenance for reliable operation.

Table 3.4 below shows some of the general attributes of diesel compression ignition systems, in comparison with petrol powered systems. Diesel engines can be sub-divided into two general categories: "low speed" and "high speed". Low speed engines run in the 450 to 1200 rpm range and tend to be heavier and more expensive than high speed engines, which run at 1200 to 2500 rpm. Slower diesel engines also tend to have a longer operational life and are better suited to continuous operation, but have a higher initial cost.

Table 3.4 Comparison of Diesel Compression and Other Ignition Type Systems.

(Source: Fraenkel; 1986 p85)

	Diesel High Speed	Diesel Low Speed	Petrol	Paraffin
Average Fuel to Shaft Efficiency.	20-35	20-35	10-25	10-25
Weight per kW of Rated Power(kg).	10-40	20-80	3-10	4-12
Running Speed (rpm)	1200-2500	450-1200	2500-3800	2500-3800
Typical Operational Lifetime.	4000-8000 hrs	8000-20000 hrs	2000-4000 hrs	2000-4000 hrs
Typical Power (kW).	2-15	2-15	1-3	1-3

When selecting a diesel engine for use to drive a borehole pump careful consideration of the type and size of engine are needed. Firstly, if it is to run continuously or for long periods then it is necessary to select an engine with a rated power output greater than that actually required. The manufacturer's rated power output is the maximum power output of the engine over short periods. The maximum sustainable output of the engine is usually at a speed about 70 to 80% of its rated speed. By running the engine slightly below its rated power a higher efficiency is achieved as well as avoiding premature wear.

Further 'derating' of the engine is required to compensate for high altitudes or high air temperatures. A further 10% derating is usually recommended by manufacturers for each 1000 metres above sea level, plus another 1% for each $5^{o}C$ air temperature raise above $16^{o}C$ at the air intake. Excessive derating should be avoided, however, as running the engine far below its design output tends to cause coking of the cylinder.

Despite their widespread use and ready availability, there is little reliable data available on the efficiency of diesel powered pumping systems. Figure 3.8 shows the range of efficiencies that typically occur for each component of an engine powered pumping system (Fraenkel; 1986 p88).

The efficiency of a diesel engine 'in the field' does not, in general, conform to the figures of 30 to 40% found in engineering textbooks. In fact, manufacturer's efficiency figures are often based on dynamometer tests conducted with optimally tuned engines operating on a test bed.

It can be seen that fuel spillage can result in up to 10% of the fuel purchased being lost. Spillage can occur when fuel is transferred, in loose joints, and in leaky fuel lines or worn high pressure lines in the engine.

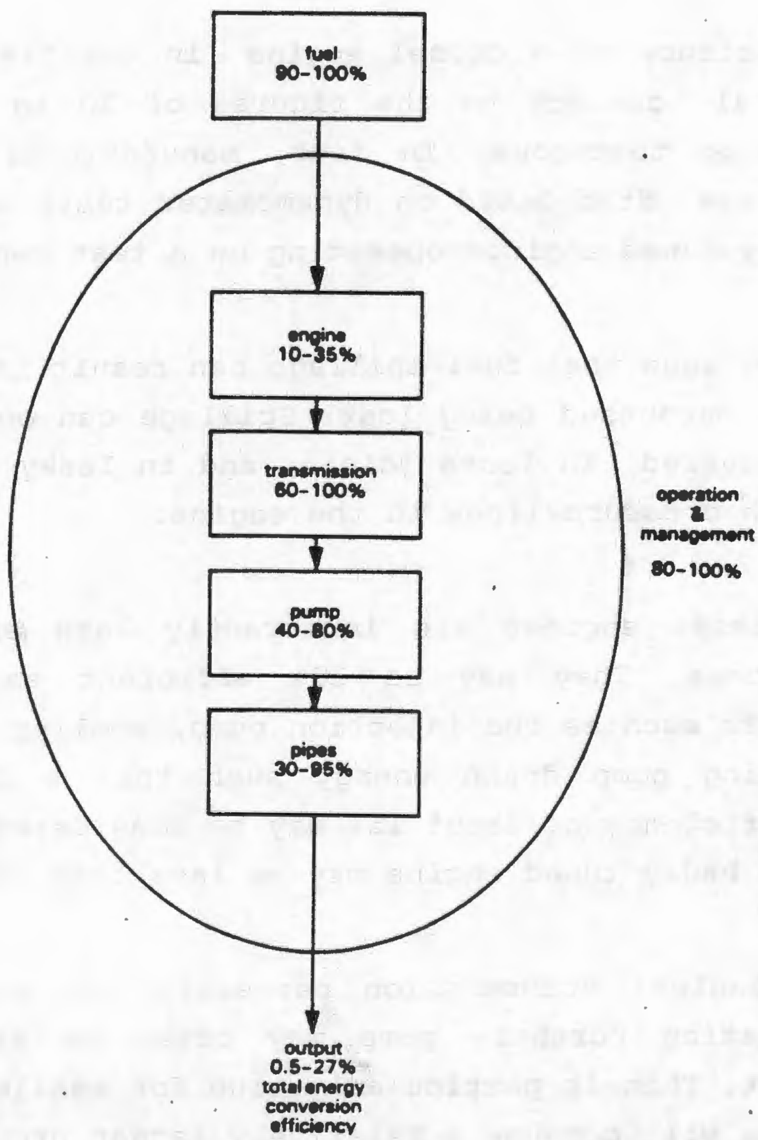
Small diesel engines are inherrantly less efficient than larger ones. They may be 20% efficient as engines but components such as the injection pump, cooling fan and water circulating pump drain energy such that a fuel to shaft power efficiency of about 15% may be considered realistic. A worn and badly tuned engine may be less than 10% efficient.

The mechanical transmission necessary to, say, operate a reciprocating borehole pump may often be as low as 60% efficient. This is particularly true for smaller engines, as a gearbox will consume a relatively larger proportion of its power.

Figure 3.8

Typical Efficiencies of an Engine Powered Pumping System

Source: Fraenkel; 1986 p91.



A good account of the difficulties of operating a diesel powered water supply in rural areas has been given by Feachem *et al* (1978 p30), who investigated extensively the condition of improved water supplies in the Mokhotlong and Mafeteng Districts of Lesotho. A high reliability for gravity fed supplies was found (90% working), but only 40% of pumped water supplies were found to be working. Four diesel installations were found in the Mafeteng District and none in the Mokhotlong District. Only one of these was working, and only one case of a succesful repair to a diesel engine was found. In that case the village had hired an Afrikaner garage owner to repair the engine.

A total of six diesel installations were investigated during the Lesotho study. The most common problems were found to be breakdowns and difficulties of collecting regular cash contributions to buy diesel. Of the six installations, two had their running costs paid from outside the village and one was in an exceptionally wealthy village near Maseru. Of the remainder only one was working, and that intermittently. It was estimated that that village was without water for two weeks every month while collections were made to buy diesel. It was concluded that:

> "... we do not consider diesel pumps appropriate for water supplies to small communities like Lesotho's villages. The only rural communities for which they might be suitable would be those adjacent to missions or other institutions with the financial, technical and manpower resources to take full responsibility for their operation and maintenance." Feachem *et al*; 1978 p32.

A diesel engine, properly installed, serviced and maintained, can provide 10 000 hours or more of trouble free pumping before an overhaul is required. However, there are several pitfalls that can reduce the service life markedly.

Firstly, the engine must be properly mounted on a concrete foundation block. If it is not, then the effects of vibration will damage the engine. Secondly, it is necessary to choose the correct size of engine for the output required. As discussed above, the problems of derating and low efficiencies can make this a difficult task. In some cases the correct size of engine may not be available- for example, if 3 kW are required, then the best available engine may be 5 kW. Underloading or overloading the engine are each equally detrimental, and can cause carbon to deposit on the valves, the cylinder rings to bed in, or the bearings to fail.

Thirdly, a new engine requires servicing after approximately 25 hours of use, such as re-torqueing the cylinder head and adjusting the tappets. Manufacturers usually detail these requirements in a servicing manual, but a sufficiently skilled person may not be available to carry out the service in a rural village.

Recently the price of diesel engines has increased rapidly, mostly due to the fluctuating Rand exchange rate. This has affected even 'locally produced' engines, such as the Lister, since even these are only assembled in South Africe from imported parts. Other recently introduced Japanese engines have grabbed a large share of the market since they are relatively cheap. However, the low cost of these engines is, at least partly, due to the use of cheaper, less corrosoin resistant materials.

3.2.5 Biogas Pumps

Diesel pumping systems are frequently used in developing areas, but, as discussed in Section 3.2.4, the delivery and cost of fuel is problematic. It is possible, however, to substitute for diesel by powering the system with locally produced biogas.

Biogas, which consists of 50 - 65% methane (CH_4), and 35 to 50% carbon dioxide (CO_2), is produced by the anaerobic digestion of organic waste matter. The biochemical reactions involved in anaerobic digestion are complex, utilising different micro-organisms in different stages of the process.

Three distinct types of methanogenic bacteria exist, distinguished by the temperature at which they function. Thermophilic microbial species are active at about 45 to 60 ^{o}C, mesophilic at 30 to 45 ^{o}C and cryophilic at 0 - 30 ^{o}C. Each group of bacteria are very temperature sensitive and a sudden change of as little as 3 ^{o}C can reduce the microbial population.

The digestion process requires the correct input of organic material and water. Ideally, the material used should have a carbon to nitrogen ratio (C/N) of between 25 to 30 to 1 and the water content should represent about 80 to 90% of the total mass. Table 3 shows the nitrogen content and C/N ratios of some commonly available organic materials.

Table 3.5 Nitrogen Content and C/N Ratios of Various Waste Materials (dry mass basis).

Material	N%	C/N
Urine	15-18	0.8
Pig manure	3.8	13
Cow manure	1.7	18
Hay	4.0	12
Lucerne	3.0	20
Wheat Straw	0.3	128
Raw Household Refuse	2.2	25

Source : Williams; 1985 p98.

When collecting waste material to be used in an anaerobic digester, different forms of waste should be combined to give a C/N of as close to 30:1 as possible.

The biogas yield from an anaerobic digester will typically be of the order of 0.4 to 0.5 m^3 biogas/kg volatile solids, with a retention time of the material in the digester of between 10 and 20 days, depending on the operating temperature.

Methane has a calorific value of 37.3 MJ/m^3 , which falls to about 18 to 24 MJ/m^3 if carbon dioxide is present. It is a flammable gas when mixed with air at concentrations of 5 to 15% and so can be used as a substitute for diesel.

Davidson (1984, p5) reports the use of a biogas pump operating at a cattle post in Botswana. Dung is collected for use in the digester and the biogas produced is used to substitute 75 to 80% for diesel in a diesel driven pump. The organic material remaining after the digestion process is dried and used as a fertiliser. The system was tested by the Botswana Technology Centre (BTC) and the RIIC (Rural Industries Innovation Centre) in Botswana. Their results are shown in Table 3.6.

Table 3.6 Performance of the BTC Biogas Pump.

	RIIC	BTC TEST
Head	75 m	80 m
Output (water)	4.5 m^3/hr	2.7 m^3/hr
Diesel Consumption	0.28 l/hr	75% substitution
Rated engine power	6 kW	6 kW

Source: Davidson; 1984 p5.

If it is assumed that a mixture of cow manure and wheat straw is used for digestion, and the efficiency of convesion of calorific energy to mechanical energy is 30%, and the pump converts mechanical energy to hydraulic energy with an efficiency of say 60%, then using the above values for the calorific content of biogas it can be shown that, for the BTC results, it is necessary to input approximately 6 kg of cow manure and 3.8 kg of wheat straw per day. Combined with a water input of about 38 litres per day these inputs ensure the correct C/N ratio and water content for anaerobic digestion.

These figures, although calculated in a simplistic manner, serve to illustrate some social problems that can arise with the use of biogas in a rural context. First, it is necessary to have the regular co-operation of water users in the collection of dung and vegetable matter for the digester. Secondly, it is necessary to have an operator on site, who is familiar with the amounts and ratios of cow manure input to vegetable input required. If a biogas storage facility is available, such as a rubber inner tube, then the mass required can be exceeded as long as the correct rates are maintained. It is worth noting, however, that dung is often collected in rural areas for use as a substitute for fuelwood.

The use of biogas for substitution in a diesel powered water lifting system requires that modern diesel technology be placed in a traditional context and environment. Apart from the problems of fuel cost and delivery previously mentioned, diesel systems have further inherent disadvantages. The problems of servicing and maintenance of the motor, as discussed in the previous Section, are likely to make the unit inoperable within a relatively short period.

These problems, together with the other problems listed for biogas production, mean that there are probably very few villages with the necessary infrastructure to independently operate and maintain a biogas water supply system. Further investigation into biogas is justified, however, as it does offer a renewable energy resource in a rural environment. Its' use in Southern Africa is unlikely to become widespread until the complex set of social, organisational and technical problems associated with it are resolved.

3.2.6 Animal Pumps

The sustainable power output available from draught animals, such as donkeys or oxen, is not well documented. There are three general classes of data available: 'rule of thumb' data, based on animal weight; field data, which is unfortunately often unreliable or incomplete; and the results of some controlled laboratory tests, which tend to give results based on animals in prime condition. The variables involved in animal power are complex - weight, age, condition, quantity and quality of feeding, nature of work (short duration or continuous) and the environmental considerations of altitude, humidity and so on.

Kennedy and Rogers (1985 p80) undertook a detailed study of the literature related to animal power and concluded that the data given in Table 3.7 offered a "reasonable assessment of animal power", but added that there is a need for reliable field data based on draught animals in developing countries, "in whatever condition they are - provided this can be specified in some way".

Table 3.7 Animal Power

Weight of Animal (kg)	Single Animal (W)	Pair of Animals (W)
325	190	340
400	235	425
500	295	525

Source : Kennedy and Rogers; 1985 p80.

(Two animals harnessed together are less effective than two animals working separately - an overall effectiveness of 90% was assumed).

Animal-powered water lifting devices can be divided into two broad categories, distinguished by the movement of the animal involved. First, there are devices based on linear movement in which the animal walks in a straight line, usually lifting a bucket attached to a rope and pulley. This system is often used to lift buckets of water from deep wells. The animal pulls the full bucket up on a rope and is then disconnected from the rope and walked back to the starting point near the well. The water lifting process is therefore not continuous. Two operators are needed for this system, one to lead the animals and one to empty the bucket. The 'rope and bucket' system is common in India and other part of the near East, but has not been used in Southern Africa.

The second form of animal powered water lifting is based on circular movement, with the animal walking continuously in a circle, turning a wheel or drum. This type of movement is used throughout the near East and Asia for Persian Wheels.

In Botswana the Rural Industries Innovation Centre (RIIC) have developed and manufactured a borehole animal pump based on circular movement. This pump employs three animals, each harnessed to a drawbeam, which turn a Mono Pump (rotary drive, positive displacement - see Section 3.2.1.2) via a chain gear step up transmission system. The beam radius is 5.6 metres and the step up ratio is 1 to 1000 rpm (RIIC), or 1 to 650 at the Botswana Technology Centre (BTC). The RIIC animal pump has been tested at the BTC under non-optimum head conditions and units installed in Gamorotswana and in Swaziland have also been tested. In Gamorotswana nine donkeys are being used to drive the pump in three to four shifts of one to two hours. Davidson (1984 p4) has reported the results of tests of the RIIC animal pump and these are shown in Table 3.8.

Table 3.8 Output of the RIIC Animal Pump

	Botswana Technology Centre	Swaziland	Gamorot-swana
Head	10 m	66 m	50 m
Output	2.5 m^3/hr	3 m^3/hr	5 m^3/hr
Animals used	6 donkeys	2 oxen	9 donkeys

(The B.T.C. data were adjusted for a theoretical efficiency loss due to a low head) Source: Davidson; 1984 p4.

Davidson (1984 p4) concluded that the results of the tests on the RIIC animal pump were within expected pump and system efficiencies and power output of donkeys, which was put at between 0.2 and 0.25 h.p. It can be seen that, despite the adjustment of the BTC data for a theoretical efficiency loss at the lower head this data is inconsistent with the other results.

Use of the RIIC animal pump in Botswana has several advantages. It is manufactured locally, using available materials, and the power source, draught animals, is available throughout most of the country. In addition, the system is easy to operate and maintain. It should be noted that no long term monitoring of the system has been done, so the full maintenance requirements and lifetime of parts are not known.

Disadvantages of the animal pump are that it requires at least one full-time operator to look after the animals, the animals have to be trained and kept in good health and the system is relatively expensive. The unit cost for the BTC test was P4500 in 1984 (approximately equal to R5600). This excludes the cost of the animals and the borehole equipment.

Some social factors of introducing animal power within a South African context may need careful consideration. In many traditional societies, cattle are held as a form of capital and prestige, with a man's wealth often determined by the number of cattle he owns, and are often imbued with ritual significance. Water lifting by animal power to meet community water needs may require the communal ownership of cattle and so would involve giving up some of the ritual and/or ethnic significance of individual ownership.

3.2.7 Solar Pumps

In the last decade a considerable amount of research has taken place on the technical and economic aspects of solar power utilization. As a result, a large amount of data, including the results of field trials and analyses, is available. The largest single research effort into solar power relevant to water supplies in underdeveloped areas was that initiated in 1978 by the United Nations Development Programme for the "Testing and Demonstration of Small Scale Solar Powered Pumping Systems". The project was carried out by the World Bank, who assessed existing solar technologies, conducted field trials and laboratory tests and concluded in 1985 that "there are some conditions under which solar pumps already can provide the best solution to local water needs." (Kenna & Gillet; 1985 pi).

The solar power resource is vast, with an average irradiance of 1353 W/m^2 falling on the earth's atmosphere. Some of this is absorbed or reflected, leaving a global irradiance (the total power received by a horizontal surface at sea level) of about 1000 W/m^2 at noon at a favourable site. This global irradiance is made up of two components: direct radiation from the sun and diffuse radiation from the sky. The total solar energy received in a day varies from 2 MJ/m^2 (0.55 kWh/m^2) in the Northern Hemisphere winter to 20 MJ/m^2 (5.55 kWh/m^2) in tropical regions.

Solar powered water pumping systems require the conversion of incident radiant energy to mechanical energy. This can be done in two ways: by using a solar thermal device or photovoltaic cells.

Solar thermal devices for water lifting are not common, although the principles of operation are fairly simple.

Bernard (1983 p14) describes a water lifting device which uses solar energy to heat and evaporate a small quantity of water within a closed container. A pipe is connected from the container to a body of water seven metres below. When the container cools (after sunset) a partial vacuum occurs, drawing water up the pipe into the container. A simple valve prevents the water from falling back down the pipe. Tests at Lyon University showed that a tank of 274 litres capacity reached a temperature of around 130 ^{0}C. Over a head of seven metres the tank filled to 75% of its capacity, equivalent to 254 litres. The efficiency of this form of solar conversion is approximately 2% that of an ordinary pump. The device, however, does have the advantages of simple construction, requiring only a tank, piping and two valves, and little or no maintenance.

Solar thermal pumping systems have been developed in this country with the support of Grinaker. However, the "Camel Pump" as it is known, has not yet reached commercial production.

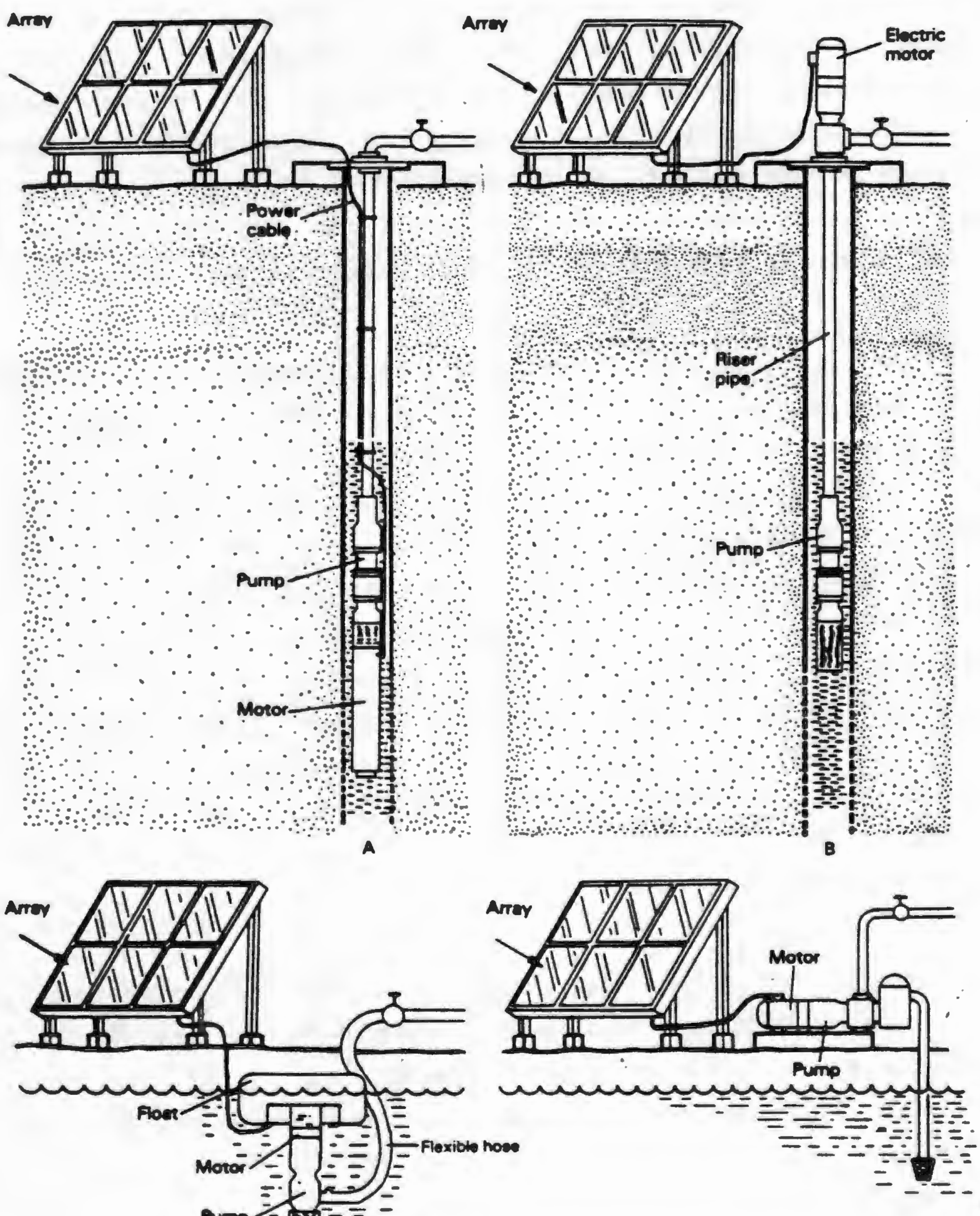
The more common method of solar power collection is that involving photovoltaic (PV) arrays. In this system solar energy is converted to electrical energy and used to drive an electric motor. Schematic diagrams illustrating this type of system are shown in Figure 3.9.

At present monocrystalline silicon is mostly used in PV cells, although other forms of silicon such as polycrystaline or amorphous silicon are increasingly being used. Other semi-conductors are also being studied as possible alternatives to silicon, such as cadmium sulphide and gallium arsenide, but are not yet commerically available.

Figure 3.9

Examples of Solar Photovoltaic Pump Configurations.

Source: Fraenkel; 1986 p120.



Examples of solar pump configuration
A. submerged motor/pump set
B. submerged pump with surface motor
C. floating motor/pump set
D. surface motor with surface mounted pump

The successful implementation of a solar water pumping unit requires a considerable amount of site evaluation in order to correctly size the PV array such that the required amount of water is supplied all year round. First, it is necessary to know accurately the amount of solar energy available. The use of mean annual solar insolation data is not sufficient, since a system based on this figure will be unable to meet the water demand in months of low solar insolation. Month by month data on the solar energy available is required. Secondly, it is necessary to know accurately the amount of water required throughout the year. This is particularly important if water from the system is to be used for irrigation or other agricultural purposes.

When both sets of data have been collected, it is necessary to choose a 'design month', such that the water demand in that period is maximum with respect to the availability of solar energy, i.e. the ratio of water demand to available energy is at a maximum value. Once a suitable water output has been calculated, an efficiency factor for the rate of conversion of electrical energy to the increased potential energy of the water over the combined static and dynamic heads can be used to calculate the necessary power output of the photovoltaic unit. The lack of solar radiation recording stations in underdeveloped areas is a problem, and interpolations often have to be made between existing Weather Bureau stations.

An example of the steps and assumptions required to correctly size a photovoltaic pumping system are shown in Appendix 6.4.7. The technical specifications of a commonly available solar PV module, and the system configuration used by the Energy Research Unit at the Sondela Community Garden in KwaZulu are also shown.

Care must be taken when selecting the electric motor and pump sub-system to be used with a photovoltaic power source because the power input varies with the sun's intensity throughout the day. Hence the sub-system must be designed to operate efficiently and reliably over a wide range of voltage and current levels.

The first consideration is the starting threshold of the sub-system. For positive displacement reciprocating pumps the motor has to overcome the peak starting torque of the pump. A centrifugal pump will rotate at low irradiance levels but not actually start lifting water until a threshold power input level is exceeded. A typical starting threshold for a solar pump unit is 300 W/m^2 (Kenna & Gillet; 1985 p129) so that on overcast days, when the insolation level may not exceed 300 W/m^2, the pump may not lift any water.

The second consideration is the type of electric motor to be used. This is generally a choice between a d.c or an a.c. motor. This choice must be made in conjunction with the type of power conditioning device to be used. Power conditioning devices are installed between the PV array and motor to maximise the current level such that the motor operates effectively at low insolation levels and to optimise the power output from the array.

The most commonly used power conditioning devices are d.c. to a.c. inverters or batteries. The use of inverters allows the designer the choice of a wider range of available a.c. motors than d.c. motors, which also tend to be more expensive. Disadvantages of using an inverter are the additional costs, which may offset the saving on an a.c. motor, an energy loss, although some inverter manufacturers claim efficiencies greater than 90%, and a reliability loss.

Batteries connected to a d.c. motor are often used for power conditioning and controlling as they provide continuous energy storage, such that the minimum insolation levels are not wasted, and they operate at a fixed voltage. An on-off switching device coupled to batteries can allow the pump to operate as long as the battery output remains above a certain value. When the output drops below that value the pump is automatically switched off, and the batteries can recharge. Disadvantages of batteries are that they have a low efficiency of energy storage and a short lifetime relative to the other components of the system which introduces reliability, maintenance and replacement requirements.

Another control strategy is to use a dc/dc converter in order to match demand to panel output characteristics.

A further requirement when designing a solar water supply is the use of a water storage tank. Ideally this should provide several days' water requirements, to allow for cloudy periods and the servicing or repair of the pump system. A tank shaped with a low aspect ratio (ratio of height to diameter) should be used in order to minimise the additional water lifting head.

Davidson (1984 p10) reports the testing of a solar water pumping system by the Botswana Technology Centre (BTC). This system consisted of 12 batteries, 18 Arco solar panels of 43 Wp, a Mono Pump (rotary, positive displacement) driven by a 1.2 kW d.c. motor and an electrical controller. Operation of the pump is based on charging the batteries until the voltage is sufficient to start the pump. The pump then operates until either the voltage drops or the borehole runs dry. The BTC found that this system gave an average of four hours of pumping every day, producing on average 40

m^3/day over a 50 metre head. The energy collected was 860 kJ per panel per day, giving an array to water pumped efficiency of 30%.

The cost of the BTC system was in excess of P40 000 (Davidson; 1984 p43) excluding tanks and borehole equipment. Davidson (1984 p25) found the BTC system to be economically competitive with other systems (animal, wind, electric and diesel) in Botswana in conditions of low heads and flow rates. However, it is expected that the capital costs of solar panels will fall (they have already fallen considerably), which would make solar systems economic over a wider range of applications.

A disadvantage of solar power is that the manufacture of PV systems requires a high technology not usually found in developing countries. Hence the systems have to be imported, requiring foreign exchange which increases both the financial and economic costs.

A solar powered water lifting system was recently installed by the Energy Research Institute of the University of Cape Town at the Sondela Community Garden, Nyavu ward, in the Valley of a Thousand Hills, KwaZulu. The design parameters of this system were a water output of 17 m^3 per day over a total head of 14.5 metres and a delivery distance of 150 metres. The pump was used to lift water from a surface source for use in the community garden.

The cost of the system was in excess of R22 000, which was met partly by the Development Bank and partly by the CSIR. The chosen system consisted of 18 MSP-103 solar panels, of 41 Wp manufactured by M Setek Co Ltd, a dc/dc converter, a 1 hp dc motor, and a BP4L Mono Pump with a 40 mm Monostroom solar lift head. The solar panels constituted the largest part of the total cost, as each unit was R780. The system was supplied by Mono Pumps (Africa) Pty Ltd.

The system was sized for the month of June, which was considered to be the poorest month in terms solar radiation at the site. No solar radiation data for the Nyovu area was available, so data from the Durban area was used to size the array. An effective daily operational period of 7.7 hours was assumed, with an average solar incidence of 377 $W/m^2/day$. The average power from each panel was then 15.5 W. The efficiency of the dc/dc converter was assumed to be 98%, and that for the dc motor, 62%. The efficiency of the Mono pump was assumed to be 59%. It was estimated that this system would give an output of 27 m^3/day in December. The steps and assumptions used to size the system are shown in Appendix 6.4.5.

Apart from cleaning the surface of the solar panels, it was recommended that the gland of the Mono BP4L pump be checked once a year. The lifetime of the carbon brushes of the dc motor was estimated to be 2000 to 2400 hours. At an average of, say, eight hours pumping per day, this represents 200 to 250 days of operation.

Although solar pumping systems consist of some highly sophisticated technology, the hardware produced is generally robust and very reliable. The servicing requirements of a solar system are minor, such as keeping the panels free from dust and dirt and protecting the system from accidental damage by animals or people. However, apart from the usual problems associated with the maintenance of below ground pumping equipment, it is possible that even a simple electrical fault, such as a loose connection, could not be traced and repaired in a village context. In addition, the servicing and repair of electric motors and control systems may be very costly and time consuming in developing areas.

The use of a photovoltaic pumping system in the Sondela community garden has been referred to as "hopelessly premature", (Atmore; 1986 p27). Atmore went on to question whether the pump could be called an 'appropriate technology' whilst it was completely beyond the means- financially and administratively- of those who were intended to use it. Whilst solar pumps are already attractive for use in certain applications, their high capital costs and high technology requirements will preclude any widespread use in underdeveloped rural areas in the short term. However, if the international momentum of cost reductions of solar modules continues, they may well have more widespread applications in the future.

3.2.8 Hydraulic Rams

A hydraulic ram, or hydram, is a device which uses the momentum contained in a flow of water running through it to lift a small volume of this water to a higher level. Schematic drawings of a traditional, or Blake hydram, and a South-East Asian hydram are shown in Figure 3.10. The hydram incorporates very few moving parts and is mechanically extremely simple, resulting in high reliability, minimal maintenance and a usually long operational life. Unfortunately, its operation is restricted to sites having suitable water flows. A schematic diagram of a typical hydram installation is shown in Figure 3.11.

Although hydrams are not suitable for use in boreholes, their potential for water lifting at the surface and simple design and maintenance requirements makes them suitable for use in underdeveloped rural areas. The Valley Trust has in the past used hydrams in the Valley of a Thousand Hills for domestic water supply. Unfortunately that installation failed during the recent drought.

Various types of hydram are available, although only one- Blakes Hydram- was found to be marketed in South Africa. It is possible to produce a low cost hydram using standard pipe fittings. Some simple designs improvised from pipe fittings have been developed by aid agencies (Fraenkel; 1986 p138).

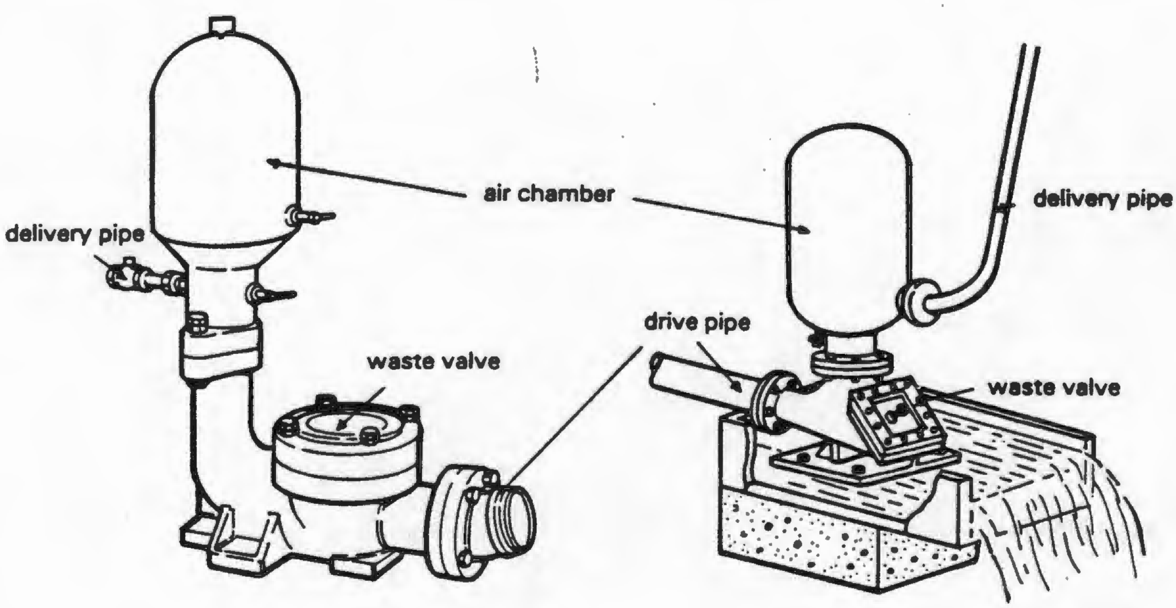
In a typical hydram installation, a supply head is created either by digging a small contoured diversion canal bypassing a river, or, in the case of small streams, by creating a weir and installing the hydram directly below it. In all cases the operation of a hydram requires the availability of a suitable supply of continuously flowing water.

Appendix 6.4.6 includes the input capacity of different sizes of hydram (it is the input which determines the delivery flow at any given head), typical hydram performance figures. Blake Hydrams are marketed in South Africa by Stewart & Lloyds, although it is reported that only four units were sold in 1985.

Figure 3.10

Traditional (Blakes) and South-East Asian Type Hydrams.

Source: Fraenkel; 1986 p136.



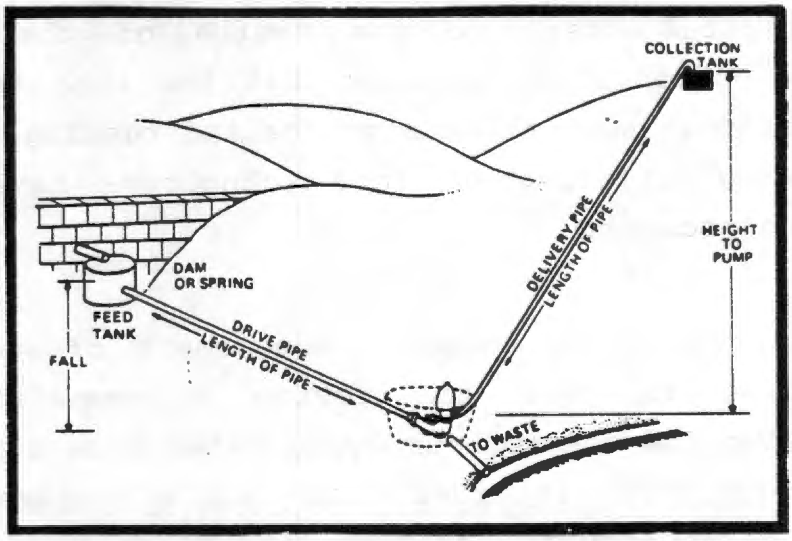
Traditional (Blakes) European hydram design

South-East Asian type of hydram

Figure 3.11

Schematic Diagram of a Typical Hydram Installation.

Source: Stewarts & Lloyds (Pty) Ltd.



3.3 Economics of Water Lifting Technologies.

The economic considerations relevant to the selection of water lifting technologies for use in underdeveloped rural areas extend beyond the selection of the technology with the lowest capital cost, to the choice of the most cost-effective option. This implies that the long term economic considerations- such as maintenance and running costs during the expected lifetime of the technology- have also been taken into account.

The objective of an economic assessment of water lifting technologies is then to provide a comparative figure representing the cost of supplying water from a borehole for human consumption. In order that such a comparative figure for each technology is achieved, there are three principles that must be adhered to: firstly, all the relevant costs must be included, secondly, each cost must be properly evaluated, using up-to-date data and the results of reliable field trials wherever possible; and thirdly, all the assumptions applied to the different technologies must be consistent and clearly stated.

The calculation of a realistic cost estimate for use as an aid to technology selection is, unfortunately, not a straight forward task. Many of the costs are not fixed and there are a multitude of parameters and constraints that do not readily lend themselves to financial quantification. In addition, there is a general shortage of reliable field data for most water lifting technologies, since most water supply agencies do not at present conduct monitoring programmes of their schemes.

3.3.1 Economic Theory

Three techniques that are commonly used for making economic appraisals of technologies are the Payback Period, the Rate of Return and Life Cycle Costs.

The Payback Period technique involves calculating the length of time required for the cost of the initial investment to be repaid as a result of the benefits accruing from the new technology. It can be seen then that this technique is not suitable for evaluating water lifting technologies since many of the benefits of an improved water supply are not financially quantifiable.

The Rate of Return method involves calculating the discount rate (the rate at which the value of a sum of money decreases over time) at which the technology costs and benefits over it's usefull lifetime are equal. This method also requires the financial quantification of the benefits occuring as a result of the technology application, which precludes it's use for assessing water lifting technologies. The Rate of Return is favoured in other areas, however, since it provides a figure that is independent of any assumptions on the values of future discount or inflation rates .

The Lifecycle Costs method has been widely used for the economic assessment of water lifting technologies (Davidson, 1984; Kenna & Gillet, 1985; Fraenkel, 1986). It involves calculating the present value of all the costs (including future costs, such as replacement systems) associated with a technology over a specified period. Hence, in this system the lifecycle costs of various technologies performing a specific task are comparable, since it is assumed that the benefits derived from each are equal.

Since different technologies often have different usefull lifetimes, it is usual to annualise the lifecycle costs to obtain present values representing all the present and discounted future costs. The annualised lifecycle costs may then be used to calculate the unit water output costs of each technology, ie the cost of a unit quantity of water lifted through a given head. This figure is expressed as $c/m^3.m$, (cents/volume flow rate x head).

The future costs of each technology are converted to their equivalent present value using a formula called the Discounted Cash Flow, or DCF. The general principle of DCF is that money available in the future is worth less than if an equivalent sum were available today. For example, the value of R1000 is less today than it was in 1980, and will be even less in 1990. The rate at which money 'depreciates' in this manner is determined by the Discount Rate. Of course, R1000 invested in a Building Society today will have accumulated interest by 1990, but whether the final sum of capital plus interest will be worth more than it is now depends on the interest rate and the rate of inflation (amongst other things), and is a matter for debate.

The DCF formula takes all the future payments associated with a technology and discounts them back to their present value using selected interest and discount rates. In this case water lifting technologies are compared by using the DCF formula and annualising the costs to produce a value for the cost of water lifted in cents per $m^3.m$ (volume flow rate times head) for a specified range of flow rates (in m^3 per day) and heads.

As stated above, there is a dearth of reliable field data on the maintenance and servicing requirements of water lifting technologies, and even on the output of technologies in the field. Although the common causes of failure of some technologies are known (such as piston-cylinder failure in handpumps and windmills, or the failure of motor brushes in photovoltaic systems), it is not possible, in general, to put a reliable figure to the lifetime of pump components in the field (although motor brushes are an exception, since they have been widely used and monitored). It is also extremely difficult to assign an accurate figure to the lifetime of a water pumping system. As will be seen in Chapter Four, some installations breakdown within a month, whereas other similar systems continue to produce water for long periods.

In effect, then, the calculation of the lifecycle costs of various technologies involves four main assumptions: the discount rate, the escalation rate (the rate of inflation with respect to the discount rate), the technology lifetime and the technology maintenance costs. If all four variables were given the same value for each technology (with the maintenance costs as a percentage of capital costs) then the deciding variables would be the initial capital cost and the output of each technology over the head in question. Hence, those technologies with a high output with respect to capital cost would appear less expensive than those with a low output.

The solution then was to assign each technology a figure for it's lifetime and maintenance costs based on information gained from manufacturers, users and other published economic analyses. In this way it was possible to calculate the unit water costs for each technology.

For each technology a value was assigned for its' lifetime in years, and its' maintenance costs, as a percentage of its' capital costs. The number of replacement units required over the period of analysis (20 years), and the cost of each replacement unit required in the future was converted to its' equivalent present value using the formula

$$R_{ep}PV = E_{rep} \cdot \Sigma_{j=1}^{Nrep} \left\{ \frac{(1+E)}{(1+D)} \right\}^{j.k}$$

where $R_{ep}PV$= Replacement Present Value,

E_{rep}= Equivalent Replacement Cost,

E= Escalation Rate,

D= Discount Rate,

k= pump life (years)

Σ= sum for j=1 until j= N_{rep}

and N_{rep}= the number of replacements required over a 20 year period.

The present value of all the operation and maintenance costs (OMPV) over the 20 year period were then calculated using the formula

$$OMPV = OM * \frac{(1+E)}{(D-E)} * (1 - \{(1+E)/(1+D)\}^N)$$

where OM= Operation and maintenance costs over a single year.

N= period of analysis, 20 years.

The lifecycle capital (LCC) cost of the technology was then the sum if its' initial cost and the present value of its' future operation, maintenance and replacement costs. This value of the lifecycle capital cost was then annualised over the 20 year period of analysis to produce a yearly cost of pumped water (PMT). The formula used to annualise these costs was:

$$PMT = LCC * \frac{D}{(1-(1+D)^{-N})}.$$

The annualised capital cost was divided by the product of the technology's yearly water output and head to produce the cost of pumped water in c/m^3.m.

Unfortunately it was not possible to include all the technologies covered in Section 3.2 in the economic analysis. In particular, biogas and animal pumps were excluded since insufficient output and cost data were available. Similarly, solar thermal devices are not included in the economic analysis as no manufacturers of such units were found, and only a very small amount of field data was available.

The assumptions made during the economic analyses are listed in detail under the heading of the pump in question. In general, manufacturer's ouput data was used throughout. All the costs refer to 1986 prices. The cost of a pump installation was taken to include the pump and power source (where applicable), and the below ground rising main and pump rods. The latter were included since it is necessary to differentiate between pumps using piston-cylinders and those operating on the rotary positive displacement principle, for which the below ground equipment is considerably more expensive. The cost of borehole drilling and casing is excluded, as is the cost of any reservoir or water reticulation systems associated with certain types of pumps.

In the case of handpumps and footpumps, where multiple installations are often needed to produce the required daily output, the cost of the extra boreholes was included as an initial capital cost, but excluded from the replacement capital costs.

3.3.2 Results and Discussion.

The results of the economic analyses are shown in Tables 3.9 and 3.10, and Graphs 3.1 to 3.6. Table 3.9 and 3.10 show the pumped water costs over the full range of heads and flow rates investigated (H=30m and 60m, and Q=5, 10, 30 and 50 m^3/day). The base case values of the discount rate and escalation rate for the analysis were assumed to be 5% and zero respectively. Graphs 3.1.1 and 3.1.2 compare the pumped water costs calculated for H=30 metres and H=60 metres respectively. Graphs 3.2 and 3.3 show the sensitivity of pumped water costs to changes in the discount rate and escalation rate respectively. These graphs are based on the pumped water cost for the base cae of H=30 metres and Q=30 m^3/day. Graphs 3.4.1 and 3.4.2 compare the pumped water costs of handpump and windpump systems respectively for a head of 30 metres and flow rates of 5, 10, 30 and 50 m^3/day. Finally, graphs 3.5 and 3.6 show the sensitivity of pumped water costs to variations in the assumptions of maintenance costs and pump lifetimes respectively. These figures are also based on the pumped water cost for the case of H=30 metres and Q=30 m^3/day.

Key to Graph Notations.

Unfortunately, due to the limitations of the computer software package used for the economic analysis, it was necessary to abbreviate the names of pump systems included in the various graphs. The abbreviations are explained below:

CL= Climax Lever handpump.

MD= Mono Direct Drive handpump.

NL= Nimric Lever handpump.

CW= Climax reciprocating windmill.

M&S= M&S Rotary windmill.

D= Diesel pump system.

S50%= Solar, assuming a 50% reduction in panel costs.

TABLE 3.9
PUMPED WATER COSTS: H=30m, D=0.05, E=0.

Head: 30 metres. Pump	Q=5 m3/day Cost c/m3.m	Q=10 m3/day. Cost c/m3.m	Q=30 m3/day. Cost c/m3.m	Q=50 m3/day. Cost c/m3.m
Mono "Direct Drive"	(1) 0.47	(3) 1.00	(7) 0.84	(12) 0.89
Climax "L"	(1) 0.44	(2) 0.59	(5) 0.56	(8) 0.56
Climax "No 104"	(1) 0.75	(3) 1.41	(7) 1.16	(12) 1.22
Mimric "R145"	(1) 0.44	(2) 0.58	(6) 0.68	(9) 0.63
Mono Pedal Pump	1.03	1.17	1.49	1.42
Climax windmill	1.63	1.13	0.72	0.43
Mimric windmill	1.08	0.59	0.29	B/C
Southern Cross	1.30	0.70	0.33	0.59
"M&S Rotor"	3.61	1.80	0.60	0.36
Climax rotary	2.99	1.49	0.50	0.30
Diesel	1.37	0.96	0.69	0.42
Solar	2.59	2.24	1.98	1.48
Solar (50%)	1.56	1.25	1.03	0.77

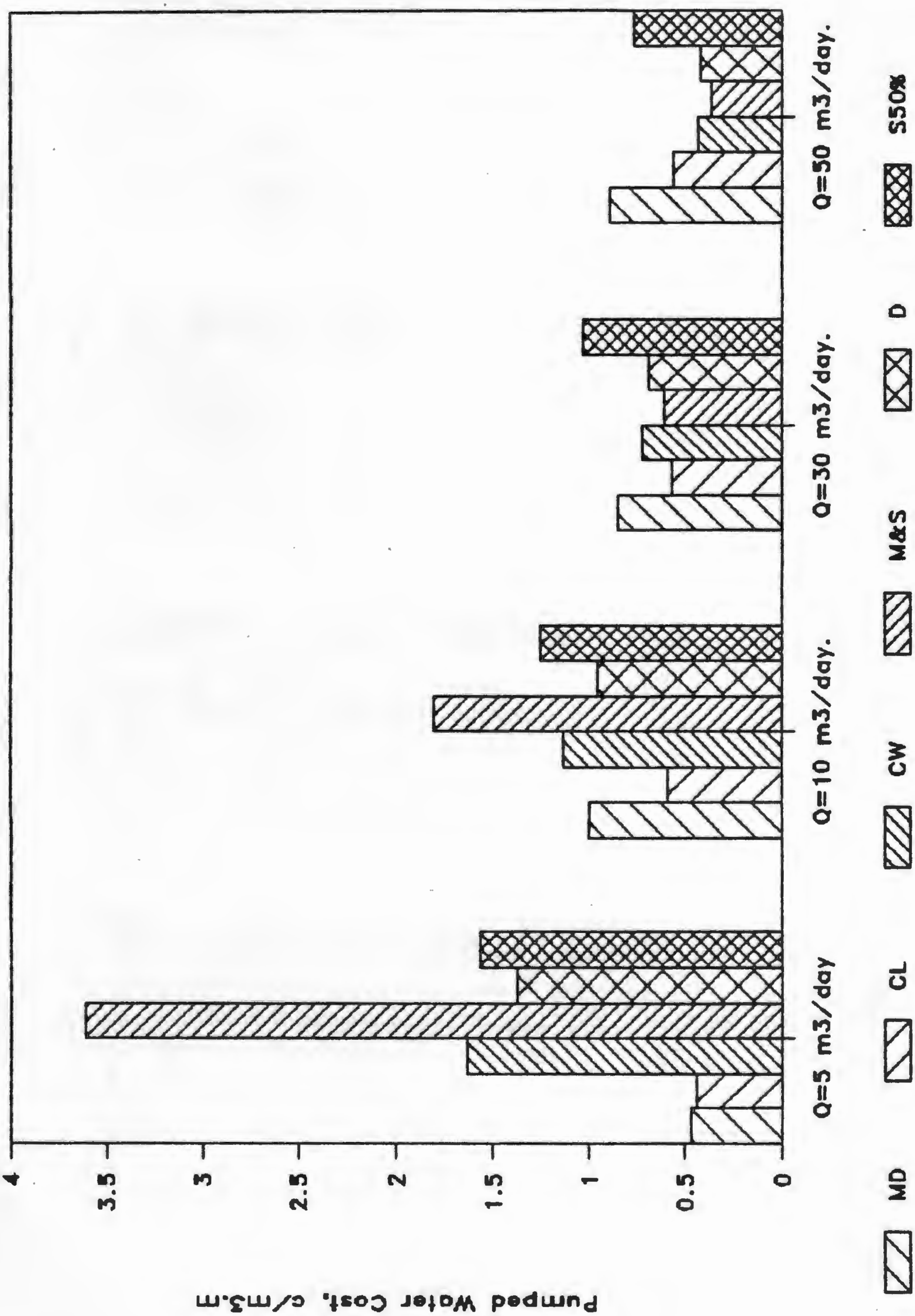
(5)= 5 units needed to produce required output.
B/C= Beyond Capacity.

TABLE 3.10
Pumped Water Costs H=60m, D=0.05, E=0.

Head: 60 metres. Pump	Q=5 m3/day Cost c/m3.m	Q=10 m3/day Cost c/m3.m	Q=30 m3/day. Cost c/m3.m	Q=50 m3/day. Cost c/m3.m
Mono "Direct Drive"	(2) 0.93	(3) 0.75	(8) 0.73	(13) 13
Climax "L"	(1) 0.34	(2) 0.45	(6) 0.52	(10) 0.53
Climax "No 104"	(2) 1.20	(4) 1.31	(15) 1.74	(25) 1.75
Mimric "R145"	(1) 0.34	(2) 0.45	(4) 0.33	(7) 0.37
Mono Pedal Pump	0.51	B/C	B/C	B/C
Climax windmill	1.18	1.13	0.38	0.23
Mimric windmill	0.72	0.49	B/C	B/C
Southern Cross	0.81	0.55	0.51	0.35
"M&S Rotor"	2.08	1.04	0.35	0.21
Climax rotary	1.49	0.75	0.25	0.15
Diesel	1.27	0.59	0.27	0.20
Solar	2.50	2.19	1.57	1.53
Solar (50%)	1.51	1.23	0.83	0.79

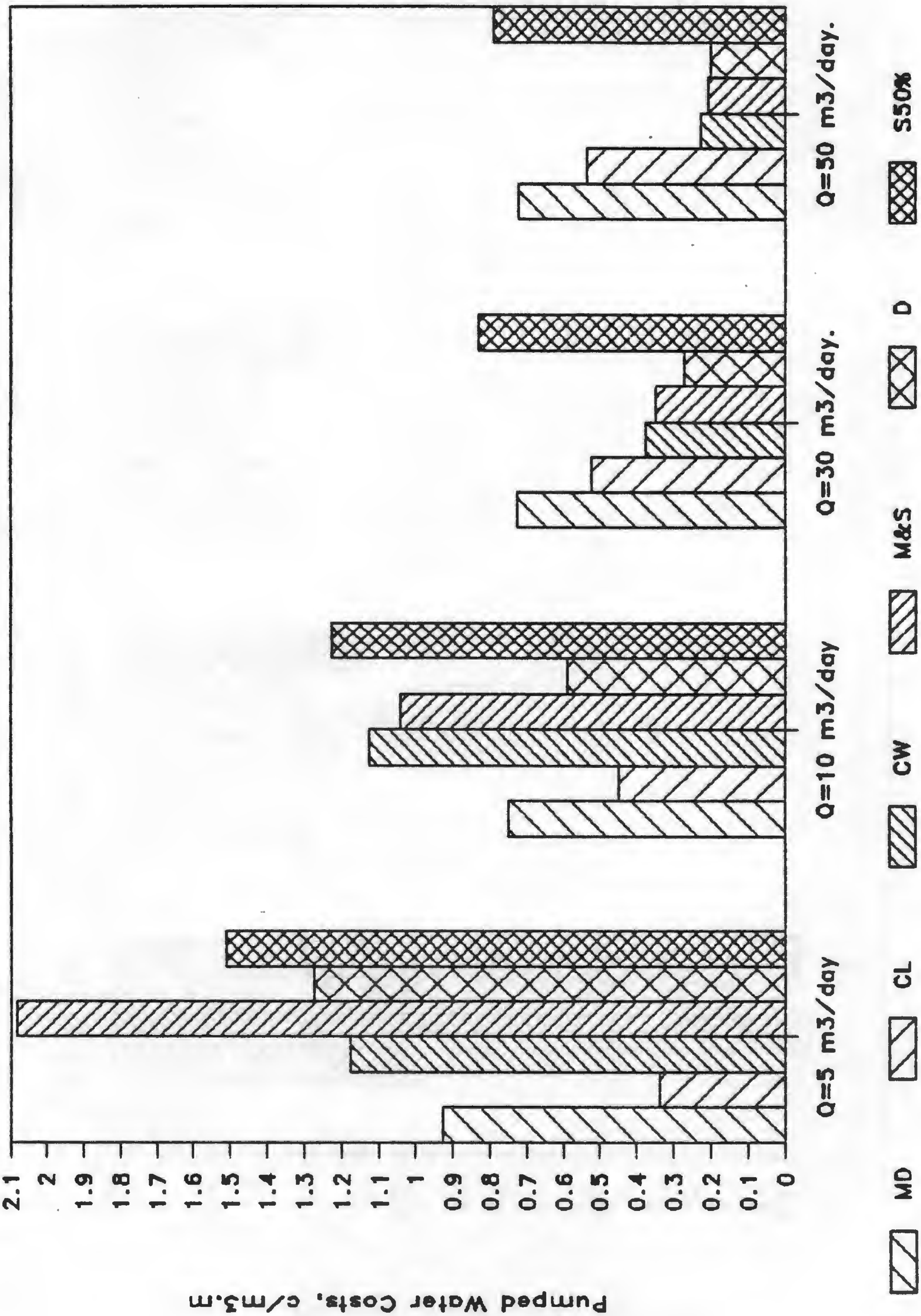
Graph 3.1.1

Pumped Water Costs, H=30 metres.



Graph 3.1.2

Pumped Water Costs, H=60 metres.



3.3.2.1 Handpumps.

Four types of handpumps manufactured in South Africa were included in the economic analysis. They are the Mono Direct Drive, the Climax Lever and the Climax Wheel, and the Nimric handpump. In the base case (H=30m, Q=30 m^3/day, D=0.05, E=0) the cheapest handpump appears to be the Climax Lever, which requires five installations to produce 30 m^3/day. In comparison, seven Mono Direct units are required. Graph 3.5 shows that the Climax handpump remains the cheapest handpump even if its' maintenance costs are 20%, and those of the Mono handpump about 1%. Similarly, the Mono handpump is only cheaper than the Nimric handpump (Graph 3.6) if its' lifetime is sixteen years and that of the Nimric two years.

At a 30 metre head, and flow rates of 5 and 10 m^3/day reciprocating handpumps offer the cheapest option, followed closely by Climax windmills and diesel systems. At H=30 metres and Q=30 m^3/day, Nimric and Southern Cross windmills, as well as diesel pumps are competitive with handpumps.

At a 60 metre head the Climax and Nimric Lever handpumps again are the cheapest systems at flow rates of 5 and 10 m^3/day. At higher flow rates over this head both rotary and reciprocating windmills, as well as diesel systems are less expensive.

The most economical handpumps appear to be the reciprocating lever types. This is because their capital costs are less than the positive displacement Mono handpump, and their outputs are greater than both the Mono and the wheel type Climax handpump.

Assumptions. Manufacturers' output data was used throughout. A 10 hour pumping day was assumed. In the base case the lifetime of the Mono Direct Drive handpump was put at 8 years, and that of all the other handpump types, 5 years. The maintenance costs of all the handpump types was assumed to be 5% of initial capital costs per annum. The Mono HP12L handpump unit is capable of lifting water over heads up to 45 metres, after which the HP9M unit is required. The outputs of the Climax Wheel and Nimric Lever pumps at 30 spm (strokes per minute) were used.

3.3.2.2 Pedal Pumps.

The economic analysis of pedal pumping units is based on those produced by Mono Pumps (Africa) Pty Ltd. The performamce figures used, however, are those produced by Rod, Marcus and Kitshoff (1983 p14), since these are based on field data.

As with handpumps, a number of pedal pump units are required to meet water requirements greater than 5 m^3/day. As can be seen on Table 3.9, seven pedal pump units would be required to produce the base case output of 30 m^3/day. The Mono pedal pump does not appear competitive with other pump technologies due to its' relatively high capital cost and relatively low output. It is important to remember, however, that pedal pumps are still an experimental technology. Further research and design innovations, such as utilising a piston-cylinder instead of a rotary positive displacement type, may make pedal pumps more economically attractive.

Assumptions. An 8 hour pumping day was assumed. The lifetime of the unit was assumed to be 5 years, and maintenance costs were assumed to be 5% of capital costs.

3.3.2.3 Windpumps.

In the base case (H=30 metres, Q=30 m^3/day) the Nimric windmill appears to be the cheapest of all the technologies available. At lower flow rates, windmills are more expensive than handpumps and diesel pumps, but less expensive than solar pumps. The M&S Rotor appears costly at low flow rates since only one size of the windmill is available, with a rotor diameter of 5.5 metres. Hence it is extremely oversized at lower head and flow rates.

At a head of 30 metres and output of 50 m^3/day, however, the M&S Rotor provides the cheapest pumped water cost. The Climax rotary windmill is slightly less expensive than the M&S Rotor, which is reflected in its' marginally lower pumped water costs.

At a head of 60 metres and a flow rate of 5 m^3/day, reciprocating windmills are more expensive than handpumps but cheaper than diesel or solar pumps. At higher flow rates over this head the cost of windmill pumped water drops considerably, but only the M&S Rotor becomes cheaper than diesel power.

Graph 3.5 shows that the cost of pumped water for Climax windmills doubles if the maintenance costs increase from 2% to 20%. The M&S Rotor also has a high sensitivity to maintanance costs. The Nimric windmill, however, does not show such a strong sensitivity to maintenance costs, probably due to its' lower capital costs. It is interesting to note that if the maintenance costs of Nimric windmills are 20% of capital costs (per annum), and those of Climax 2%, the Nimric windmill still provides the cheaper pumped water of the two.

Assumptions. Climax data shows outputs in windspeeds of 2.7 m/s and 4.4 m/s (10 km/hr and 16 km/hr). Other manufacturers (except Midkaap Engineering, who produce the M&S Rotor) show an "average daily output". A 20 hour pumping day at 2.7 m/s was assumed for Climax windmills, except for flow rates of 30 and 50 m^3/day, where a windspeed of 4.4 m/s was necessary for the required output.

The output figures produced by Midkaap Engineering for the M&S Rotor were regarded as unusually high. A 5 hour pumping day was assumed for H=30 metres, and a 10 hour pumping day for H=60 metres.

All prices used were for a complete windmill with a 9 metre tower.

In the base case the lifetimes of all the reciprocating windpumps were assumed to be 12 years. Maintenance costs were assumed to be 5% of capital costs.

3.3.2.4 Diesel Pumps.

At a head of 30 metres and flow rates of 5 and 10 m^3/day diesel systems are uncompetitive with handpumps or windpumps. At H=30 metres and Q=50 m^3/day diesel becomes more competitive than the reciprocating windmills, but remains more costly than rotary windmills.

At higher heads (60 metres) but low flow rates diesel appears more expensive than the Mono, Nimric and Climax Lever handpumps. At a flow rate of 30 m^3/day over this head it is competitive with the rotary windmills.

Graph 3.2 shows that diesel systems are not particularly sensitive to variations in the discount rate. Similarly, Graph 3.5 shows that rising maintenance costs affect the cost of pumped water from a diesel system less than windmills. Graph 3.6 shows that diesel systems become more cost effective up to a lifetime of about ten years, after which an increasing lifetime does not noticeably affect the cost of pumped water.

Although diesel pumps are one of the cheapest technologies at high heads and flow rates, it is important to remember that diesel systems are capable of lifting far greater quantities than those considered here. For example, a diesel system may be suitable for providing large peri-urban areas with water, where the cost of diesel, and the provision of maintenance are the responsibility of a Divisional Council, or other controlling body.

Assumptions. The required output of the diesel engine was calculated using an overall engine to pumped water efficiency of 20%. The prices used are those of an appropriately sized Lister diesel engine, with a standard power head and cylinder.

In the base case the lifetime of the diesel engine was assumed to be 10 000 hours, and was then calculated according to the number of pumping hours required per day. The maintenance costs were assumed to be 5% of capital costs. The cost of diesel was put at 50 c/litre, which is slightly above that paid by farmers.

3.3.2.5 Solar Pumps.

It can be seen from graphs 3.1.1 and 3.1.2 that the cost of pumped water from a solar powered system is less than that of the M&S Rotor or Climax windmill at H=30 metres and Q=5 m^3/day, if a reduction of 50% of the price of photovoltaic panels is assumed. It is also interesting to note that at an output of 50 m^3/day over the same head the solar system is less expensive than the Mono handpump. This is due to the extra boreholes required for the handpump, and the cost of replacement pumps over the 20 year period of analysis.

It will be seen from the assumptions listed below that the solar systems were sized for a mean irradiance of 377 W/m^2 for 7.7 hours per day in the month of June for a site near Durban. This value of the irradiance is slightly pessimistic, and may well be exceeded at other sites. For example, a site in the Kalahari would have a mean irradiance up to twice that of the Durban site, such that a solar system may appear more attractive than is the case in this report.

Further, although pumped water costs for heads lower than 30 metres were not calculated for the purposes of this report, it has already been shown elsewhere that solar systems are already competitive at low heads and flow rates (Kenna & Gillet; 1986 p10). In that report it was found that solar systems are economic where less than 100 m^3.m (volume flow rate x head) are required and the mean windspeed at the proposed site of the pump is less than 4 metres per second.

<u>Assumptions.</u> Sizing and cost calculations followed those of Mono Pumps (Pty) Ltd, who designed and provided the system installed at the Sondela Community Garden, in the Valley of a Thousand Hills near Durban, by the Energy Research Institute of the University of Cape Town. An overall array to pumped water efficiency of 30% was used, which is

confirmed by the field data included in Davidson (1984 p10). The system was sized for the month of least solar insolation (377 W/m^2) over a period of 7.7 hours per day, except for $Q=50\ m^3/day$, when an insolation of 500 W/m^2 was used. The maintenance costs were assumed to be 1% of capital costs, and the lifetime of the systems was put at 20 years.

The cost of solar photovoltaic panels used in the economic analysis (R780 for a panel of 41 Wp) was based on those manufactured by M Setek Co Ltd, and marketed in South Africa by Mono Pumps (Africa) Pty Ltd. The technical specifications of these panels are shown in Appendix 6.4.5. Since solar PV units are a recently introduced technology, and the price of panels is likely to fall as production costs are reduced (and sales are increased), solar water lifting systems were analysed twice: firstly using the current cost of solar panels, which is about R780, and secondly assuming a 50 % reduction in panel costs. The effect of changes in the discount rate on the cost of pumped water (at 50% panel price) was calculated, and is shown in Graph 3.2(2), which is included in Appendix 6.4.5. These curves are not shown in Graph 3.2 since it would have been necessary to compress the y-axis scale such that the values of other curves would have been lost.

3.3.2.6 Summary.

The economic analyses have succesfully identified the variations in pumped water costs for the most commonly used technologies (handpumps, windpumps and diesel pumps) for a range of locally produced pumps, and for solar pumping units that are available in South Africa. Unfortunately, the short duration of the project, combined with the dearth of output data and cost figures available for the lesser used technologies has had the result of excluding those technologies from the economic analysis.

It can be seen that each of the commonly used technologies has adavantages over the other technologies under certain head and flow rate conditions. At a head of 30 metres and flow rates of 5 and 10 m^3/day the recipricating Climax Lever and Nimric handpumps have the lowest pumped water cost. At higher flow rates over that head windpumps and diesel pumps become more competitive. This is not only because their pumped water costs have fallen, but also because these technologies are capable of meeting these daily flow rates from a single borehole.

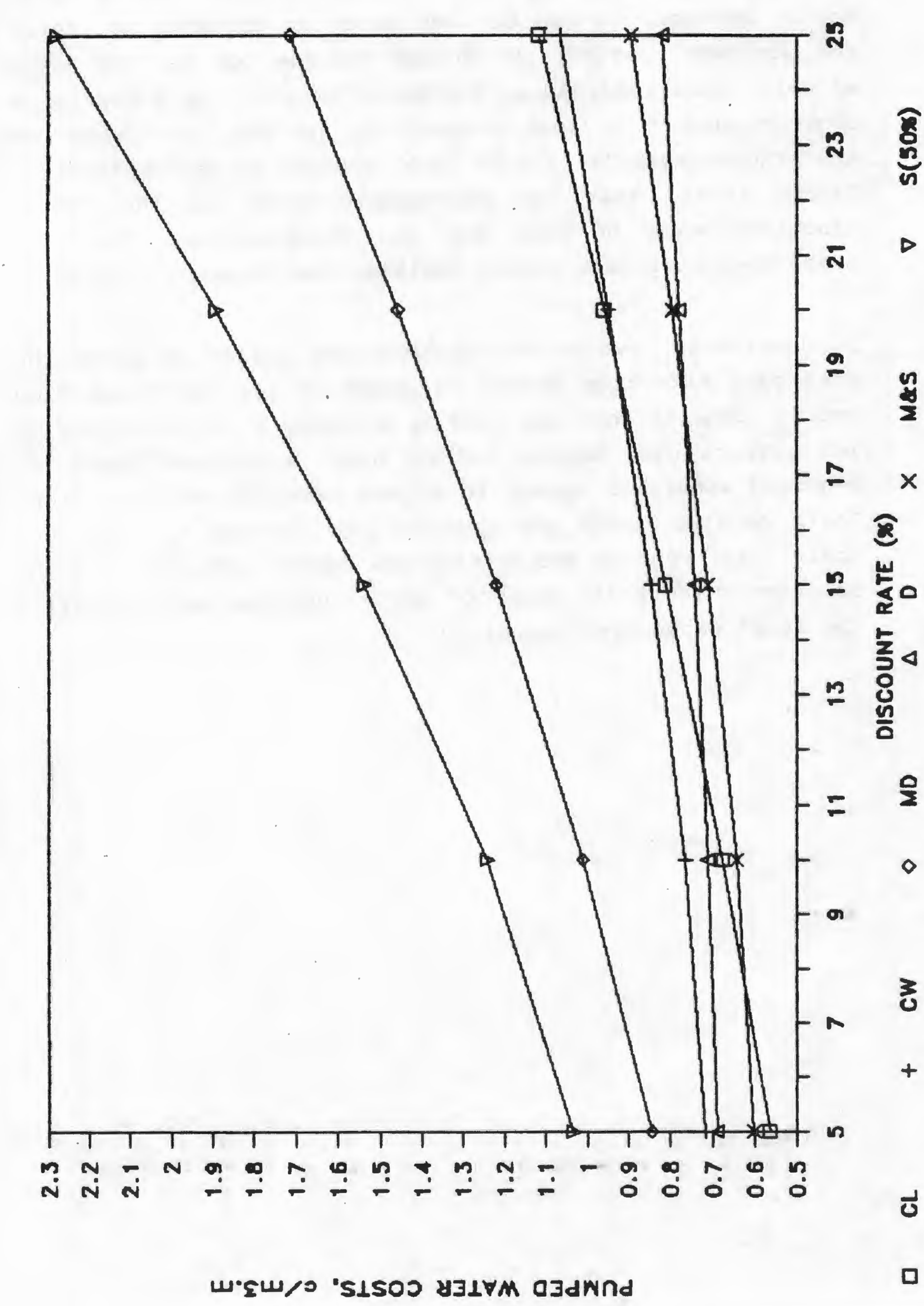
At a head of 60 metres and flow rate of 5 m^3/day the reciprocating Climax and Nimric handpumps still appear economical, since only one installation is required. The Mono handpump appears more expensive than the reciprocating handpumps, due to its' higher capital cost and lower output. At higher flow rates over this head the choice is mainly between reciprocating or rotary windmills, and diesel systems. In this respect it is worth noting that the four makes of windmill included in the analysis vary with respect to each other. For example, the Nimric windmills are considerably cheaper (in terms of capital cost) than the other designs, since they do not incorporate a gearbox.

Southern Cross windmills, in comparison, are the most expensive, but incorporate a four posted rather than three posted tower. The M&S Rotor and Climax Rotary windmills are consistently the cheapest in terms of their pumped water costs. However, as can be seen from the assumptions listed for windpump systems, the output figures for the M&S Rotor windmill were regarded as rather optimistic. As a result, a shorter pumping day was assumed for the M&S Rotor than for the other windmills- and it still appears to be competitive. It is likely that the maintenance costs of the rotary windmills would be less than the reciprocating windmills, since they utilise a rotary positive displacement cylinder.

In conclusion, reciprocating handpumps appear to offer the most cost effective option in cases of low heads and flow rates, although they may also be preferable in situations of low outputs over higher heads. Where a greater output is required windmills appear to be the least expensive option. Their capital costs are greater than diesel systems, but their lower running and maintenance costs, combined with the relatively short lifetimes of diesel engines make windmills the least expensive technology.

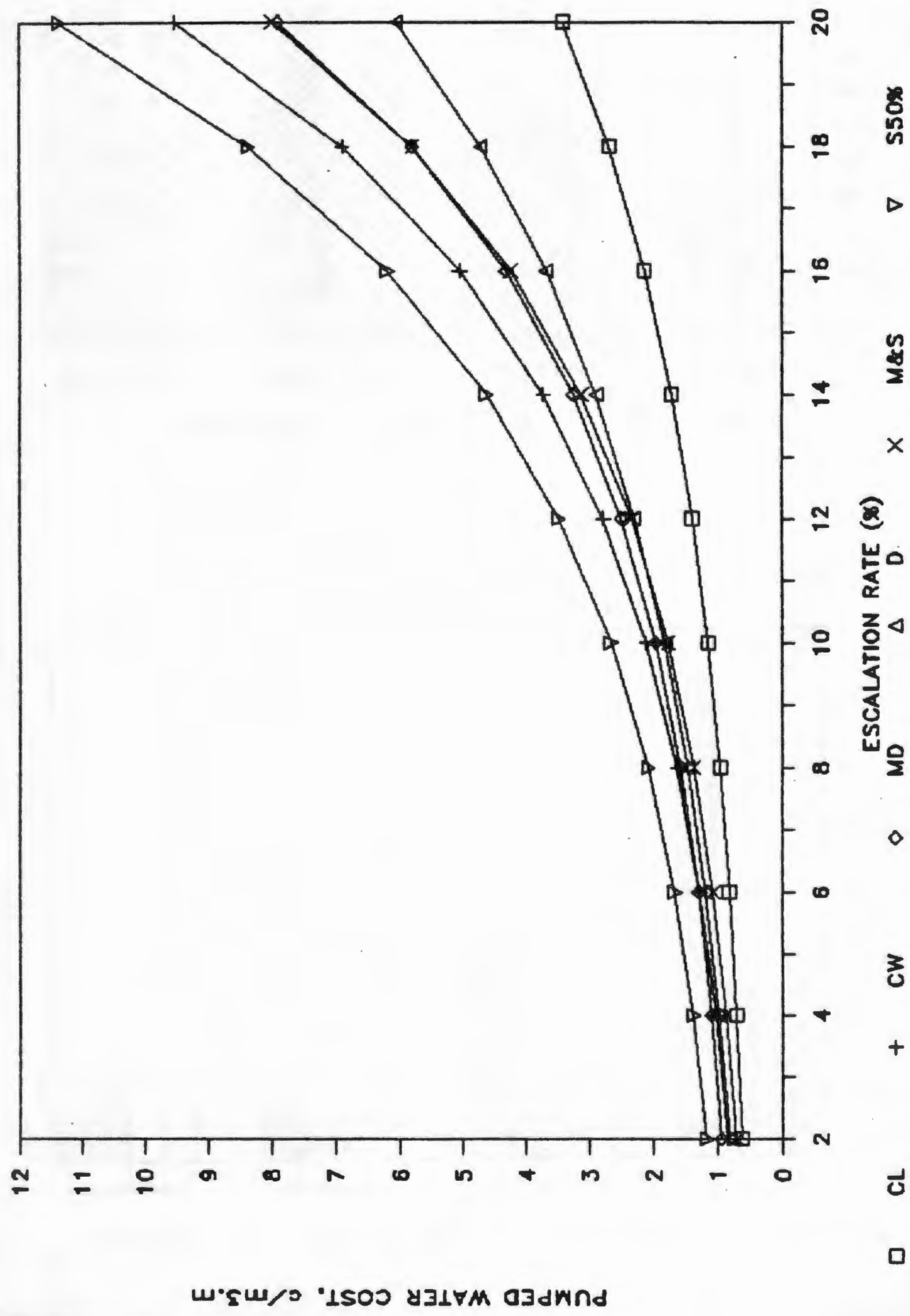
Graph 3.2

Pumped Water Costs vs Discount Rate.

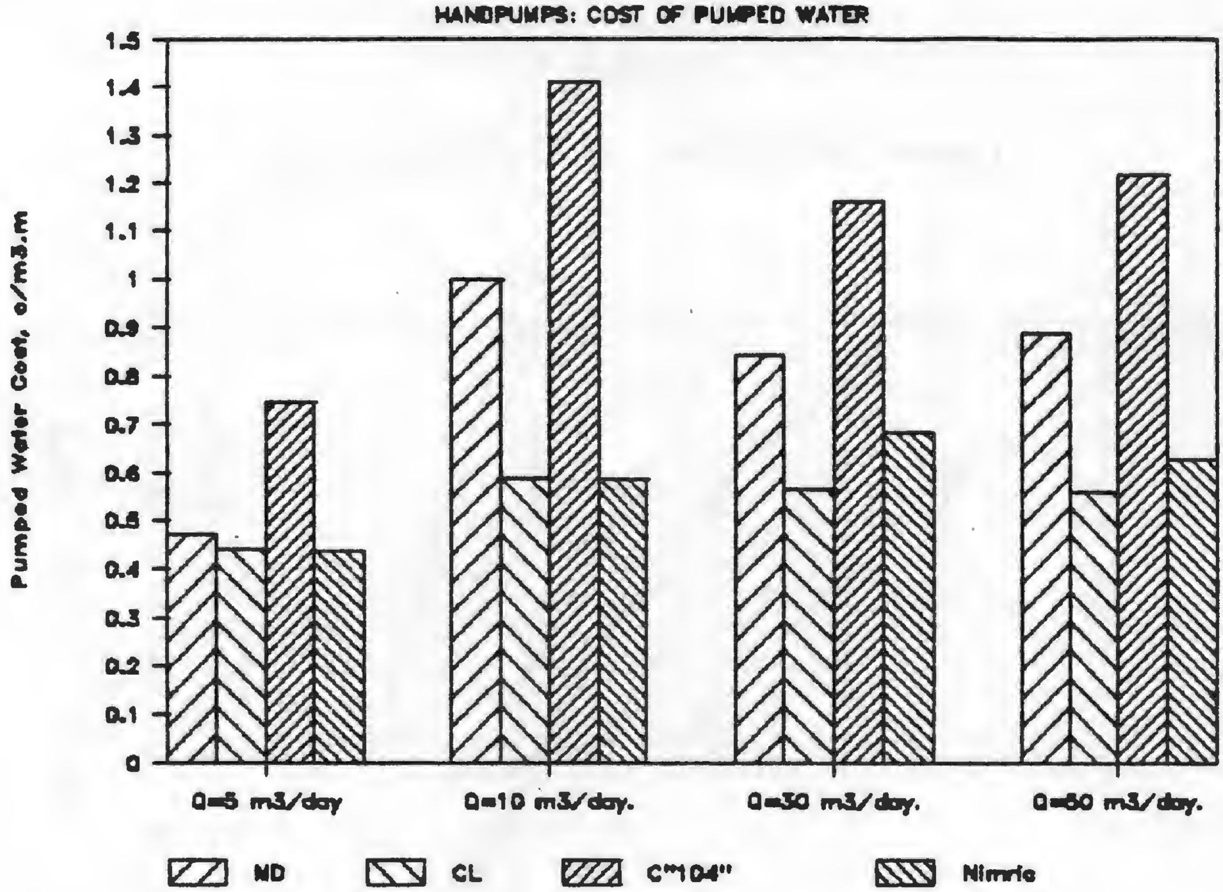


Graph 3.3

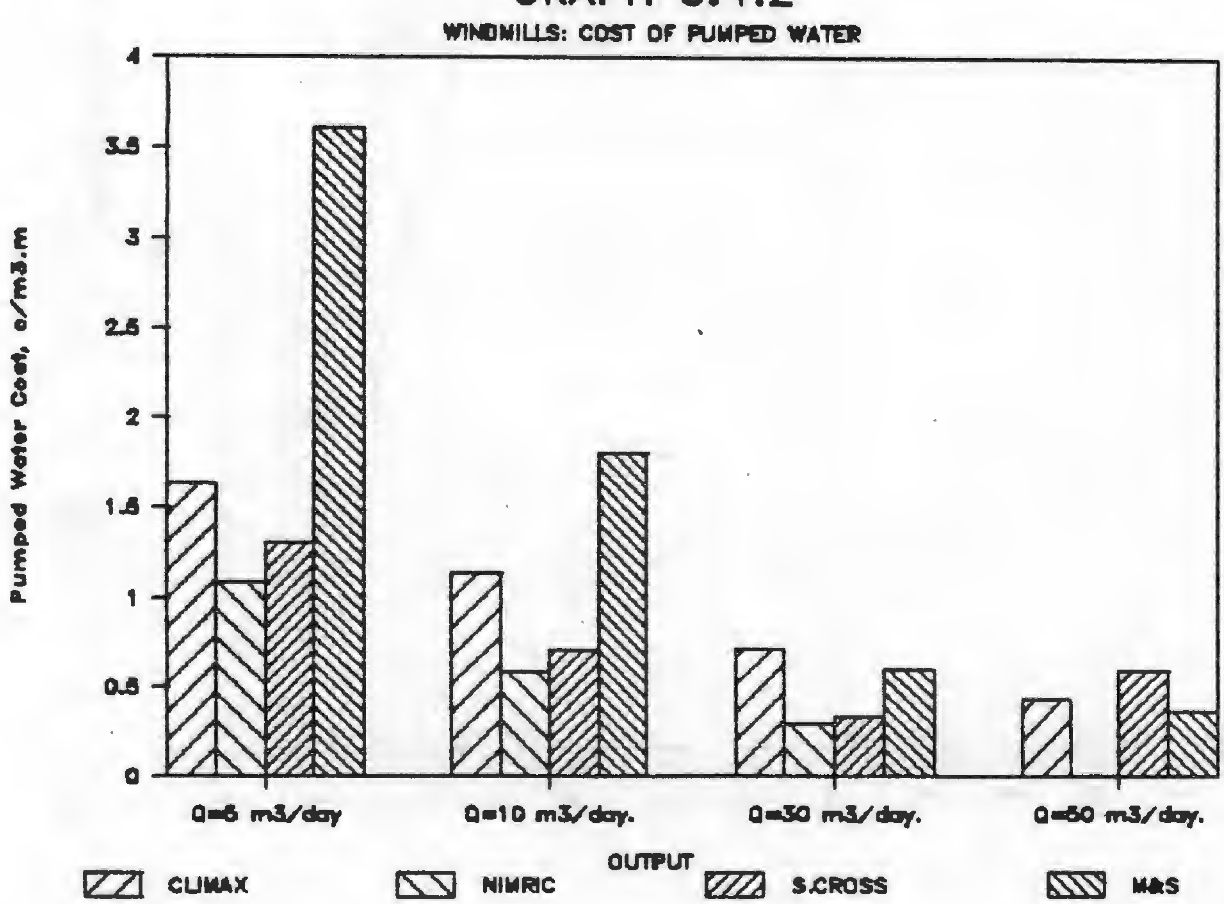
Pumped Water Costs vs Escalation Rate.



GRAPH 3.4.1

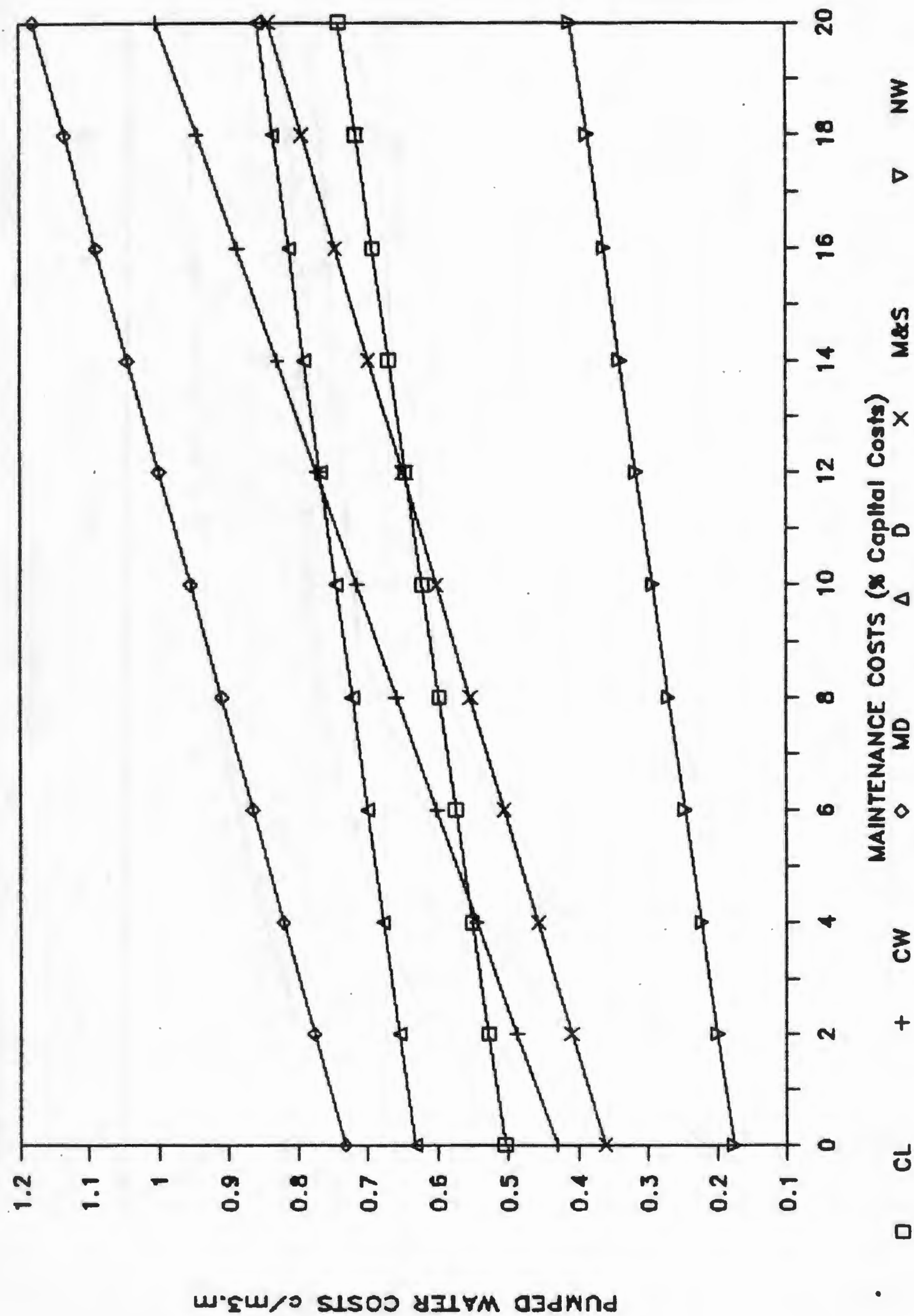


GRAPH 3.4.2



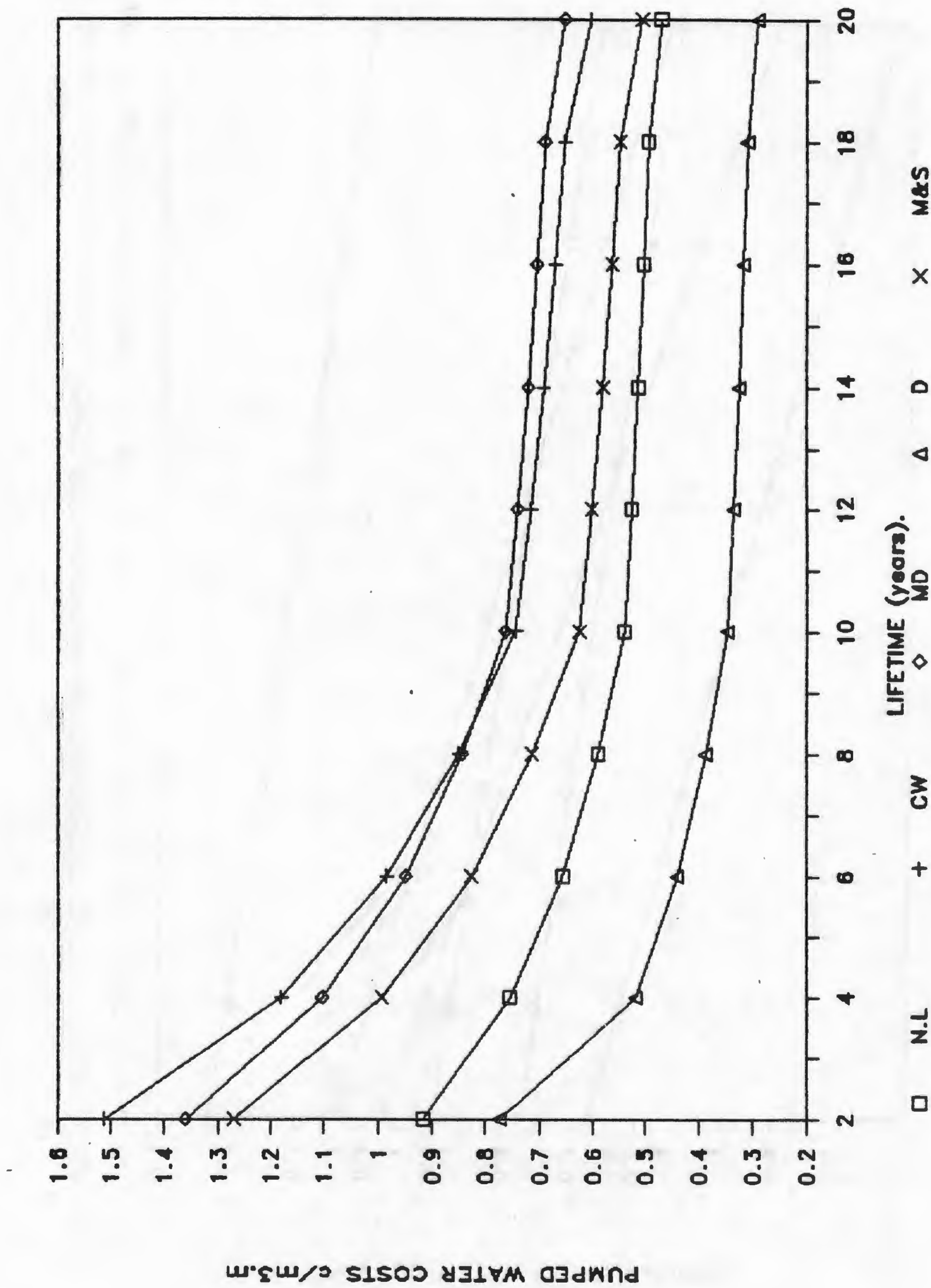
Graph 3.5

Pumped water Costs vs Maintenance Costs.



Graph 3.6

Pumped Water Costs vs Lifetime.



Chapter Four

Rural Water Schemes in South Africa: Case Studies in KwaZulu and Transkei

Introduction

The problems of water supply in underdeveloped rural areas exist throughout South Africa and the independent 'Homelands'. In recent years the South African Government, Homeland Governments and many aid organisations have allocated increasing sums of money to the provision of water supplies in rural areas.

A wide range of technologies and implementation methodologies have been adopted, but there has been little or no effort to assess the success, failure or relative merits of those methodologies or technologies.

Due to financial and time limitations imposed by the project, the assessment of village water supply schemes was restricted to those in KwaZulu and Transkei. However, the technologies most commonly used in these areas for village water supplies - handpumps, windpumps and spring protection - are typical of those used throughout South and Southern Africa.

In this Chapter the organisation, implementation methods, technologies and provision of maintenance services are described for Government administered water supply schemes in Transkei and KwaZulu, and for schemes administered by aid organisations in these areas.

The schemes are then evaluated in terms of their success in providing an adequate, reliable supply of water, based on the user's perception of the scheme, as identified by the use of interview questionnaires, and observations made during the village case studies. The technological and methodological implications of the results of the village case studies are then discussed.

4.1 KwaZulu Village Water Schemes

Village water supply schemes in KwaZulu are administered by the KwaZulu Department of Agriculture and Forestry, the KwaZulu Water Development Fund and, to a lesser extent, by aid organisations such as Valley Trust and World Vision.

The Department of Agriculture and Forestry and the Water Development Fund operate in tandem, providing the same type of water schemes - boreholes equipped with handpumps, but with slightly different implementation methodologies. Valley Trust and World Vision provide water supplies based primarily on spring protection. The methodologies of these organisations are similar to those of the Transkei Appropriate Technology Unit, which is described in Section 3.1.1.

4.1.1 Government Administered Water Schemes

The administration of KwaZulu's Agricultural services is divided into four regions, with about six districts per region. Each district is then subdivided into wards, with each ward being named after its' Headman. The regions are administered from the KwaZulu Legislative Assembly in Ulundi.

At present the provision of village water supplies in KwaZulu is restricted to areas which have undergone betterment planning, although this rule was not applied during the 81/83 drought. In the betterment planning process, agricultural, grazing and woodlot areas are identified, and residential areas chosen, usually such that people are housed near roads. The residential areas are not chosen with respect to water resources, with the result that less water may be available for domestic purposes after betterment planning than before.

Villages in need of water supply improvement are identified by Agricultural Officers of the Department, who submit a report to their regional office, which is then forwarded to the central administration in Ulundi. The Department presently budgets for between 150 and 200 boreholes per year (Berridge; 1986 Pers Comm).

The Department collates the reports submitted by its field officers and, based on this information, draws up a priority list of villages for borehole water supplies. In order to achieve the most efficient use of their fixed financial resources, a single district is chosen for water supply improvement rather than one ward. Water supply schemes are then implemented throughout the needy wards in that district, such that the travel costs incurred by the contracted borehole driller are minimised.

The water schemes are implemented by a contracted borehole driller, the borehole site being chosen by geological survey. The contractor is responsible for checking the output and water quality of the borehole and installing a Mono Direct Drive handpump.

The technology used for village water supplies is fixed at one Mono Direct Drive handpump, irrespective of whether 20 or 200 families are to be served. Although some National reciprocating hand pumps have been used, Mono handpumps are regarded as the most reliable make available. Some wind pump schemes have been installed, but windmill supplies are no longer favoured due to their high cost and susceptibility to storm damage.

Until recently no central record of borehole installations in KwaZulu was kept. However, Agricultural Officers are now instructed to record the position of boreholes in their districts, such that the Department will eventually be able to produce a map of water sources in KwaZulu.

The average depth of boreholes in KwaZulu is 30 to 60 metres, but they can be found as deep as 80 metres. Boreholes are accepted for use in village water schemes with a minimum output of 600 litres/hour (Berridge; 1986 Pers Comm)

In 1981 the KwaZulu cabinet passed a resolution that urban water supplies would be the responsibility of the Department of Works, the provision of rural water supplies the responsibility of the Department of Agriculture, and maintenance of those supplies the responsibility of the Tribal Authorities. The latter part of this resolution was not successfully implemented and maintenance became the responsibility of the Department of Agriculture and Forestry. Water supply teams were created for this purpose and are presently administered from the Legislative Assembly in Ulundi.

The stated policy of the Department is to develop springs in favour over borehole supplies wherever possible. The Department provides free transport and materials at cost price for spring protection, and a supervisor to direct the construction. However, it was found during the course of the case studies that many unprotected springs exist in close proximity to borehole supplies.

In general there is little or no community involvement with government administered water supplies in KwaZulu. Although the practice of establishing water committees and handing over the completed water supply scheme to the community has begun in the Southern Region, the other three regions have not yet adopted this approach.

4.1.2 KwaZulu Water Development Fund

The KwaZulu Water Development Fund was established in 1981 as a result of the severe drought which occurred during the summer of 1980. The first actions of the Fund were to hire water tankers to provide immediate relief to drought stricken areas. After that the Fund began working towards providing long term solutions to the problems of water supply and initiated a programme of providing borehole water supplies similar to those used by the KwaZulu Government. Extensive fund raising activities have since been carried out. Money collected by the Fund is administered by the South African Sugar Association.

From its inception the Fund has recognised the need for the participation of communities in the development of their own water supplies. However, it has also been recognised that the use of community participation is not always appropriate, and water supplies may be implemented without community participation on humanitarian grounds. For example, during the 1983/84 drought boreholes were installed without the usual community contributions in order to alleviate the effects of the water shortage.

In general, the implementation methodology of the Fund is that the community elect a Water Committee under the supervision of an Agricultural Officer. The committee is then responsible for raising a financial contribution to the cost of the scheme, usually of the order of R1 000 to R1 500 (the total cost of each completed borehole installation and Mono Direct Drive handpump being about R4 200).

Once completed the borehole installation is handed over to the community, and they are responsible for maintenance of the supply. The community is advised to raise money for repair or replacement of the supply. More usually, however, the schemes are repaired by Government maintenance teams.

Villages are selected for water supply improvement in the same manner as that described for the Government administered schemes. The schemes are the same in all respects, except for the community participation and financial involvement.

The 1984/85 progress report of the Fund records that, since its inception, a total of 459 boreholes had been commissioned. The total number of boreholes sunk was 623: uncommissioned boreholes were either dry or rejected as the water was unfit for human consumption. The Fund operates three borehole drilling machines on a contract basis, whereby dry boreholes are not paid for.

The report also states: "A recent survey concluded that- (1) No boreholes had failed because of water flow. (2) Those that were out of order were being repaired by the community concerned and/or the KwaZulu Government. Only 6% of the boreholes at the time of the survey were experiencing problems, which is not an abnormal percentage".

This may be compared to the results of the village case studies in KwaZulu, in which it was found that a considerable percentage of the boreholes studied suffer from inadequate yield and communities generally regarded the maintenance of boreholes and pumps to be the responsibility of the Government.

4.1.3 Independent Water Supply Schemes

4.1.3.1 Valley Trust

The Valley Trust is a non-profit, non-Government organisation, which "promotes health among the Zulu people in the Valley of a Thousand Hills outside Durban" (Mann; 1985 p1). The philosophy of the organisation is to apply a holistic approach to the interlinking causes of poverty and underdevelopment - poor education, unemployment, migrancy, illegitimacy, discriminatory legislation, unhealthy diets and inadequate water.

The Valley Trust's Technical Section approaches these problems with projects that link rainwater collection, improved pit latrines, spring protection schemes and piped water supplies.

In all these projects the Valley Trust acts in an advisory role, relying heavily on community involvement in planning, construction and maintenance of the projects. In addition, the Valley Trust provides technical training facilities in spring protection and ferrocement construction techniques. These technical services are provided free to communities, who are then responsible for collecting money to pay for hardware and materials.

A water committee is elected to organise the collection of money for spring protection, usually at a rate of R1 per head initially, followed by regular collection of 10c or 20c per person. A maintenance officer is chosen at a village meeting and observes the construction of the spring protection and is advised on maintenance or repairs that may be necessary.

An interesting feature of the Valley Trust's spring protection programme is that knowledge of it has spread by word of mouth through the Valley of a Thousand Hills, such that three or four applications for assistance with spring protection are received monthly by the Trust (Mtembu; 1986 Pers Comm)

The Valley Trust has in the past used various technologies for water supply apart from the rainwater collection and spring protection used presently. In 1979, 12 shallow wells equipped with Stewart & Lloyds manufactured wing pumps were installed. The installations failed within a short period, however, either due to blockages in the well or failure of the pump. None of these installations presently exists. A hydro ram has also been used in the past, which failed during a drought period (Friedman; 1986 Pers Comm).

The problems of water collection in the Valley of a Thousand Hills are those of water quality, quantity and distance. It is conceded by the Valley Trust that spring protection is not an ideal solution to the problem of distance to water. A proposed solution to this is the use of mobile diesel or petrol driven pumps to lift water from the spring collection tank to the top of the hill, an estimated height of usually 30 to 40 metres. Dr Irwin Friedman of the Valley Trust favours such pumps as an appropriate technology in the Valley of a Thousand Hills, which could provide a high level of water supply at a reasonable cost. An additional advantage would be that all the hardware associated with the water supply scheme would be above ground, providing easy access for maintenance.

Due to the financial and time restraints of the project, it was not possible to evaluate the spring protection programmes of the Valley Trust. However, the planning methodology, construction techniques, community role and maintenance service are similar to those of TATU. Two spring protection schemes administered by TATU are assessed in Section 4.5.4.

4.1.3.2 World Vision

World Vision was founded in 1950 in Korea by an "itinerant American evangelist" (Cuthbert; 1986 p2), and became established in South Africa in 1967. It is a world-wide Christian charity, operating in 90 countries with a staff of over 15 000.

In South Africa World Vision is reported to be involved in 247 projects helping over $^1/_2$ million people (ibid). The field expenditure for 1986 was R8.4 million in South Africa, one-third of which was raised within the country.

All of World Vision's projects are community based, with the objective of improving the quality of life for the whole of man - physical, spiritual and educational, with the ultimate goal of "helping people stand firm on their own feet" (Cuthbert; 1986 p2).

In KwaZulu, World Vision and Valley Trust have initiated a unique water supply project which involves laying twelve kilometres of pipeline in the Valley of a Thousand Hills. This will provide access for more than 13 000 people to clean piped water (Whibley; 1986 p5). It is a community project providing short term employment for hundreds of men as labourers, and permanent positions for stand-pipe attendants and water bailiffs.

In this project, people will pay for their water (at a rate which is about ten times as much as paid by 'whites' for water) as well as a joining fee of R20. The water is supplied by the Pinetown Regional Water Services Corporation. Whibley (1986 p5) reports that, according to Mr R E Mills (the Chief Engineer), "If people can raise the finance, we shall be happy to provide them with water". It is argued by the South African water authorities that the provision of water is the responsibility of the KwaZulu Government - despite the fact that many of the resources (dams and pipes) are in South African territory, but often pass through or very close to underdeveloped rural areas on their way to white suburbs.

World Vision also provides spring protection schemes in KwaZulu. Their method of spring protection is similar to that used by other aid organisations - constructing a concrete box to enclose the eye of the spring and piping the water under gravity to a ferrocement tank. As with the other projects, the community donates labour and materials. A financial contribution is collected wherever the community can afford it.

4.2 KwaZulu Village Case Studies

Village case studies were conducted of Government and Water Development Fund administered water supply schemes. As described in Appendix 6.1, Methodology, information in the case study villages was collected by the use of interview questionnaires, informal discussions and direct observation. In some of the case study villages, village meetings were attended at which the problems of water supply were discussed. All the villages were visited during June 1986, with the exception of Mndini and Luyengweni, which were visited in April 1986.

4.2.1 Nhlangwini, Location No. 8.

Nhlangwini is in the northern part of the Sipofu district of KwaZulu, about 20 km from High Flats. The village was visited in the company of Mr Mkhitni, a Senior Agricultural Officer of the Department of Agriculture and Forestry. A village meeting was attended, during which the problems of water supply and other problems concerning the implementation of "betterment planning" of the village were discussed. Questionnaire interviews were administered to users of the four borehole installations discussed below by Mr Godfrey Ndlovu, a villager with Standard 8 education.

Eleven boreholes were installed in the Location during January 1985 and fitted with Mono Direct Drive handpumps by contractors operating on behalf of the South African Sugar Association (SASA). The location of the boreholes was decided by the contractor, with no input from the community involved. Although the benefitting community usually contributes to SASA administered schemes, there was no financial or labour contribution in this case.

At the village meeting several villagers complained that there were too few pumps with respect to the population, with the result that long queues occurred and people resorted to collecting water from unprotected springs. There were instances of diarrhoea thought to be caused by water from these springs.

The attitude of the villagers who attended the meeting was generally that it was the Government's responsibility to maintain the handpumps and to either provide further boreholes or protect the existing springs.

Before installation of the boreholes a meeting was held between the Tribal Authority and the Senior Agricultural Officer for the district, at which an "umbrella" water committee was established for the Location. At later meetings it was claimed that sub-committees were formed for each borehole. However, it was found that these sub-committees had not become active, and many villagers were unsure of their existence.

Ndwebu

The Mono Direct Drive handpump installed at Ndwebu is used by over 80 families. Although the pump was operable, it was observed to be difficult, with a heavy ratchet action of the handle. It was observed that the pump produced 20 litres of water in ten minutes (equivalent to an output of 120 l/hour). The depth of the borehole was reported to be just over twenty metres.

The previous water source at Ndwebu was an unprotected spring. The time taken to collect water from the spring averaged 35 minutes. All respondents said they had collected water three times a day from the spring, and now collected water three times a day from the handpump.

The villagers complained that it was harder to get water now than before the pump was installed, and reported having to wait in queues at the pump, commonly for one hour but up to three or four hours. The pump was reported to run out of water during busy periods.

It was claimed that the water committee had been chosen by the Government, and that it was the water committee's responsibility to repair the pump. None of the respondents thought the handpump operated adequately. Suggestions for improvement of the water supply situation included spring protection, dam construction and the use of a windpump.

Assessment

The handpump was given free to the community, who were reportedly not consulted about the scheme. A water committee was formed, but appears to have no responsibilities and has not performed any useful function. An unprotected perennial spring exists in the area which, although not confirmed by observation, is used for domestic water when the pump runs dry or there is a long queue.

The user's perception of the water supply scheme is that, although it provides clean water, it has not reduced the burden of water collection in terms of time or distance, and may even have increased it, due to the periods spent queuing and the difficulty of operating the pump. It should also be noted that several pit latrines are sited on the slope above the handpump.

Pitoli

The Mono Direct drive handpump installed in January 1985 at Pitoli was found to be barely operable and the pumping action was accompanied by the sound of falling water. It was observed that ten minutes of continuous pumping, requiring a considerable effort, produced ten litres of water (equivalent to a continuous output of 60 litres/hour). The depth of the borehole was not known. However, the pump was observed to be situated approximately ten metres from an unprotected spring.

It was found that not all the villagers used the handpump, due to the low output, but collected water from the unprotected spring instead. A protected spring also exists nearby, but it was found that the spring box was broken and villagers regarded water from this source as dirty.

Water collection times for the spring were reported to be between thirty and forty-five minutes, with an average of three trips per day. The collection times were found to be the same for the handpump. There were several complaints of having to queue for long periods at the handpump. In addition, the pump was reported to run out of water during busy periods.

All the respondents said that no water committee was formed, and that it was the Government's responsibility to repair the handpump.

Assessment

Although it was claimed by the Tribal Authority that water committees had been elected for all the boreholes, there was no evidence of a committee existing for the Pitoli pump, and the poor condition of the pump had not been reported.

The pump suffers from a mechanical problem, possibly a faulty foot valve or broken riser main, as well as an inadequate borehole yield causing it to run dry during busy periods.

The villagers prefer water from the handpump, but resort to spring water as the pump output is insufficient. The spring was reported to occasionally dry up. None of the users thought the pump was adequate and it has not reduced the burden of water collection or significantly increased the amount of water available.

Mdonini

The Mono Direct Drive handpump installed at Mdonini was found to be operating adequately, with an observed output of twenty litres in three minutes without undue effort (equivalent to 400 litres/hour). The pump is mounted on a concrete foundation, around which was observed a muddy splash pool littered with sugar can stalks.

There were no meetings to discuss the project and no water committee was elected. The previous source of water used was an unprotected spring, which occasionally dried up. Water collection times from the spring were reported to be between 15 and 30 minutes, with three or more trips per day. Collection times from the handpump were also reported to be between 15 and 30 minutes, but all respondents reported having to wait in queues, for periods ranging from ten minutes to one hour. In addition, the pump was reported to run out of water during busy periods.

Water from the handpump was regarded as cleaner and hence was favoured over water from the spring. None of the villagers admitted to still collecting water from the spring.

All respondents said it was the Government's responsibility to repair the pump if it broke down. None of the villagers thought the handpump was adequate; four suggested protecting the spring and installing a collection tank and one suggested building a dam.

Assessment

As with the other installations investigated, there was no evidence of a water committee having been elected. The pump output was adequate, but according to users of the installation there is a reduction in output during peak periods, resulting in queuing, and occasionally the flow stops altogether.

The user's perception of the scheme is of a Government provided pump that is the responsibility of the Government. It has increased the amount of water available, but has not reduced the burden of water collection.

Eluphepheni

The Mono Direct Drive handpump installed at Eluphepheni during January 1985 was found to have no handle. According to a nearby resident, the handle was removed by the contractor who installed the pump in order to prevent children from swinging on it before the concrete foundation had set. The pump was found to be loose on its foundation, and sand below the concrete had been removed, making that unstable also. The villagers use a nearby protected spring for their water. This was also found to be in a state of disrepair, with the collection tank loose on its foundations and a very slow input of water.

There were no village meetings to discuss the handpump project, but a water committee for the area was reported to exist. The villagers regarded it as the Government's responsibility to repair the pump.

Assessment

A water committee was reported to exist, but the missing handle had not been reported and the pump not repaired in over a year. As with the other handpumps, the villagers regarded maintenance to be the responsibility of the Government. Their perception of the handpump is that it has failed and will probably never be repaired. Hence, in their view, a new installation is needed.

Summary

Nhlangwini is relatively fortunate to have received eleven borehole installations, as many similar villages in the area have only one or two handpumps and many more have none at all.

The handpumps were donated free to the community by the Water Development Fund. Although the Tribal Authority was consulted, and an "umbrella" water committee formed, the villagers were not involved in the planning or implementation of the scheme. Where water committees for individual boreholes were formed, they appear to have no responsibilities or functions. In particular, it was found that the communication of malfunctioning or broken handpumps was inadequate.

The Mono Direct Drive handpumps operate adequately, but a high proportion of the installations visited suffer from poor borehole yields. In periods of continuous use the boreholes then run out of water, resulting in queues.

In addition, an alarmingly high number of people are served by each handpump. Feachem *et al* (1978 p37) regard one handpump as sufficient to serve approximately 150 people. Although an accurate population estimate was not obtainable, a figure of sixty to eighty families or more for each handpump was common. The results of such heavy use and inadequate borehole yields are that long queues occur, insufficient water is available and people resort to other sources of water, such as the unprotected springs which occur throughout the location.

4.2.2 Impaphala

The village of Impaphala is situated in the Ntuli Ward of the Inkanyesi District of KwaZulu. The district has a mean annual rainfall of 850 mm and was fortunate not to suffer the recent drought. Impaphala was visited in the company of Mr Myeza, a Senior Agricultural Officer of the Department of Agriculture and Forestry. Interview questionnaires were administered to users of the borehole installation by Mr Myeza. An informal village meeting was attended, during which the problems associated with water supply were discussed.

A Mono Type 3 handpump was installed in the village in 1982, following a request to the Government by an informal leader of the area, Mr C Mtshali. The pump was installed by a contractor, with no labour, financial or planning input from the village. At that time, however, a water committee was elected following two village meetings. The Chairman of the Impaphala Water Committee (Mr Xulu), who is also a village Induna, was interviewed. It was found that the Committee is still in existence with a responsibility to "safeguard the pump".

Before installation of the pump the villagers utilised an unprotected spring and river water. All the villagers interviewed collected water three times a day from these sources, with the time taken for each trip varying from 15 minutes to 60 minutes. Three trips are now commonly made to the handpump, but all the villagers claimed that each trip now took longer. Increases of between 5 and 15 minutes were reported.

The handpump is regularly used by sixty families. In addition, people from nearby villagers who own cars occasionally use the pump. It was reported that the Mono Type 3 handpump had not broken down once in four years of use. It was observed that twenty litres of water could be pumped in five minutes (equivalent to 240 l/hr), but the effort required for this was considerable, such that longer times were common. Many villagers complained of long queues at the pump, often for between thirty minutes and an hour.

The villagers said it was the Government's responsibility to repair the pump, and that the pump was occasionally serviced by a Government employee.

It was suggested that, in order to improve the water supply situation, the springs should be protected (these are presently used for washing water) and further boreholes should be provided.

Assessment

The four years of uninterrupted service provided by this handpump is the longest recorded of all the borehole installations visited during the study. Many other installations were found which had failed within a year. Three factors can be identified which may have influenced the reliability of this pump: first, the borehole yield is adequate and the pump does not run dry; second, the pump has been serviced by a Government employee; third, the community and water committee regard the well-being of the pump to be their responsibility, and recognise that misuse or abuse would damage the pump. The attitude of the villagers may be influenced by the apparently progressive leadership which was observed in the Induna, Mr Xulu, and in Mr Mtshali, a prominent and wealthy farmer.

A combination of these factors has resulted in the pump providing the highest level of service practical for the scheme: a reliable supply of clean water, although with an insufficient output with respect to the number of users. As with the other schemes visited, the problem of queuing can lead to villagers collecting water from unprotected surface sources.

4.2.3 Mbongolwane

The village of Mbongolwane is also in the Ntuli ward of the Inkanyesi district of KwaZulu. It is situated about ten kilometres east of Impaphala, near a small 'white' settlement called Petts Shop. There is a hospital about 1,5 kilometres from the village.

A Mono Direct Drive handpump was installed in the village in 1983. The pump was donated by the SASA to alleviate the effects of drought and there was no community financial contribution to the scheme. A water committee was elected following two village meetings, with the responsibility to "watch for the handpump" (Mr P Dlamini, Secretary of the Water Committee).

Mbongolwane was visited in the company of Mr Myeza. An informal village meeting was attended, during which the problems of village water supply were discussed, and interview questionnaires were administered to users of the handpump.

Other sources of water existing in the area are an unprotected spring, a river and another handpump situated at the hospital. Prior to installation of the village handpump water was collected mostly from the river, which was reported to have become "lower and dirty" during the drought, and the unprotected spring. Water from the handpump is now favoured over these sources as it is regarded as being cleaner.

It was found to take fifteen minutes to fill a twenty litre bucket (equivalent to a continuous output of 80 l/hr) from the pump.

It was reported that the pump output diminished during busy periods which caused queues to develop. The handpump is utilised by thirty families, although it was admitted that families further away regularly collected water from the river. Some villagers complained that water from the pump was occasionally dirty. This was thought to be the result of villagers washing clothes near the handpump.

The handpump was reported to have broken down during the winter of 1985. The handle was broken and was repaired by a Government worker. The pump was out of order for three weeks, during which time water was collected from the river and unprotected spring. A few villagers said they collected water from the hospital pump during that time.

Water collection times from the river (the most popular source before installation of the pump) were found to be between fifteen and thirty minutes, with most people completing two trips per day. No time saving in collecting water from the handpump was reported.

A range of suggestions for improving the water supply situation were recorded. The most frequent suggestions were that more handpumps should be installed and the spring should be protected. Other suggestions included providing standpipes and training a villager to service and repair the pump.

<u>Assessment</u>

The Mbongolwane handpump has replaced the river as the main source of water for the villagers. However, the low output of the pump and its remoteness for some of the villagers has resulted in the continued collection of river water for domestic consumption.

The villagers have accepted a responsibility for the condition of the handpump, and the Water Committee helps to ensure it is not damaged negligently. When the pump was out of order most of the users preferred to collect water from the nearby river, than walk the 1,5 kilometres to the hospital pump.

4.2.4 Mnafu

Mnafu is in the southern part of the Sipofu district of KwaZulu, about 15 km from Sipofu itself. The village was visited in the company of Mr Mkhitni, a Senior Agricultural Officer of the KwaZulu Department of Agriculture and Forestry. A village meeting was attended, during which the problems of water supply in the area were discussed. Interview questionnaires were administered to users of the handpump installations described below by Miss Gertrude Cele, a resident of the village with Standard 8 education and a sound knowledge of English.

Eleven boreholes were drilled during August 1985 by a contractor operating on behalf of the South African Sugar Association, and fitted with Mono Direct Drive handpumps. Interview questionnaires were administered by Miss Cele to users of six of the handpumps prior to my arrival in the village, only four of which I was able to visit.

A village meeting was held before installation of the handpumps, attended by representatives of the Mnafu Tribal Authority, villagers and Mr Mkhitni. At the meeting an "umbrella" water committee for the area was established, and it was agreed that the community would contribute R1 000 per borehole and elect water committees for each pump, with the responsibilities of collecting money, safeguarding the pump against misuse and reporting breakdowns to the Tribal Authority.

At the village meeting attended during June 1986, there appeared to be a general disillusionment with the handpumps, as they had not improved the water supply situation as had been expected. The most common complaints were that the output of the pumps was insufficient, which resulted in long queues, and that there were too few pumps with respect to the population. There were also several complaints that water from the boreholes was dirty and discoloured.

It became apparent during the meeting that although water committees had been elected for each pump, they had not become active and the financial contribution towards the scheme (R20 per family) had not been collected. Many families appeared to be reluctant to pay since the boreholes had not noticeably improved the quality or quantity of water available to them, and in addition were sited far from the household and were difficult to operate. As a consequence it was reported that water was frequently collected from unprotected springs.

The Deputy Chief of Mnafu, Mr Herbert Cele, was very critical of the return to surface water sources and reluctance to pay financial contributions. He attributed the discolouration of the pump water to grease in the pump, and emphasised that the amount of R20 per family had been agreed upon by the community at the initial meeting. He then added that complaints about the boreholes should not in future be directed at the water committee, but should go straight to him instead. Finally Mr Cele said that villagers were not used to the taste of underground water and ordered that the collection of money should continue until everyone had paid.

Enkambeni

The Mono Direct Drive handpump installed at Enkambeni during August 1985 was found to be inoperable. It was reported to have failed "within days" of being installed.

A water committee was elected by the community before the pump was installed following three village meetings. However, the failure of the pump had not been reported to the Tribal Authority, Umbrella Water Committee or the district Agricultural Officer. The financial contribution to the scheme was reported to have been collected.

A protected spring exists near the site of the pump, which is presently the only source of water for the villagers. It was found that the foundation of the concrete reservoir was cracked, which resulted in water leaking. The spring was reported to occasionally dry up during the winter months.

The villagers were found to view responsibility for repair of the pump as that of the Water Committee. Unfortunately no committee members were available for comment during the visit.

Assessment

The failure of the Enkambeni handpump has not had a detrimental effect on the water supply situation since water is available from the protected spring. However, this source was reported to be insufficient and unreliable, such that some form of water supply improvement is necessary.

The water committee responsible for the pump has failed to facilitate any repair. The consequences of this may include a general disillusionment on the part of the villagers with the payment of financial contributions to water supply improvement and the efficacy and desirability of water committees.

Mntengwane

The Mono Direct Drive handpump was installed at Mntengwane in August 1985, following three village meetings, the election of a Water Committee and a collection of household financial contributions to the scheme. The only other source of water in the area is a nearby river, which was reported to dry up during the winter months.

All the villagers interviewed or spoken to said they often had to wait in queues and that the water from the pump was dirty or discoloured and smelled. Some villagers said they used water from the river in preference, as "... the one in the handpump is sour and smelling". Water from the handpump was found to have a slight sour taste, but no discolouration or odour was observed. The output of the pump was not recorded.

No breakdowns of the pump were reported. None of the villagers interviewed knew whose responsibility it was to repair the pump, or who would pay for such repairs.

Suggestions for improving the water supply situation included installing a different kind of pump, preferably a windpump, and reducing the wastage of water collected from the pump. It was not specified how such wastage occurred, or how it could be reduced.

Assessment

The handpump has provided an alternative and possibly more reliable source of water for the residents of Mntengwane. Unfortunately, the problems of queuing and water quality have reduced the benefits to the community, resulting in many villagers continuing to collect water from the river for domestic use. These problems had not been reported to the Tribal Authority or the umbrella Water Committee.

Esiqungeni

The Mono Direct Drive handpump installed in Esiqungeni in August 1985 was found to be operable, but with problems of difficult movement and sour tasting water.

The other water sources that exist in the village are a river and unprotected spring, both of which were reported to occasionally dry up. All the villagers interviewed said that the water from the handpump was dirtier than the other sources. In addition, the villagers complained that operation of the pump was difficult and that it occasionally would not move at all.

The output of the pump was observed and it was found to take fifteen minutes of continuous pumping, requiring a considerable effort, to fill a bucket of twenty litres capacity (equivalent to a continuous output of eighty litres per hour). A small amount of water was tasted, and found to be slightly sour, but odourless and colourless. A large splash pool was seen around the pump, littered with pieces of sugar cane and other organic material, and with a noticeable population of flies and other insects.

Most of the villagers said that they still collected water from the river or spring, especially during busy periods or when the handle of the pump was found to be stuck. The only suggestions for improving the water supply situation were that the Government should provide more boreholes.

Assessment

The handpump installed in Eqiqungeni has provided an alternative source of water, but one which is unreliable and not perceived as providing good quality water. As a result of the queues, poor quality water and difficulty of operation of the handpump, villagers have continued to collect water from the river.

Upper Mnafu

The Mono Direct Drive handpump was installed in Upper Mnafu following a single village meeting at which a water committee was elected. The committee was responsible for collecting the household financial contribution to the scheme, but at the time the village was visited not all the contributions had been paid.

The villagers were found to be reluctant to use water from the pump. At the village meeting attended by myself and Mr Mkhitni, there were several complaints from residents of Upper Mnafu that the pump water was dirty, unfit to drink and that "red worms with black heads" were occasionally found. These were said to also occur in a nearby pool of surface water. It was also claimed that the pump water was not suitable for washing clothes as it spoilt the colours of garments.

The only other source of water available in the village is an unprotected spring. Although the handpump output was sufficient, many villagers said they preferred to use water from the spring as this was cleaner and tasted better.

It was observed that the pump was sited on a concrete foundation, around which existed a muddy splash pool littered with sugar cane sheaths. As with the pump at Esiqungeni, this pool was observed to support flies and other insects.

Assessment

The handpump has provided an alternative, more reliable source of water. Unfortunately the problem of water quality has meant that villagers continue to use water from the unprotected spring.

The water committee appears to be inactive: many household contributions to the scheme had not been collected at the time the village was visited, and the condition of the pump and its surroundings appear to have been neglected. The pump has not reduced the burden of water collection, although more water is now available than before it was installed.

Summary

Before summarising the relative merits of the Mnafu handpump schemes, it is important to remember that Mnafu is relatively fortunate to have received such a scheme. According to Mr Mkhitni, the Senior Agricultural Officer of the Sipofu district, only six out of twenty-eight locations in the district have received borehole installations.

The handpump schemes were planned and heavily subsidised by the SASA. The community contribution of R1 000 per borehole was paid to the SASA from the Tribal Account. Water committees were elected for each borehole but at the time the village was visited, ten months after installation of the pumps, not all the family contributions had been paid. Other than collecting money, the water committees appear to perform no other function.

The users of the handpumps complained frequently of the low output of the pumps and the poor quality of the water. However, these complaints had not been reported to the Tribal Authority or the umbrella water committee. The failure of the Enkambeni handpump and the difficulties of operation of other pumps had also not been reported.

With the exception of the Enkambeni installation, the Mono Direct Drive handpumps were observed to operate adequately, but frequently suffered from inadequate borehole yields.

The handpump installations are inadequate with respect to the number of people served by each. The recommended number of users of a single borehole installation is 150, equivalent to about thirty households (Feachem *et al*; 1978 p37). The handpumps in Mnafu served commonly between fifty and eighty families. This factor, combined with the problems of inadequate borehole yield and poor water quality has resulted in villagers continuing to use other sources of water, including rivers and springs.

4.3 Summary and Discussion of the KwaZulu Case Studies

The results of the village case studies conducted in KwaZulu are summarised in Table 4.1. From this Table and the preceding pages it can be seen that a number of inadequacies and problem areas were identified in the present water supply technologies and methodologies applied in KwaZulu.

The choice of Mono handpumps in KwaZulu is predicated by a desire to reduce the number of pump failures and the pressure on the water supply maintenance teams. However, there are certain opportunity costs associated with the use of the Mono pump. Firstly, Mono pumps are more expensive than equivalent recipricating pumps and have considerably less output. Secondly, it was found in some villages during the study, notably Pitoli, Enkambeni and Esiqungeni, that the use of Mono handpumps is not necessarily "maintenance free". The main causes of failure were insufficient borehole yields, failure of the bottom valve, so allowing water to drain out of the rising main, and problems associated with the ratchet operation of the handle. A positive point to note is that no instances of pump failure due to damage caused by misuse or pilferage were recorded.

Of the 24 Mono Pump installations covered, 15 were found to be working adequately, 7 were supplying water but with operational difficulties, and two were not working at all. Of the 7 working with difficulty, 2 produced dirty or discoloured water which villagers claimed was unsuitable for drinking, three operated with a heavy or difficult action and minimal output, and one had a faulty footvalve, requiring strenuous effort to produce a trickle of water. Of the two not working, one had no handle and one a suspected broken shaft.

Hence, of this non-random sample of installations, it can be seen that approximately 40% of the installations were not

Table 4.1 Summary of KwaZulu Village Case Studies

Village	Pump	Output	Community Contribution	Problems
Nhlangwini, Location No 8				
Ndwebu	Mono D D Jan. 1985 W.D.F.	120 l/hr	Water Committee formed, but inactive.	Heavy action Queueing Insufficient borehole yield
Pitoli	Mono D D Jan. 1985 W.D.F.	60 l/hr	Water Committee formed, but inactive. Pump conditiion not reported.	Heavy action Queueing Insufficient borehole yield
Mdonini	Mono D D Jan. 1985 W.D.F.	400 l/hr	None.	Queueing Insufficient borehole yield
Eluphepheni	Mono D D Jan. 1985 W.D.F.	Inoperable	Water Committee formed, but inactive- missing handle not reported.	Handle missing
Inpaphala	Mono Type 3 1982 Govt.	240 l/hr	Water Committee formed, still active "to safeguard the pump".	Queueing
Mbongolwana	Mono D D 1983 W.D.F.	80 l/hr	Water Committee formed.	Queueing Insufficient borehole yield
Mnafu				
Enkambeni	Mono D D Aug. 1985 W.D.F.	Inoperable	Water Committee formed, but inactive.	Possible broken shaft Breakdown not reported
Mntengwani	Mono D D Aug. 1985 W.D.F.	unknown	Water Committee formed, some households paid R20.	Queueing Dirty water
Esiqungeni	Mono D D Aug. 1985 W.D.F.	80 l/hr	Water Committee formed, but problems not reported.	Queueing Dirty water Difficult operation
Upper Mnafu	Mono D D Aug. 1985 W.D.F.	unknown	Water Committee formed, some households paid R20 Committee now inactive.	Queueing Dirty water

working adequately or reliably. Although this figure is not statistically representative, for the reasons discussed in the Methodology (Appendix 6.1), it is worth noting that the villages were selected by the water supply planners. The Inkanyesi and Sipofu districts were chosen for their relatively high level of community involvement.

It can also be seen that the present provision of one Mono handpump per village, irrespective of the number of the number of families resident in the village, does not provide an adequate amount of water to meet domestic water requirements. As a result many villagers continue to collect water from unprotected surface sources. Further, for each village that has recieved a Mono Pump installation, there are a considerable number of others that have recieved no water supply improvement at all.

It was stated by representatives of the KwaZulu Department of Agriculture and Forestry that there is an increasing realisation that maintenance of village water supplies should be, at least partly, the responsibility of the village. Although in some cases village water committees were found to have been elected with the introduction of the Mono pump, no evidence of village maintenance was found. Instead, a considerable proportion of the water committees were found to be inactive, or have no meaningfull responsibilities. An exception was found at Mbongolwane, where a Mono Type 3 handpump was found to have been operating for over four years. In this instance an active water committee exists, with the responsibility of ensuring the correct use of the pump. The committee had succesfully organised repair of the pump on more than one occasion. Conversely, in Mnafu where villagers had contributed financially to the scheme through the Tribal Authority as well as electing "umbrella" and local water committees, pumps were found which had been either broken or operating inadequately since their installation.

At the time Mnafu was visited, little evidence of the existence of water committees was found and there were no signs that the pumps would be repaired in the near future. Rather than repair the pumps the villagers were discussing what other means of water supply improvemant could be utilised. There appeared to be no recognition that the pumps could be repaired by the Department of Agriculture and Forestry.

The KwaZulu Water Development Fund does not involve itself with the repair of the pumps it provides. Instead, maintenance of the pumps is "handed over" to the community. It appears, however, that little or no provision is made, or guidelines given on how this responsibility is to be handled by a community. In effect, the Water Development Fund pumps become the responsibility of the Department of Agriculture and Forestry. Since the villagers are often not aware of the available maintenance services, or do not know how to call on this service, many Development Fund handpumps breakdown and are not repaired.

The Agricultural Extension Officers of the Department of Agriculture and Forestry have many responsibilities, one of which is to encourage communities to become involved with their water supplies, through advice and guidance in electing water committees, collecting household contributions and so on. However, it is evident that these extension services are already overstretched and incapable, due to logistic and financial difficulties, of effecting a meaningful presence in most villages. In particular, an insufficient number of Extension Officers and an inadequate provision of transport from the centralised administrative centres was noted. This factor has tended to exacerbate the poor levels of community participation and responsibility, as well as the poor level of communication between villages and district offices, which causes further delays in the reporting of pump breakdowns.

A further factor identified during the village case studies in KwaZulu was the large number of unprotected springs existing in villages that had received Mono Pump installations. Many of the protected springs were also reported to be in a bad state of repair.

The KwaZulu Department of Agriculture and Forestry do conduct a limited number of spring protection schemes, and offer materials and assistance to communities to construct their own schemes. However, the large proportion of villages with unprotected springs encountered during the case studies would suggest that this option is underexploited at present.

Village water supplies in KwaZulu are compared to those in Transkei (windpump and spring protection schemes) in Table 4.2, which is situated at the end of Section 4.6, page 190.

4.4 Transkei Village Water Schemes

Introduction

Village water supply schemes in Transkei are administered by the Transkei Department of Agriculture and Forestry and the Transkei Appropriate Technology Unit, TATU. Although TATU is largely funded by the Transkei Government (TATU Progress Report, 1986 pii), their methodologies and activities are not influenced by the Government, and are regarded here as being non-Governmental.

4.4.1 Government Administered Water Schemes

The administration of Transkei's water supply services is divided into three regions and 28 districts, administered by the Department of Agriculture and Forestry. The administrative centre is in Umtata, from which all water supply and related services are directed.

In Transkei, as in KwaZulu, the provision of Government administered water supplies is confined to villages which have undergone "betterment planning". The betterment planning process involves the establishment of four grazing camps, a communal arable plot and the rehabilitation of the population into a selected area. This area is usually chosen to be near a road, with little or no reference to the availability of water (Shaker; 1986 Pers Comm).

The Tribal Authority is responsible for applying for water supply improvement. As with the KwaZulu Government schemes, a single district is identified for priority in order to save transport costs. Transkei has its own borehole drilling machine, which was donated by World Vision.

Between 100 and 150 boreholes are reported to be drilled per annum. The usual water supply scheme then involves the installation of a windmill, the construction of a distribution reservoir at the highest point in the village and the reticulation of water under gravity to standpipes. The standpipes are reported to be sited such that no household is more than 250 metres away from a water point.

On average between thirty and forty such schemes are implemented yearly in Transkei, each serving a village of usually 450 to 550 people. The average cost of each scheme is reported to be R120 000, comprising about R15 000 for the windmill, R15 000 - R20 000 for the reservoir, R4 000 - R5 000 for the borehole, and the remainder for piping (the largest component), transport and labour (Shaker; 1986 Pers Comm).

In the last ten years 1 300 such schemes have been implemented. It was estimated that at April 1986, 800 to 900 of these were in working order (ibid). In 1986, R750 000 was allocated to maintenance of Transkei's windmill water supplies (Mcetywa; 1986 Pers Comm). The distribution of this money was as follows: R300 000 to private contractors for repairs; R450 000 to the Department for maintenance services, consisting of R350 000 for spare parts and R100 000 for transport and labour.

The Departmental maintenance services are administered from Umtata. Three maintenance teams are used, each consisting of one trained windmill operator and six labourers. The major problems associated with maintenance were reported to be a shortage of experienced windmill operators and the high cost of spare parts.

On average the first breakdown of a windmill scheme was estimated to occur three months after installation. The most common causes of failure were reported to be rotor failure in high winds, failure of the transmission gearbox on the rotor head, and failure of the piston-cylinder pump unit, most commonly due to being pumped dry. The average time taken for repair was reported to be three months, but was dependent upon the time taken for the Department to be notified by the village concerned.

The windmills employed within Transkei consist of 60% Southern Cross (most commonly the Seneschal model) and 40% Climax (most commonly the Nos. 10, 12 and 14). With respect to reliability and maintenance, Climax windmills were reported to be favoured, due to their stronger 4-posted tower and the relative simplicity with which the gearbox can be replaced.

The windmill schemes are planned, implemented, maintained and financed entirely by the Department of Agriculture and Forestry. There is no community involvement, except that manual labourers may be hired from the community to assist in the laying of pipelines.

The provision of windmills in Transkeian villages for water supply is viewed by the Department as an interim scheme. It is eventually intended to provide reticulated water supplies in each district, which will comprise a central reservoir and purification system, with a reticulation system to distribution reservoirs in each village. Each of Transkei's 28 districts will be served by such a scheme, which are to be funded by the Development Bank.

In addition to the present provision of windmill reticulated water supplies, the Department of Agriculture and Forestry also installs Mono Direct Drive handpumps. These are used in villages which are in need of water supply improvement, but are not likely to receive a windmill scheme in the near future. The handpumps are donated free to the Government by World Vision, who then take no part in the planning or implementation of the schemes. The number of handpumps donated varies according to the stated need of the Department. Shaker (1986 Pers Comm) reports that 150 handpumps were installed in 1985. As with the other Government schemes, there is no community involvement in the planning, installation or maintenance of these handpump schemes.

4.4.2 Independent Water Supply Schemes

The largest and most active independent organisation involved in the provision of rural water supplies in Transkei is the Transkei Appropriate Technology Unit, TATU (although, as mentioned previously, TATU is largely Government funded).

TATU was established by officials within the Department of Commerce, Industry and Tourism who identified the need for an Appropriate Technology and Rural Development Organisation in Transkei, as a "parastatal organisation with the specific mission of discovering exactly what technologies, techniques and self-help community development approaches work best for Tanskeians at this moment in their history" (TATU Progress Report; 1986 piii). As such many demonstration projects are carried out by TATU, usually in partnership with motivated villages, to identify the costs and benefits of alternative methods of meeting basic needs such as clean water, village access roads, irrigated communal gardens, low cost self-help housing, rural clinics, rural self employment, community woodlots and simple pit latrines. In all of TATU's schemes the villagers are involved in self-help activities, such that a monetary or labour contribution is exchanged for TATU's assistance.

The development of small water supplies is primarily associated with the Rural Works Branch of TATU. Spring water sources are mainly used, although streams may be harnessed when they are situated near residential areas or gardens.

The methods of spring protection and community involvement used have already been reviewed in Section 3.1.1. Although this project has foccussed on water lifting technologies and their applications, it was considered desirable to investigate further the methods and results of spring protection, for two reasons. First, the potential for spring protection to improve rural water supplies in Southern Africa is vast, and surprisingly under-exploited - Dr Cecil Cook of TATU has estimated that up to 60% of Transkei's rural water requirements could be met through spring development. And secondly, spring protection techniques involve a relatively simple technology which facilitates the use of a high level of community involvement and responsibility. The TATU administered schemes involve the community at all levels - planning, finance, implementation and maintenance - and so provide a strong contrast to the Government administered water schemes.

4.5 Transkei Village Case Studies

Village case studies were conducted of three Government administered windmill water supply schemes and two TATU administered spring protection schemes. As described in Appendix 6.1, information in the case study villages was collected by the use of interview questionnaires, informal discussions and direct observation.

4.5.1 Tabase

The village of Tabase is situated about fifteen kilometres north-east of Umtata. Tabase was visited in the company of Mr Malundi, a Maintenance Officer, and Mr Shadwell, a Planning Officer of the Transkei Department of Agriculture and Forestry. Interview questionnaires were administered to users of the windmill installation by Mr Malundi, and informal discussions on the problems of water supply were held.

A Southern Cross "Seneschal" type windmill was installed in Tabase in 1975, following a request to the Government by the Development Committee of the village. The windmill was installed with two reservoirs, each of four metres diameter, serving six standpipes located in the village. A village meeting was reported to have been held before the windmill was installed, and a water committee was chosen by the Chief. At the time the village was visited none of the villagers available were sure if the committee was still in existence.

The villagers generally thought that the windmill was adequate and provided sufficient water of good quality. However, at the time of the visit three of the six standpipes were out of order, with the result that some villagers had to walk a considerable distance (up to half a kilometre) to use one of the three operational standpipes. Associated with this were some complaints of queues at the operational standpipes, especially during the early morning and evening. It was also claimed that the system ran out of water. This was reported to occur on average once a month, during windless periods.

A considerable reduction of water collection times was reported. Collection from the river (the only other source of water in the village) commonly took between 45 and 60 minutes, with two or three trips being made per day. Water collection from the standpipes was reported to take between five and twenty minutes, with as many as six trips per day.

The last breakdown of the windmill occurred during 1980 (although some villagers were unsure of this), when the windmill rotor was damaged in high winds. The rotor was reported to have been repaired between two and three months after the breakdown occurred. Whilst the windmill was out of order the villagers obtained water from the river.

The only suggestion for improvement of the water supply situation in Tabase was that the broken standpipes should be repaired. It was not possible to identify the fault during the visit.

Assessment

The installation of the windmill reticulated water supply in Tabase has greatly improved the quality and amount of water available to the villagers.

The population of Tabase at the 1976 census was 1 432. Hence the 1986 population, calculated on a basis of a 2.4% growth compound (Shaker; 1986 Pers Comm) is approximately 1 820 (although this figure does not allow for any rural migration which may have occurred during that ten year period). Assuming the population is 1 800 (which may be regarded as a conservative figure for the above reason), each of the six standpipes serves 300 people. As shown in Section 2.3, the amount of water collected per capita from communal standpipes can be expected to be about 40 litres per day. Since the design output of each standpipe is 15 to 20 l/minute, a simple calculation will show that each tap would have to be in operation continuously for ten hours per day to provide this amount (assuming an output of 20 litres/minute at all six taps).

Conversely, if the three taps presently in use operate continuously for ten hours per day, at an output of 20 litres/minute, then 20 litres per person per day is available. Since it was observed during the visit that the taps were not used continuously, then either an amount of less than 20 litres per person per day is collected, or villagers continue to obtain at least a part of their daily water requirements from the river.

It was observed that two reservoirs were in use, each of 4 metres diameter and 2 metres height, hence with a total storage capacity of 50 272 litres. The capacity required to store one day's water use, at 40 litres per person per day in Tabase, is 72 000 litres. Feachem *et al.* (1978 p37), in their assessment of windpumped supplies, showed that "one windless day (midnight to midnight) ... necessitates about two days storage to tide the village over until the wind blows".

In conclusion, the windmill reticulated water supply in Tabase does not provide an adequate volume of water. Although the water is of good quality, and when all the taps are working the burden of water collection has been reduced, the storage capacity of the system is inadequate and there are insufficient standpipes with respect to the population to provide an adequate volume of water.

4.5.2 Xhwili

The village of Xhwili is situated approximately two kilometres from Viedgesville, twenty kilometres South-West of Umtata. Xhwili was visited in the company of Mr Malundi and Mr Shadwell of the Transkei Department of Agriculture and Forestry. Interview questionnaires were administered to users of the windmill reticulated water supply by Mr Malundi, and informal discussions were held.

A Southern Cross "Seneschal" type windmill was installed in the village in 1981, together with a single four metre diameter reservoir tank with a reticulation system to six standpipes. A single village meeting was held prior to installation of the system and a water committee was chosen by the Chief. At the time the village was visited it was found that the water committee was no longer in existence. During installation of the system villagers were employed by the Department as manual labourers.

Prior to installation of the windmill the villagers obtained water from a nearby river and an unprotected spring, both of which were reported to dry up occasionally. Water from the standpipes was generally regarded as cleaner and preferable to that from the previous sources. The time taken to collect water from the standpipes was commonly reported to be between five and fifteen minutes, compared to collection times of up to an hour for the river. There were some complaints of queues at the standpipes during peak periods.

At the time the village was visited there was no water in the reservoir or the standpipes, although water had been previously available (it was reported that the reservoir had been overflowing a week earlier). The shortage of water was due to a lack of wind. Several villagers said they would have to fetch water from the unprotected spring until the reservoir was full again. The villagers claimed that the system ran out of water on average once every three weeks to a month.

The windmill pump rod broke during 1984, causing the system to be out of order for three weeks, although the repairs themselves required only two days to complete. Some time before that the windmill sails were damaged in high winds. This was reported to have taken a month to repair. It was observed that the brake cable of the windmill had been disconnected. Mr Malundi said that this was done to prevent villagers from tampering with the windmill. The villager's attitude was that they were forbidden to touch the windmill, as they may be charged with "damaging Government property".

The responsibility for reporting any breakdowns of the windmill was found to be that of the village "ranger", who is a paid Government employee responsible for maintaining stock fences.

Assessment

The provision of a windmill reticulated water supply system in Xhwili has improved the water supply situation in terms of the quality and quantity of water and the effort required to collect it. However, it is clear that the reservoir has insufficient storage capacity - one reservoir of 2 metres height and 4 metres diameter contains about 25 m^3, whereas the population of the village is 1 100 (Shaker; 1986 Pers Comm), which at 40 litres per person per day requires 44 m^3 of water for one day's use. This has resulted in the villagers continuing to occasionally use the river and spring. The villager's perception of the supply appears to be that it is reliable and adequate, although some problems of queuing were recorded.

4.5.3 Ambrose

The village of Ambrose is situated in the Mount Frere district of Transkei, about seventy kilometres north of Mt Frere itself. Ambrose was visited in the company of Mr Zipete, who was at that time Acting Director of TATU. In contrast to Tabase and Xhwili, which were both identified for case studies by Mr Shaker of the Department of Agriculture and Forestry, Ambrose was selected independently for study. Mr Zipete agreed to accompany me to translate and administer questionnaire interviews.

A Southern Cross "Seneschal" type windmill was installed in the village in 1983, with a single 4 metre diameter reservoir serving six standpipes. There were no village meetings to discuss the project and no water committee was formed. The windmill, reservoir, pipes and standpipes were installed by Government employees and no village labour was used.

At the time the windmill was installed the only available sources of water were two umprotected springs. It was found that the windmill sails had been severely damaged by high winds approximately three months after the system was installed. The windmill was still out of order at the time the village was visited. It was claimed by the villagers that they had tried repeatedly to contact the maintenance department in order to have the windmill repaired.

Early in 1986 the villagers became frustrated with the water supply situation and approached TATU to help them protect the springs. At the time the village was visited one spring had been successfully developed and a second protection scheme was underway.

Mr Joller, the Spring Development Committee Treasurer, suggested that to further improve the water supply situation in Ambrose the existing windmill should be repaired and a community member should be trained in servicing and maintenance techniques. In addition, it was suggested that that person should be allowed to use the windmill furling device during periods of high winds.

Assessment

The windmill water supply scheme installed in Ambrose did not improve the water supply situation due to its failure in high winds and the failure of the Government, for whatever reason, to repair the windmill.

It was found that the scheme had had a negative impact on the community- they had experienced the improved water supply for a short period, but then were left with only the eyesore of the broken windmill and its reservoir.

An interesting point is that the villagers have initiated their own water supply improvement with the aid of TATU. In this scheme they cooperated fully by providing the necessary money and materials, electing a Spring Development Committee and choosing a community person to maintain the spring developments. As such they embraced the concept of village level maintenance and now recognise that the windmill scheme could have been successful had a village operator been chosen and trained.

4.5.4 Mndini and Luyengweni

The villages of Mndini and Luyengweni are situated in the Mount Frere district of Tanskei, about fifteen kilometres from Ambrose and sixty kilometres from Mt. Frere itself. They were visited during April 1986 in the company of Mr Zipete of TATU. There were two objectives for this visit: first, to field test the questionnaire and second to gain some village-level insight into the operations of TATU.

At the time Mndini was visited the villagers were in the process of protecting two springs. Several women from the village were observed breaking rocks and carrying them to the eye of the spring, under the supervision of a TATU employee.

An informal discussion was held with the women working at the eye of the spring, and the Secretary of the Water Committee. The committee was elected following two village meetings, and given the responsibilities of managing the spring projection project, organising the labour needed to cap the eye of the spring and dig a trench for the pipeline, and collecting the household cash contributions to the project. The villagers who helped with the namual labour were rewarded with beer and food.

The total cost of this spring protection scheme was R2 589-00. Each user contributed R9-15 to the scheme, although at the time the village was visited not all the contributions had been collected.

Not all of the households in Mndini were involved in the scheme. Those whose houses were nearer another unprotected spring did not contribute to the scheme and continued to collect water from the other spring.

A similar situation was encountered at Luyengweni. In this case one of the two springs used for water collection had been successfully protected during February of 1986. Villagers living nearer the unprotected spring were reported to be continuing to use that water source.

The spring protection scheme was initiated by the sub-headman of the village, Mr Alfred Monakali, who contacted TATU and asked for their assistance. Two village meetings were held. At the second meeting a TATU representative helped the village elect a water committee, which was given similar responsibilities to the Mndini water committee. In this case the financial contribution was set at R10-50 per person.

An informal village meeting was held at which the spring protection scheme and the problems of water supply in general were discussed, attended by the author, three members of the water committee (including Mr Government, the Chairman of the Committee), the sub-headman and three women from the village.

There were some complaints that water from the reservoir tap was not always clean. It was thought that this may have been caused by a dirt blockage in the spring box. However, it was later found that the spring water had always been 'milky' - a problem that could not be solved by spring protection.

The suggestions for improvement of the water supply situation in the village were mainly that the other springs should be protected, and that further standpipes should be connected to the water reservoir. There was some discussion amongst the water committee members of how this could be achieved.

Assessment

The protection of the springs at Mndini and Luyengweni has improved the quality and quantity of water available to those villagers who use the springs. In addition, the establishment of responsible water committees and the training of villagers in maintenance requirements should ensure that the springs provide a reliable source of water. A further benefit of the continuing operation and motivation of the water committee is that the villagers are now aware of their own potential to improve the water supply situation. Luyengweni was the only village encountered during the village case studies at which the villagers were motivated to improve the water supply situation of their own accord.

4.6 Summary and Discussion of Transkei Village Case Studies

The field studies conducted in Transkei were less comprehensive than those in KwaZulu. This was, at least partly, due to less commitment from the Transkei Department of Agriculture and Forestry. Whereas in KwaZulu the author was able to interview Government representatives at the central, regional and district levels, it was only possible in Transkei to meet represantatives at the central Government level in Umtata. In addition, the villages selected by the Transkei Department of Agriculture and Forestry for study were all near Umtata and hence within easy reach of the maintenance and extension services. It was for this reason that Ambrose was identified for investigation as a contrast to Xhwili and Tabase, and as more representative of underdeveloped rural areas. However, since only three villages having Government administered water supply schemes were investigated it is not possible to confidently generalise the results. The findings of the village case studies in Transkei are summarised and compared to the handpump schemes used in KwaZulu in Table 4.2, which is presented at the end of this Section.

The three case studies of Government administered schemes and interviews with Government representatives in Umtata did, however, identify a large proportion of the variables and constraints pertaining to village water supply schemes throughout Transkei.

It can be seen that with the adoption of windmill reticulated water supply schemes a considerable amount of money has been invested in Transkei's rural areas. The total cost of 1300 instsllations, at an average of R120 000 each, is over R150 million. In comparison, between R840 000 and R 1050 000 are spent annually by the KwaZulu Government in providing between 200 and 250 Mono pump installations. Although the water supply level of Transkei's schemes is high (water reticulated to standpipes) it was admitted that between 30% and 40% of installations were not working as of April, 1986. This figure, provided by a Government representative, may be regarded as a conservative estimate.

The main causes of breakdown were found to be: rotor failure in high winds, transmission system (gearbox) failure, and failure of the piston cylinder seals. Differences in the ease with which Southern Cross and Climax windmills could be repaired were identified. The main cause of gearbox failure in each type was identified as breakages of the gear link arms and wear of the gear teeth. The gear arms were described by Mr Malundi, a Maintenance Officer, as "very delicate". The Climax gearbox was reported to be sturdier than the Southern Cross. Overall, Climax windmills were reported to be more reliable, due to their sturdy four posted tower and cast iron gearbox. It was also thought to be easier to repair the Climax gearboxes.

The provision of maintenance for Transkei's windmills has proved to be a costly and difficult exercise. As stated earlier, R750 000 was allocated to maintenance in 1985, of which R350 000 was spent on spare parts. The average operational period from installation to the first breakdown was reported to be three months. It was claimed by some Government representatives that, until recently, the average time taken to repair an installation was a year. The main causes of delays were poor communication between the villages and the centrally administered maintenance services, and delays in obtaining spare parts from the central stores. The average repair time has been shortened by the aquisition of further maintenance vehicles.

The problem of poor communication is exacerbated by the fact that the windmills are installed with no community participation. The only community contribution to a scheme may be during the construction phase, when labourers are occasionally hired from the village. In most cases the villagers are specifically instructed not to touch or interfere with the windmill. This is done to prevent negligent damage to the windmill through misuse or abuse, such as swinging or sitting on the structure. However, as a result the villagers are not able to apply the windmill brake during periods of high winds, or to provide the necessary lubrication to moving parts.

The village rangers, employed by the Department of Agriculture and Forestry to maintain stock fences, are theoretically responsible for all the Department's property in the village, including the windmill. Unfortunately, the rangers are usually either not aware of that responsibility, or have received no instruction to enable tham to lubricate or reef the windmill.

In Xhwili it was observed that the windmill reefing chain had been removed. Although Southern Cross windmills are designed to reef automatically in high winds, as well as having a manual reefing mechanism, the state of the Ambrose windmill (Section 4.5.3) testifies that the automatic system alone is insufficient to prevent damage to the windmill in high winds.

The reservoir and distribution networks of Transkei's village water schemes constitute up to 80% of the total cost of the scheme (depending on the costs of installation, labour and transport). Whilst the provision of standpipes can reduce the burden of water collection, in terms of the time taken and distance walked, it was seen that in both Xhwili and Tabase not all of the standpipes were working. Even when all of the standpipes were working, and assuming an optimum output from the windmill, it was shown in Section 4.5.1 that the system was unable to provide 40 litres per person per day (the average amount found in Section 2.1 to be collected when water from standpipes is available). A more detailed investigation would be required to determine the actual amount of water that is available daily to the villagers.

Table 4.2 KwaZulu and Transkei Village Water Supply Technologies

	Handpumps	Windmills	Spring Protection
Agency	KwaZulu Govt. (Water Dev. Fund)	Transkei Govt	TATU Valley Trust
Makes used	Mono D D	Southern Cross Climax	N/A
Total Cost	R4 000	R120 000	R1 000 to R2 000
Community Contribution	None (R1 000 to R2 000 + water committee)	None	Money + Labour + Water Committee
Number served by each installation	20 to 200 families	500 to 1000+ people	100 to 500+ people
Maintenance	Govt. teams	Govt. teams	Village
Problems	Low output Queueing Breakdown Slow repair	Breakdown in high wind Slow repair	Restricted applications
Average time to first breakdown	1 year	3 months	not known
Average repair time	Six weeks or longer	three months or longer	not known
Average lifetime	2 to 5 years if serviced & repaired	not known	not known

Chapter Five

Discussion and Recommendations.

Introduction

In this chapter the technical, economic and social information presented in the earlier chapters is drawn together in order to construct an overview of the problems of water supply in rural areas, the technologies that are available to solve those problems, and the methods of planning and implementation that facilitate successfull water supply schemes.

The major difficulties of water supply in rural areas are described first, followed by a review of the water lifting technologies available, and an assessment of their potential for use in rural areas. Attention is then focussed on the technologies that are most widely used at present- handpumps, windpumps and diesel pumps. For each an assessment is made of their usefullness for rural water supply, from the technical, economic and social viewpoints included in the report. This is followed by an evaluation of the role rural communities can play in the provision of successfull water supply schemes. The report ends with some more general conclusions on the selection and application of water lifting technologies that are capable of meeting the complex technical, economic and social conditions that prevail in underdeveloped rural areas. Areas requiring further investigation are then identified and recommendations are made for further coordinated research.

5.1 The Water Problem.

The provision of water for domestic consumption is a key problem in underdeveloped rural areas of Southern Africa. The traditional sources of water, such as springs, ponds and rivers are unable to meet the needs of a rural population that is expanding rapidly. The problems associated with the provision of water for domestic consumption in rural areas may be grouped into three distinct categories:

i) Quality. The main sources of water presently exploited in underdeveloped rural areas are shared with other water users, such as cattle and livestock, are susceptible to faecal contamination, and would under normal circumstances be classified as unfit for human consumption. As a result, rural communities, who have very little access to health care services, suffer from a host of water related diseases and infections. For example, diarrhoea caused by the ingestion of faecally contaminated drinking water is thought to be the single largest cause of infant mortality in underdeveloped rural areas.

ii) Quantity. The amount of water used by rural communities is determined by two factors- the distance the water source is from the household, and the amount of water available. Surveys in Ciskei, Transkei and KwaZulu have shown that, where water is only available from surface sources, a rural household may use less than 70 litres per day, equivalent to about 15 litres per person. This low volume of water means that an insufficient amount is available for washing, cooking or sewage disposal. Many households have adapted to the water shortage by recycling water that is used for bathing or dishwashing, a practice which has obvious implications for personal hygiene and the transmission of diseases.

iii) Distance. The collection of water for use in the household is an extremely arduous task for rural women, who are also frequently responsible for cooking, washing, tending vegetable gardens and collecting fuelwood. The recent 'betterment' policies of the Homeland Governments have served to increase the effort required to collect water, by siting households on higher land near roads. Since springs, ponds and other surface sources of water are then situated below the household, the effort required to carry water to the home is increased considerably. Eberhard (1986 p70), in his surveys of energy consumption in rural areas, found that rural women spend on average three hours per day making three trips, each of a kilometre or more, to collect water.

The three problem areas of rural water supply- quality, quantity and distance- can only be fully resolved by the provision of clean reticulated water in the household, a solution that is exluded by it's high cost. However, the use of water lifting technologies supplying water to standpipes situated throughout a village can drastically reduce the burden of water collection, increase the amount of water available and provide water of good quality, free from pathogens.

5.2 The Technologies Available.

A number of technologies are available for water lifting in rural areas. Some of them have been traditionally used for water supply, such as some water lifting devices that utilise animal power, whereas others utilise forms of energy that have only recently been harnessed for this purpose, such as photovoltaic cells. In Southern Africa, however, the use of water lifting devices has only recently become important, unlike Asia or China, where many of today's 'alternative' technologies have been used for centuries.

The water lifting devices reviewed in this report may be divided into three broad categories- those that are still experimental, those have a recognised potential for certain applications, and those that are already widely adopted. Although the three categories are discussed seperately below, some technologies fall on the boundary between two or more categories. The reasons for this are social or economic, rather than technical, and are discussed where necessary.

5.2.1 Experimental Technologies. Two experimental water lifting technologies have been covered in this report- footpumps and biogas pumps. Footpumps have been included in this classification since, although they are now in commercial production, they have yet to be widely adopted.

The most recent applications of foot pumps in KwaZulu, by Wits University in conjunction with the Red Cross, indicate that the use of footpumps may be a more efficient and ergonomic way of exploiting the widely available and often underexploited human power potential. By designing a pump unit specifically for use in rural areas it has been possible to produce a unit that is efficient, easy to use and free from the usual problems of pilferage. As this experimental operation continues, and the servicing and maintenance requirements of the pedal pump become known, it is expected that it will be an attractive alternative to the handpumps presently used. It's present application, however, is restricted to lifting surface water for irrigation and for purification to provide drinking water. Hence it is necessary that a pedal pump for use with borehole installations be tested, since the cost of water purification systems is presently prohibitively expensive.

From the limited applications that already exist, it can be seen that the social considerations of foot powered water lifting devices are not as complex as many other technologies. In the KwaZulu example some modifications were necessary to provide a seating arrangement that was comfortable to all users, and some modifications of earlier designs were required to prevent the pilferage of bicycle parts from the pump. A further social problem associated with use of pedal pumps is related to the fact that only rural men tend to ride bicycles, and not rural women. Since it is the women who are usually responsible for collecting water, the application of a pedal pump may require that this practice is changed. It is possible that the men of a village may interpret such a change in habits as a threat, which in turn may result in malicious damage to the pump. Such problems can be avoided by the carefull and respectfull introduction of the pump to the community.

Biogas pumps are still in an experimental stage despite the fact that they use widely avaliable and well known diesel technologies. The use and operation of biogas digester units is difficult from logistical and organisational viewpoints: a trained operator is required to load the correct proportions of organic material and water, and the daily involvement of the community is needed to provide the necessary input materials. In addition the technology involved in the digestion process constitutes a further demand for trained maintenance personnel.

A further disadvantage of biogas pumps is that the primary energy source- cattle dung and vegetable waste- is often used as fuel for fires, and so may not be readily available for use in the digestion process. In general, the social aspects of biogas production require the most carefull consideration of all the water lifting technologies reviewed, since the long term cooperation of the community is needed to fuel the pump.

5.2.2 Potential Technologies. As discussed earlier, potential technologies are regarded as those that are already suitable for use in underdeveloped rural areas, but have not yet been widely adopted. The technologies included in this report that are regarded as having a potential for widespread use are animal pumps, solar pumps and hydraulic rams.

Animal pumps have been traditionally used in other parts of the underdeveloped world, but have yet to make a substantial impact in Southern Africa. The principles required to operate an animal pump are well known, with several units being succesfully used in Botswana. The technical requirements of an animal pumping system are not complex, except that a step up gearing system from the animals to the pump is usually required. The energy source- cattle or donkeys- is available in many rural areas, but is subject to a complex array of traditional and ethnic values. The use of cattle for powering a communal water pump may require that many of these traditional values are given up.

Solar power has been the focus of a considerable amount of research during recent years. However, despite the enormous amount of power available from the sun, it's use has been limited so far by the high cost of energy conversion units. A cheaper alternative, and one which does not appear to have been investigated fully yet, is the use of solar thermal devices. Although the ability of some solar thermal devices to lift water, such as that described by Bernard (1983 p14), is restricted to low heads, their simple construction and hence servicing and maintenance requirements should make solar thermal devices suitable for a number of rural applications.

Photovoltaic water lifting devices require a considerable amount of site evaluation if they are to provide sufficient water reliably all year round. The technology used to convert light to electricity is possibly the most elegant of all the power producing technologies- there are no moving parts, no high temperature working fluids and hence negligible wear and maintenance requirements. Hence it is generally regarded as being suitable for remote applications where servicing facilities are not readily available. However, although the servicing requirements of photovoltaic system are minor, a simple fault such as a loose connection could cause the system to fail, and it is unlikely that a villager would be able to effect a repair. The high cost of PV panels has restricted their use so far. At present, a PV panel of 40 Wp costs about R800, and it is likely that ten or more units may be required to meet the water needs of an entire community. The cost of PV cells is falling rapidly, however, and with the introduction of the next generation of thin film modules the potential exists for photovoltaics to become more cost effective.

At present the cost of pumped water using a photovoltaic system is in excess of the more widely used technologies. In the economic analysis it was seen that, even with a 50% reduction in panel costs, solar pumping systems are not competitive at the heads and flow rates considered. It is important to note, however, that the assumptions applied in this study to size the solar pumpiing system were based on a pessimistic value of daily solar insolation. Further, other studies have already found solar PV systems to be competitive at low heads and flow rates.

The social considerations relevent to the use of PV water lifting devices are minimal, since it is likely that the community would not be involved in the day to day servicing or maintenance of the system. Some elementary servicing functions could be carried out by a villager on a daily basis, such as cleaning the panels of dust and dirt.

Hydraulic rams have been used in many parts of the world for rural water supplies. They have the advantages of a technically simple operating design that uses a free energy source. Unfortunately, it is the unreliability of that energy source (small streams and rivers) that has restricted the use of hydrams in Southern Africa's underdeveloped rural areas. The servicing and maintenance requirements of hydrams are not complex, since the technology involves a minimum number of moving parts. A disadvantage, however, is that hydrams do not necessarily provide good quality water. Since stream or river water is used to 'drive' the hydram, a water purification unit may be necessary in order to provide potable water.

5.2.3 The Technologies Used. The technologies that have so far been widely adopted for rural water supply in Southern Africa are handpumps, windpumps and diesel pumps.

5.2.3.1 Handpumps. It can be seen from the literature review and the case studies that handpumps, in one form or another, have been chosen by many planners in Southern Africa to supply water in underdeveloped rural areas. The methodologies and technological implications vary a great deal, however, from the concept of Village Level Operation and Maintenance (VLOM) applied in Kenya and Malawi, to the 'no maintenance' concept of the Mono handpump. The full range of options covered by these variations has been included in this report, from the Three Tier Maintenance System associated with the India Mark II handpump, to the implementation and maintenance methodologies of the KwaZulu Government.

In South Africa, handpumps have already played a substantial role in the provision of water in rural areas. At present the technologies that are applied are generally of two types: first, the 'no maintenance' Mono Direct Drive handpump has been selected by a number of Government and aid agencies as suitable for underdeveloped rural areas. Secondly, there are piston-cylinder handpumps, such as those manufactured by Climax, National and Nimric, which appear recently to have lost a certain amount of favour with water supply planners due to their servicing and maintenance requirements. In particular, it is the failure of leather seals and washers in the cylinder, and the difficulties of replacing these parts, that has influenced the recent adoption of Mono's rotor-stator design.

The village case studies in KwaZulu have provided a usefull insight into the operation of the Mono Direct Drive handpump in the field. It was found that, of the 24 installations covered, 40% were either not supplying water or were operating with some mechanical or other difficulty. The three main problem areas associated with the pump were:

i) Inadequate borehole yields. A disturbingly high number (over 50%) of the installations visited were found to dry up during busy periods, causing queues to develop. This problem serves to highlight two important points associated with the application of handpumps: firstly, the groundwater resource is not a panacea that is capable of solving all rural water problems. Rather, it is the result of seepage and storage of rainfall, perhaps over many years. Further, the availability of the groundwater resource is directly related to the carefull management of the above ground soil and vegetation. If these are overgrazed and eroded, rainfall will not penetrate but flow away over the surface, causing further soil erosion to occur. It is important to remember that the groundwater resource is finite, and may diminish altogether if it is over exploited.

Secondly, it can be seen that handpumps that are otherwise operating adequately are suffering from borehole yields as low as 100 litres per hour. In the case of the KwaZulu water supply schemes, the boreholes are drilled by an independent contractor on the basis that the Government (or Water Development Fund) does not pay for dry boreholes. From the point of view of the contracted borehole driller, this can be regarded as an 'incentive' to find sufficient water for the installation of a handpump. Although the KwaZulu Government officially accepts boreholes with yields as low as 600 litres per hour, many of the installations visited had yields well below this figure. Hence, it is suggested that either some other contractual arrangement be made with borehole drillers, whereby the contractor is encouraged to report accurately the yield of a borehole, or the implementing agency adopt some form of independent quality control or monitoring procedure of boreholes drilled on it's behalf.

ii) Strenuous or Difficult Operation. The output of a handpump, as discussed in Section 3.2.1, is related to the pump efficiency and the strength of the operator. Since it is usually the responsibility of women and children to fetch water for use in the household, it is essential that a handpump be as easy to operate as possible. An interesting feature of the Mono Direct handpump in this respect is that the turning torque is independent of the head. In the case of reciprocating handpumps, it is the delivery head and mechanical advantage of the handle that determines the effort required to lift water.

A design feature of the Mono handpump is the ball and ratchet system of the handle that prevents the operator from turning the handle in the wrong direction. This system was observed to be operating inadequately on three of the installations visited. In these cases, the design of the handle is such that the operator is unable to make any attachment or alteration to improve the mechanical advantage of the handle. In contrast, a Nimric handpump installation was observed near Hammanskraal where the handle had been considerably extended in order to ease the difficulty of operation. This question of operator servicing and maintenance is further discussed in Section 5.4.

iii) Queueing. The problems of queueing that were observed at all of the operating Mono pump installations visited in KwaZulu are partly related to the design of the handpump and partly related to the nature of the handpump schemes themselves.

Firstly, the choice of the Mono pump for it's reportedly better reliability has certain opportunity costs associated with it. As was shown in Table 3.2, the Mono Direct Drive handpump has only one-third of the output of a Nimric or two-thirds that of a Climax handpump over a 30 metre head. At higher heads the Mono output compares more favourably, but still remains considerably below that of the Climax and Nimric lever handpumps.

However, the handpump output alone does not determine the extent to which queueing takes place, as the number of families served by the installation is also important. Although accurate population estimates were not available for many of the installations visited, it is the stated policy of the KwaZulu Government to provide only one handpump installation per village, regardless of whether 20 or 200 families are to be served. If a single handpump is to provide an amount of water equal to the expected usage by 200 families when water is collected from surface sources- which may be regarded as the minimum required to ensure that the community derives the health benefits of an improved water supply- it would be necessary for a single handpump to have an output of 14000 litres per day (at the minimum water use of 70 litres per family per day), or 1400 litres per hour if a 10 hour pumping day is assumed.

In terms of the three problem areas of rural water supply- quality, quantity and distance- it is obvious that a single handpump installation is extremely limited in the extent to which it can improve the quantity of water available, or reduce the time and effort required to collect water. The present provision of one Mono handpump installation per village is inherrently inadequate to increase the amount of water used or reduce the time taken to collect water. Further, as was seen in the village case studies, the single installation may increase the burden of water collection since a considerable amount of time may be spent waiting in queues.

Feachem *et al* (1978 p37), in their extensive analysis of rural water supplies in Lesotho, concluded that a single handpump installation, providing 14 litres per minute, or 840 litres per hour, is sufficient to provide water for 150 people. This figure was calculated from measured water consumption rates for improved and unimproved water supplies. Hence a single handpump installation is only able to meet the water requirements of 30 families- assuming the handpump operates adequately and the borehole output is sufficient.

Hence, the three benefits of improved water quality and quantity, and reduced collection times, can only be achieved with the use of handpumps if multiple installations are provided in a village. Although this option is expensive due to the extra number of boreholes that are required, there are two advantages that are worth noting. Firstly, a water supply involving multiple handpump installations would be more reliable than a wind or diesel powered supply, since a single installation could break down without jeopardising the entire village water supply. Secondly, the system is modular and can accommodate population increases by simply installing further handpumps.

In the economic analysis it was seen that the cost of pumped water from a Mono handpump is considerably more than from a reciprocating handpump. Where multiple installations are required, the reciprocating handpumps have a further advantage since fewer installations are required as a result of their higher output. It was also seen that reciprocating handpumps remain cheaper than rotary positive handpumps over a wide range of assumptions for their maintenance costs.

5.2.3.2 Windpumps. Windpumps have been widely adopted in the underdeveloped World for rural water supplies, although not as widely as handpumps. In Southern Africa windpumps have been used in Botswana, where a windmill was specifically designed for use in remote rural areas, as well as in Bophutatswana, Transkei and, to a lesser extent in KwaZulu.

The latter example provides a usefull insight into the pitfalls that are associated with rural windpump installations. Whereas windpumps have been widely used by the KwaZulu Government in the past, they are no longer favoured for two main reasons. Firstly, the failure rate of windpump installations was regarded as too high, and it is now considered that an installation requires a full time caretaker to ensure the safe and smooth operation of the windmill, and secondly, windpump installations are regarded as too expensive.

The village case studies in Transkei, although not statistically representative, did succeed in identifying the main causes of windmill failure, and how these are related to windmill technology and the implementation methodology of the water supply planners. The three most common causes of windmill failure in rural areas are: rotor failure in high winds, failure of the transmission system, and failure of washers and seals in the pump cylinder.

i) Rotor failure in high winds: Southern Cross, Nimric and Climax windmills are all designed with automatic reefing and braking systems (see Chapter 3, Section 3.2.5). However, rotor damage in high winds still constitutes one of the most common causes of windmill failure. In this respect it interesting to note that many of the windmills manufactured in South Africa are also fitted with manual reefing chains and brakes, for arresting the windmill in periods of high winds or when it is not required to lift water. As such it is implicit that an automatic reefing system is insufficient protection against the effects of storm winds.

In Transkei it was seen that villagers were often instructed not to touch the windmills, and in some cases the reefing chains had been purposely removed from the windmill. Hence, the windmill, having no caretaker and no manual brake system, is only protected against high winds by the automatic furling system. The state of the windmill installation in Ambrose may be regarded as proof of the fact that such a system is unable to protect the windmill against storm damage.

Hence it may be concluded that the protection of a rural windmill installation requires that the windmill have a manual reefing system and a trained operator of that system, in addition to the automatic system, to ensure that the sails are not damaged in periods of high winds. The implications of this conclusion on the requirements for community participation in a wind powered water supply scheme are discussed in Section 5.3.

ii) Failure of transmission system (gearbox): The failure of gearboxes on water lifting systems used in underdeveloped rural areas is well known. For example, Mono Pumps (Africa) Pty Ltd realised that the gearbox on the Mono Type 3 handpump was a common cause of failure, and redesigned the pump to its present direct drive form.

The reliability of windmill gearboxes could be increased by the use of windmill caretakers, as they could provide regular lubrication and a reduction of the stress caused by operation in high winds. In addition, alternative windmill designs exist that do not incorporate gearboxes. For example, the Nimric windmill uses a rubber coupling to convert the rotary action of the shaft to the reciprocating movement of the pump rods. A further advantage of this system is that the coupling can be renewed by a person without a great deal of technical training. Further options for the choice of windmill are discussed below.

iii) Failure of the piston cylinder seals: This is a common and well known problem with reciprocating pumps. In some developed agricultural areas, farmers have reported that it is necessary to renew leather seals as often as once every six months. The task can be simplified by using a cylinder of diameter less than that of the rising main.

In this respect it is interesting to note that rotary windmills, incorporating the rotor stator design of the Mono pump, have made a recent appearance on the South African market. At present two companies are known to manufacture rotary windmills- Climax and Midkaap Engineering. Although these windmills are considerably more expensive than reciprocating types at present, it is worthwhile noting that the capital cost of the windmill constitutes only a little over 10% of the total cost of each windmill reticulated water supply scheme in Transkei.

It was senn in the economic analysis that windmills are not competitive with handpumps at low heads and flow rates, but compete directly with diesel powered systems at higher heads and flow rates. It is also interesting to note that despite the higher capital cost of the Climax and M&S Rotary windmills, they are less expensive than the reciprocating windmills at flow rates of 30 and 50 m^3/day.

The choice of windmill reticulated water supply schemes in Transkei is an ambitious attempt to provide rural Transkeians with a high level of water supply, which reduces the time taken to collect water and provides clean water at the turn of a tap. However, the achievement of this level of water supply is hampered by the difficult conditions which exist in underdeveloped areas- poor communication, poor roads and a lack of trained maintenance personnel- as well as the relatively complex maintenance and servicing requirements of windmills, and their susceptibility to storm damage.

Some of these problems can be overcome, however, by the use of trained village operators, as well as by using windmills that do not incorporate gearboxes or cylinders. The responsibilities of such operators would include furling the windmill in periods of high winds, lubricating bearings and other moving parts, and ensuring the windmill is not damaged maliciously or negligently.

5.2.3.3 Diesel Pumps. Diesel powered water lifting systems have been widely used in underdeveloped rural areas, but as the technology selected by communities, rather than by Government water supply planners. The selection of diesel pumps by rural communities is as a result of their widespread availability and familiarity. Diesel engines are also relatively cheap in terms of capital cost when compared to wind or solar power.

Unfortunately, it can be seen that the running costs and maintenance requirements of diesel systems are often beyond the means of rural communities. In particular, the collection of regular cash contributions to buy diesel is a difficult task in rural areas, which can result in the pump not working for up to two or three weeks at a time whilst the collections take place. In addition, the long term servicing and maintenance of a diesel engine requires a degree of technical knowledge and skills that is often absent from underdeveloped rural communities. Feachem *et al* (1978 p30) found only one instance of a successfull repair to a diesel pump in the Mokhotlong and Mafeteng Districts of Lesotho. In that case the village had hired an Afrikaner garage owner to repair the engine.

Diesel powered water lifting systems, however, still appear economical when compared to handpumps and windpumps at high heads and flow rates. This is due to their low capital cost and relatively high power potential. Unfortunately, the servicing and maintenence facilities necessary to operate a diesel pump at its' full potential are not usually available in remote rural areas.

In conclusion there are three difficulties that inhibit the long term operation of diesel powered water lifting units: first, it is necessary to collect regular cash contributions to buy diesel, second, the servicing of a diesel engine requires a relatively high degree of technical know-how, and thirdly the maintenance requirements of diesel systems are beyond the scope of rural communities.

5.3 The Role of the Community in Rural Water Supply.

It can be seen from the review of international water supply schemes and the village case studies conducted in KwaZulu and Transkei that the involvement, or non-involvement of rural communities can greatly influence the long term success of a water supply scheme. In terms of the three stages of technology applications in rural areas- planning, implementation and maintenance- there are a variety of options and objectives involving the community that the water supply planner must address.

i) Planning. The planning of a water supply should include an assessment of the number of people to be served in order to determine the required output of the scheme. If the scheme is to replace a surface or other contaminated or unreliable source as the villager's main source of water, then it is necessary that the scheme provide at least as much water as the villager's present daily water use. The substitution of the new improved source for the previous source is then dependent upon the proximity of the new source to the homesteads and the acceptable taste and quality of the water.

If the new supply does not provide an adequate amount of water then, as was clearly seen in the village case studies, the villagers will continue to collect water from the previous source. As stated above, that practice may also continue if the water scheme is remote from the homestead or does not provide water of an acceptable quality.

Hence it can be seen that a benefitting community should be consulted during the planning phase of a water supply scheme on three subjects:

1) What is the present and expected future population of the village?
2) What is the present daily per capita water use, does this vary throughout the year, and what are water needs of the community?
3) Where should the new scheme, or standpipes if they are to be provided, be sited in order that water is accessible to all the villagers?

It is only by providing enough good quality water within reach of the household that the health benefits discussed in Section 2.3 can be achieved. Similarly, it is only by providing water within easy reach of the household that the use of the new water supply can be ensured. It should be noted, however, that in many cases an improved water supply must be accompanied by improvements in waste disposal practices, for example by the construction of ventilated pit latrines, in order that the full spectrum of health benefits are achieved.

A further point to note is that where single handpump installations are to be provided then it may not be possible to site the pump conveniently for all the villagers. In that case the water supply planner has implicitly admitted that the community will only benefit partially from the scheme (in this case through an increased availability of clean water), and so should seek a compromise site for the handpump, such that as many people as possible benefit from its' introduction.

ii) <u>Implementation.</u> The implementation of a water supply scheme is regarded in this case to include all those decisions and actions that are necessary from the time the site and nature of the technology to be used are chosen, to the moment the installed technology produces its' first water. It is during this phase of the water supply scheme that provision must be made for the involvement of the community in the installation of the technology, the financing of the scheme, if that is necessary, and for the future upkeep of the water supply.

As has already been discussed in Section 5.3, the results of the village case studies showed that centrally administered maintenance services are at present unable, due to logistic, financial and administrative difficulties, to provide an adequate maintenance service. In particular, villages that are remote from the District or administrative centre do not receive adequate maintenance services. Hence, it is concluded that the successfull long term operation of rural water schemes must involve the community. The logical conclusion of this statement is that the burden of water supply improvement be placed solely upon the villagers themselves- which is obviously not feasible at this time. Rather it is necessary to find a compromise, through which the efforts of the Government or water supply planner are directed towards obtaining and ensuring a certain level of long term commitment, dependent on the technology that is used, to the operation of their scheme.

The type and nature of a community's commitment to a water supply scheme is dependent upon two factors: the nature of the water supply technology, and the type and amount of regular village level Government representation. Certain technologies are suited to certain levels of community involvement- for example, the Mono Direct Drive handpump is not suited to village level maintenance, but would benefit from better care of the installation site and a reliable communication link with District maintenance services. Conversely, the India Mark II handpump is designed to facilitate village level operation and maintenance, with only the occasional involvement of District services.

The level of Government representation in a village also affects the villager's attitude to the scheme. For example, it was seen in KwaZulu that water supply schemes administered by the Water Development Fund involved the election of a water committee, the collection of cash contributions and the 'handing over' of the scheme to the community for maintenance. In effect, however, the pump became the responsibility of the Government and the water committee served little or no usefull purpose. These problems were often compounded since the condition of poorly operating or broken pumps was not reported.

The failure of village water committees or villagers themselves to accept responsibility for the pump is as a result of an inadequate provision for village level training and extension services. During the implementation of a water scheme it is not sufficient that the village hold a meeting and appoint or elect a water committee. It is also necessary that the Tribal Authority or water committee are given help and guidance on how to manage the pump installation, how to service the pump and repair it (if that is feasible), and how to call on Government services should they be needed.

For example, the provision of maintenance could be improved by giving the committee pre-printed postcards depicting the handpump installation. Such a system has been used succesfully in Kenya and Zambia (Pacey 1978). In order to report a breakdown or difficulty with the pump the chosen villager or pump caretaker has then only to circle the failed pump component and post the card. The use of this system would also help to identify the most common causes of pump failures. The primary consideration of implementing such a system is, again, an increase in the village level involvement of the Government's extension and training services.

A more radical change in Government methodology, but one that has been used extensively elsewhere in Southern Africa and in the developing world, is the training of village mechanics. The primary factor mitigating against village level technical training is obviously its' cost. However, it is worthwhile considering the potential benefits associated with village level training. Firstly, it would be possible to use cheaper reciprocating-type handpumps, whose servicing and maintenance requirements are known and whose output over a given head may be more than twice that of an equivalent rotary positive displacement type handpump. Secondly, pump caretakers can be used to make people more aware of the health benefits of clean water, so greatly increasing the community benefits of an improved water supply.

This approach has been widely adopted in India and Kenya, as discussed in Chapter 2. The handpump that is used in these countries, the India Mark II, was specifically designed for village level operation and maintenance. It is easily dismantled, the parts are standardised and interchangeable, and later versions allow the cylinder seals to be changed without lifting the rising main.

The technical training of pump caretakers has further advantages of increasing the levels of education and organisation in rural areas, providing employment and reducing dependence on centrally administered services.

iii) Maintenance. It is the provision of maintenance services that will eventually determine the extent to which a rural community derives the benefits that are known to be possible from an improved water supply. As such it is essential that the water supply planner devote at least as many resources to the upkeep of water supplies as to the implementation of new schemes.

As mentioned above, it is during the implementation phase of a new water supply scheme that the planner must make provision for the scheme's future maintenance. Many of the water lifting technologies reviewed in this report are suitable for, and would benefit from the use of village caretakers. These would need to be trained during the implementation of the scheme, but must then also be monitored for their success in their new role. It is also necessary to implement some form of monitoring procedure in order to check that new schemes are operating.

The use of the postcard scheme described above would enable the water supply planner to identify the most common causes of breakdown, and the use of regular visits by extension or District officers could ensure that the water committee and pump caretaker are still fullfilling their respective roles. In this respect, it is interesting to note that neither the KwaZulu nor the Transkei Departments of Agriculture and Forestry presently have any other form of monitoring procedure of water supply installations, other than the Extension Officers who are already overstretched and unable to maintain a meaningfull presence in many of the villages in their jurisdiction.

In conclusion, it can be seen that the long term success of a rural water supply scheme is dependent upon an adequate provision for maintenance, which in turn is dependent upon the succesfull inclusion of community participation in the planning, implementation and maintenance of the scheme and an adequate level of supervision, advice and technical guidance from Government representatives or field staff. The successfull involvement of the community requires that the water supply planner commit its' resources to establishing a meaningfull representation in the village, capable of training and guiding the villagers such that a long term commitment to the scheme is ensured.

5.4 Conclusions

In the Introduction of this report it was stated that the primary objective of this one year research project was to provide a holistic assessment of the technical, economic and social considerations relevant to the success of water supply schemes in underdeveloped rural areas. Although it has been possible to review all three aspects, both from published material and field studies, it was not possible to provide statistically sound data. This was due to time and financial limitations as well as the problems of identifying a valid sampling population.

However, the project has successfully identified areas that have not so far been adequately addressed by water supply planners, as well as areas that require further research. As such it is hoped that the project will make at least a small contribution to the understanding of the problems of water supply in underdeveloped rural areas in Southern Africa.

It can be seen that groundwater sources are often utilised in villages where suitable surface sources already exist. In such cases an unnecessarily large amount of money is spent on drilling boreholes and providing pumps in a situation where a relatively cheap and technologically simple spring protection scheme would possibly provide a greater improvement in water quality, quantity and reliability.

In particular, Transkei, in contrast to many other areas of Southern Africa, has a moderate to good rainfall and a hilly topography that appears to be almost purpose built to accommodate the widespread use of spring protection techniques. Indeed the potential of spring protection to meet the water requirements of Transkei's rural population has been estimated at up to 60%. Further, the techniques and methods of spring protection appropriate to Transkei's rural areas are already well known to the Transkei Appropriate Technology Unit and have been used succesfully for a number of years. TATU have also shown that the use of community participation in the planning, implementation, financing and maintenance of such schemes is possible in Transkei.

The use of groundwater sources does have many advantages, as it is capable of providing a reliable source of water that is free from pathogens and less susceptible to the effects of drought. These advantages are dependent on the groundwater resource being adequate to meet the water demands, and being protected from contamination from surface sources. In this respect it is interesting to note the high number of boreholes encountered in KwaZulu that had inadequate yields, and the fact that in some cases pit latrines were observed to be sited above the intallation. In a few cases the boreholes were observed to be sited within metres of spring water sources, which would suggest the pump is simply extracting spring water before it reaches the surface.

A further point to note with respect to the use of groundwater to provide village water supplies is that the amount of water extracted must not be greater than the rate at which it is recharged by rainfall. During the recent drought in KwaZulu it was estemated that 20 to 30% of borehole water supplies dried up, either due to an inadequate sized aquifer, or a drop in the water table (Berridge; 1986 Pers Comm). It is not known how many of these boreholes subsequently returned to their normal yield.

The long term availability of borehole water depends on the absorptive capacity of the soil- which in turn depends on the proper management and use of the land and vegetation. If grazing land is overstocked and vegetation is removed, then the soil's protection from rain drop impact is removed. This results in increased run-off, increased soil erosion, and less penetration of water to replenish the groundwater resource. In conclusion, groundwater sources do have many advantages over surface sources, but it's extraction is expensive and it's long term availability is dependent upon the carefull management of the soil and vegetation.

The technical aspects of rural water supply are, at present, receiving the most attention, both in terms of the amount of money invested in water lifting devices for use in underdeveloped areas and the amount of research and innovation that is taking place. However, it is apparent from the results of the village case studies that at least part of the solution of the technical problems of water supply lies in addressing the social context of the technology application.

The use of the Mono Direct Drive handpump provides a usefull insight into the social questions that need to be addressed by water supply planners. The pump, which has recently won awards for it's design, is probably as close to the concept of a 'no maintenance' handpump as any commercially viable unit could be. Yet, as was seen in Chapter Four, it's use in the field is still subject to external factors that are capable of limiting it's success at providing a reliable supply of water. A large number of installations were seen to have problems associated with inadequate borehole yields, which aggravate the problems of queueing, and many suffered from mechanical problems which were commonly not reported, either to the Tribal Authority or the Government's Agricultural Officers. Hence pumps with poor yields, due to either of the above-mentioned problems, continue to operately inadequately or even deteriorate with time.

Unless these problems of poor communication and poor community involvement are solved, it is likely that no amount of expensive, 'maintenance free' water lifting technologies can produce the community benefits of an improved water supply.

The continued use of handpumps also requires carefull thought, since it is immediately obvious that a single installation, even when operating to it's full design capacity, is only capable of meeting the water needs of no more than thirty families. Although it is possible to meet the water needs of a large rural village by the use of multiple handpump installations, the high cost of the number of boreholes required may preclude such an option.

The use of windpumps for rural water supply has so far met with only limited success due to the high incidence of breakdowns and the difficulties of providing a maintenance service in remote rural areas. Windmills, however, do have the advantages of utilising a free energy resource and have the ability to lift water over high heads, or produce high yields over low heads. As such they are suitable for supplying water to entire communities with the use of gravity fed distribution systems. These systems are expensive, but it is worth noting that the largest component of the total cost of each installation in Transkei was that of pipes and transport.

The reliability of windpumps in rural areas can be increased by the use of trained village operators or caretakers. Such a person may be chosen by the community during the installation of the scheme and given training by the Government, or alternatively the windmill manufacturer.

In general the effective long term use all water lifting technologies depends on a commitment from both the Government and the users of the supply. The commitment of the Government, as the water supply planner, is essential for the planning, financing and installation of a scheme, as well as for advisory services, technical training and other complementary inputs. The involvement of the people is essential if the scheme is to provide the long term community benefits of which it is capable. The level of commitment necessary to achieve those benefits varies according to the technology used and the policy of the water supply planner. In the case of a spring protection scheme, the community is able to contribute labour, materials, some money and a commitment to the upkeep of the supply with the help of a trained villager. In a Mono handpump scheme there is less potential for community imvolvement, but a commitment to the care and proper operation of the pump, as well as the establishment of a quick and reliable communication link with District or Regional maintenance services are essential.

At present water supply schemes in rural areas are the domain and responsibility mainly of central Government institutions. Although there have been recent attempts to involve communities, these appear to be uncoordinated and to have utilised oversimplified concepts of community 'ownership' and maintenance. In addition, Government water supply planners at present do not have the advisory or technical services necessary at village level to establish and ensure any long term community involvement, or even to monitor the operational state of water supply schemes in their Districts.

The decision of the KwaZulu cabinet to delegate maintenance of village water supplies to communities, without making any provision for the extensive advice and training such a policy would require, is indicative of the way in which central Government institutions do not appreciate the complex set of physical, economic and social conditions prevailing in underdeveloped rural areas. The decision, which eventually led to the formation of maintenance teams by the Department of Agriculture and Forestry, also illustrates the way in which the needs of South Africa's rural poor are neglected.

The presently desperate situation that exists in most if not all of the black rural areas of South Africa, in which women spend the greatest proportion of their time fulfilling the basic human needs of food, water, shelter and warmth, and the men are forced to find work as migrant labourers in the cities and mines, is not as a result of the poor endowment of these areas with natural resources. Nor is it the result of the recurrent droughts that have occurred over the last decade or more. Rather these conditions of poverty and disease are, at least partly, the result of a political system that has ignored the needs of the majority of the population and focussed it's resources and activities in the already developed agricultural and industrial sectors.

Within the last year or two there has been a growing acceptance of the idea that the black population of South Africa can be drawn into and make a substantial contribution to the national economy. In this respect it is essential that the problems of rural energy, of which water supply is but one extremely important aspect, be given immediate attention. The provision of clean, reliable and adequate supplies of water is one of the first requirements of any development or upliftment process.

The potential for large scale development of the presently underdeveloped rural areas does exist. The unique situation in which South Africa is now in, of a developed industrial economy existing alongside a massive underdeveloped agricultural or subsistence sector, can provide a great potential for rural development. Firstly, many electricity and water services pass through rural areas on their way to 'white' suburbs or industrial areas. These should be extended to serve the communities that are presently by-passed. Although these communities may not be able to afford the water or electricity tariffs that are paid by the present users, the extension of these services to include underdeveloped areas should be regarded as an investment in the future of the majority of the population. Secondly, the high standards of production as well as research and development facilities that are available in South Africa have an enormous potential to help solve the rural problems of poverty, hunger and thirst. By applying these resources to solving the real problems of the people of South Africa, and by investing present resources in the development of rural skills and infrastructure, it is possible that substantial future political, environmental and social benefits could be reaped.

5.5 Recommendations for Further Research

In the immediate future, however, if long term solutions to the problems of rural water supplies are to be found it will be necessary to have a better understanding of the concept of community participation in underdeveloped rural areas and it's effect on community attitudes, as well as a more comprehensive knowledge of the causes of water supply failure. In this respect it is recommended that a number of further independent and joint studies with water supply administrators be conducted in underdeveloped rural areas.

Firstly, it is recommended that a comprehensive study be undertaken to identify the changes in village life which accompany various types of water supply improvement. These changes are likely to include changes in the amount of water collected and the time taken to collect it. Second order changes may then include an increase in the time available for other activities, such as farming, weeding or collecting fuelwood. Improvements in the overall health of the community may also make more time available for these activities. It is also likely that changes will include an increase in productive activities and even changes in the micro-political climate existing in the village. For example, the presence of an active and successfull village water committee that is seen to be working in close cooperation with Government representatives may be interpreted as posing a threat to more traditional power structures existing in a village.

Such a study will require that at least two villages be monitored, one of which must be investigated both before and after water supply improvement has taken place, and the other village to be used as a "control" situation. Apart from identifying the changes in water collection procedures and use that occur with the introduction of a water supply scheme, such a study could monitor the changes in villagers' attitudes to the water supply as a result of any community participation methods that are employed. By conducting further such investigations, for example, at villages receiving water supplies administered by a Government department and an independent aid agency, it would be possible to identify the levels and techniques of community participation that are most likely to result in the long-term success of the water supply scheme. Such an investigation would require a substantial amount of field study and the close cooperation of both village authorities and the water supply agency.

With respect to improving the reliability of water supply schemes that already exist in the field, it is recommended that a more comprehensive survey be undertaken to identify the number of working, partially working and broken down schemes. Such a study would require a statistical sampling of the population of water supply schemes, which, as mentioned elsewhere in this report, is a difficult undertaking when survey population data are not available. However, a sampling population could be identified by using a survey to identify villages that have received a certain type of water supply improvement in, say, the last five years. In addition, it is possible to sample villages that have received water supply schemes administered by aid agencies, since they, such as TATU, tend to record more accurately the villages in which they have been operational.

Through such a survey it could be possible to determine the rate of success of water supply schemes with respect to the technologies used, the distance of the installation from the administrative or maintenance centre, the community contribution to the scheme and the economic or social status of the community. However, the difficulties of identifying and sampling a statistically valid population mean that the study would require a substantial financial input, as well as the close cooperation of water supply planners.

Thirdly, through a joint study with Transkei water supply planners it would be possible to establish demonstration projects aimed at assessing the costs and benefits of training windmill caretakers to provide 'first line' maintenance and servicing. Since the windmill installations already exist, and product training is regularly given by windmill manufacturers such as Climax, it is anticipated that the costs of establishing such projects would not be prohibitively expensive.

Finally, it is suggested that further research be initiated into the problems of rural water supply in other rural areas of Southern Africa, and that Government agencies undertaking water supply improvement schemes be encouraged to include the monitoring of their schemes as part of their normal administrative practices.

Chapter Six.

Appendices.

Appendix 6.1

Methodology

Data for the study were collected by the use of four methods: literature review (including manufacturer's technical publications, but focussing on the results of field studies wherever possible); interview questionnaires; informal interviews, discussion and village meetings; and direct observation. Each of the objectives of the project, as described in the Introduction, was achieved using one or a combination of these methods.

(i) Water Use and Requirements.

The domestic water use and water requirements, in terms of volume of water used and distance to the water source, were assessed by a review of published field studies. In particular, the 2nd Carnegie Enquiry into Poverty and Underdevelopment in South Africa and the results of Dr Anton Eberhard's village energy surveys were found to provide reliable and consistent sources of data.

(ii) Technical, Economic and Social Considerations

The technical, economic and social considerations relevant to village water supplies were identified by literature review, again focussing on the results of field studies wherever possible.

The technical considerations relevant to village water supply technologies were defined as those aspects of the technology which influence its ability to provide an adequate, reliable supply of water, such as its design, capacity, energy source and maintenance and servicing requirements.

The economic considerations were defined as those aspects of the technology that influence its economic cost (its cost from the viewpoint of the purchaser).

The social considerations were defined as those aspects of a water supply scheme, which includes planning, implementation and maintenance as well as the technology itself, which influence the ability of the technology to provide an adequate, reliable supply of water.

In addition to the literature review, manufacturer's specifications of cost and performance were collected for commercially available water lifting technologies used in underdeveloped rural areas. These included the specifications of hand pumps, wind pumps, solar pumps, pedal powered pumps, diesel pumps and hydrorams available in South Africa, and were compared to field study results or direct observations of their operation in the field wherever possible.

(iii) Technologies and Implementation Methods Used.

The technologies and implementation methods most commonly used, including identification of villages for water supply improvement and the provision of maintenance services, were identified by the use of an interview questionnaire and informal discussions with water supply planners. The questionnaire was designed following established techniques documented in Babbie (1973) and Casley and Lury (1982). A copy of the questionnaire applied to water supply planners is presented in Appendix 6.2.

Attention was focussed on the provision of village water supplies in Transkei and Kwa Zulu due to financial and time constraints. However, the technologies that are used most commonly in Transkei and Kwa Zulu - hand pumps, wind pumps and spring protection - are typical of those used throughout South Africa for water supply in rural areas.

Government water supply planners and representatives of aid organisations were interviewed. After completion of the questionnaire informal discussions were conducted, in order to clarify points that may have arisen during the interview but which were not adequately covered in the questionnaire, and to collect further detail, where that was considered necessary. Comments made during these discussions were recorded in a field diary.

In KwaZulu, Mr T Berridge of the Department of Agriculture and Forestry was interviewed. He is involved in the administration of Kwa Zulu's village water schemes and is based in the Kwa Zulu Legislative Assembly in Ulundi. In Addition, interviews and discussion were conducted with Mr L le Roux Regional Director, as well as Mr N Thomas, Mr L D Rogers and Mr P M Mabizela of the Pietermaritzburg Regional Offices.

In the Transkei, Mr M Shaker, the Principal Engineer of the Department of Agriculture and Forestry was interviewed. Mr M Mcetywa, the Head of the Maintenance Division was also interviewed. Further information on the maintenance requirements of Transkei's village water supplies was gained through discussion with Mr Malundi, a maintenance officer.

The technologies and methodologies for rural water supply of two aid organisations, operating independently of the Government administered services, were investigated. Interviews and discussion were conducted with Dr Cecil Cook, Mr Zipetu and Mr Woolamindya of the Transkei Appropriate Technology Unit, (TATU) and Dr Irwin Friedman and Mr Tim Mtembu of the Valley Trust.

(iv) Assessment of Water Supply Schemes and Community Participation

An assessment of village water schemes involving each of the most commonly used water supply technologies, including both government and aid organisation administered schemes, was made by the use of village case studies.

The evaluation of village water supplies in underdeveloped areas is generally accepted to be "difficult, expensive and time consuming" (Cairncross & Carruthers *et al*; 1980 p9). The most severe and noticeable restriction that was encountered during this study was a financial limitation on field work. In order to fully assess village water supply schemes it is necessary to sample a representative selected proportion of the population (in this case, villages which have received a particular type of water supply scheme) in order that statistically legitimate generalisations can be made about the whole population.

Three major problems were encountered which inhibited the achievement of such a generalisation. First, the target population is scattered over a large area with generally poor access to villages. Second, the population itself is not well known, even to the responsible water supply planners. For example, the KwaZulu Department of Agriculture and Forestry has only recently initiated a programme to map their borehole installations, and no comprehensive map of village water supplies exists. Hence, a statistical population frame was not available. Third, the financial restraints of the project limited each case study to a single visit. A village survey requires, ideally, a known population, a small sampling error and minimum measurement error, and a baseline survey. Unfortunately, it was apparent that this ideal could only be achieved with more extensive resources of time manpower, finance and goodwill.

An alternative approach could have been to limit the study to a single village, such that two or more visits could have been made. However, although the data collected for that village would have had a minimum measurement error, it would not have been possible to extrapolate it to generalisations about the entire population of villages with similar water supply packages.

It is recognised explicitly within this report that the results of the village case studies are non-general from a statistical point of view. However, this should not imply that the results have no value, either to the technologist or the water supply planner. For example, neither the Transkei nor the KwaZulu Governments conduct evaluation or monitoring procedures of their village water supply schemes. The case studies have identified weaknesses within the water supply schemes that are presently used. Within the context of the increasing sums of money allocated to village water supplies and the dearth of evaluation or monitoring procedures for those supplies, such a non-statistical survey can provide an important contribution to the understanding of issues relevant to successful water supply implementation. It is too often the case that policies are made and decisions implemented by central Government organisations with virtually no field insight or village level data.

The objectives of the village case studies were: (i) to evaluate whether the water supply schemes - including the technology used, planning and implementation methodologies, and the provision of maintenance services - were achieving the goal of a reliable, adequate supply of water, from the perspective of the user and with respect to the WHO recommendation of a minimum volume of 50 litres per person per day within 200 metres of the household, and (ii) to identify whether a correlation exists between the level of community participation used by the implementing agency and the success of the water supply scheme.

Although the potential benefits of a water supply scheme can extend into social organisation, economic activity or agriculture, as well as the primary health benefits associated largely with the increase of available water, water for domestic use is a basic human need. Hence, the provision of water on an adequate and reliable basis for human consumption and hygiene must be the primary objective of a water supply scheme.

Case studies were conducted of four villages with Government administered handpump schemes in KwaZulu, three villages with government administered windpump schemes in Transkei and tow villages with TATU administered spring protection schemes in Transkei.

The villages were selected in consultation with the responsible water supply planners, who were asked to identify both successful and unsuccessful schemes for investigation.

In each study village interview questionnaires were administered by an interpreter. Wherever possible the interpreter was a local person having a sound knowledge of English, or some person independent of the administering agency. In addition, discussions were held on the problems of water supply, availability and collection, Direct observations were made of the technology, its' condition, site and use by villagers.

The output of the technology was measured wherever possible, for comparison with manufacturer's data, and any difficulties or problems associated with its operation recorded.

The purpose of the interview questionnaire administered to users of each scheme was to elicit information and opinions concerning:

* the amount of water collected, distance to and nature of the water source used before implementation of the scheme;

* the amount of time spent and water collected from the improved water source;
* the nature and extent of community participation in the design, implementation and maintenance of the water supply scheme;
* the type of management and planning used;
* the type and amount of maintenance and additional or back-up services provided by the implementing agency;
* the user's perception of the water supply scheme, in terms of its overall adequacy and reliability, as well as any improvements that could or should be made.

A copy of the questionnaire applied to users of water supply schemes is presented in Appendix 6.3.

Appendix 6.2

Government Planner Questionnaire.

Questionnaire - Government Planner.

Date ,Time Place ,

Name ,

Job ,

Address

Telephone No.

1. General- types of water lifting systems.

1.1 Please describe the types of water lifting systems commonly used.

1.2 Which makes of

* handpumps
* windmills
* pedal pumps
* diesel pumps
* others (specify)

1.3 Which makes have proved to be the most reliable ?

* handpumps
* windmills
* pedal pumps
* diesel pumps
* others (specify)

1.4 Which makes have proved to be the most cost effective ?

* handpumps
* windmills
* pedal pumps
* diesel pumps
* others (specify)

1.5 Approximately how many of each type of system have been installed in this region ?

* handpumps
* windmills
* pedal pumps
* diesel pumps
* others (specify)

1.6 Approximately how many of these are broken down or out of order at the present time ?

* handpumps
* windmills
* pedal pumps
* diesel pumps
* others (specify)

2. Planning and Design.

2.1 How are villages or areas chosen for water supply schemes ?

chief or headman asks /villagers ask
water committee asks /government decides
other(specify)

2.2 How is the amount of water to be supplied determined ?

chief or headman advises /number of villagers
water committee advises /government decides
other(specify)

2.3 What are the typical system sizes or capacities for villages ?

* handpumps
* windmills
* pedal pumps
* diesel pumps
* others (specify)

2.4 What are typical water table depths ?

2.5 Who is responsible for drilling boreholes and checking water quality ?

government workers /contracted workers

2.6 What criteria are used when choosing the site of a borehole ?

2.7 Did the water table drop significantly during the recent drought and how did that effect systems ?

2.8 How is the type of technology chosen ?

government decides /water committee decides

open tender /fixed contract

initial cost /ease of maintenance /other(specify)

2.9 What criteria are used when choosing the site of a windmill ?

3. Community Participation.

3.1 How do community leaders or representatives contribute to the planning process ?

3.2 Do villlagers help or give advice in the planning of the supply ?

no /yes- In what way?

3.3 What do the villagers usually contribute toward the construction of the water supply ?

3.4 How much money does the village community usually give towards the cost of the supply ?

3.5 Are village meetings usually held to discuss the project?

3.6 Do the villagers usually form a water committee ?

3.7 What does the water committee usually do ?
talk to government /talk to contractors
collect money /nothing /other(specify)

4. <u>Maintenance.</u>

4.1 Who installs the pump at the site chosen ?
government worker /chief or headman
villagers /community worker
contracted company /other(specify)

4.2 Once the supply has been installed who is responsible for servicing it and checking its' condition ?

government worker /chief or headman

villagers /community worker /water committee

contracted company /other(specify)

4.3 Who is responsible for repairing the supply when it breaks down ?

government worker /chief or headman

villagers /community worker /water committee

contracted company /other(specify)

4.4 What is the average time a supply is out of order before it is repaired ?

days

4.5 What is the anticipated usefull lifetime of the water lifting technology ?

years

4.6 What are the usual operating costs of a water supply scheme using a

* handpump
* windmill
* pedal pump
* diesel pump
* other (specify)

Appendix 6.3

Villager Questionnaire.

Questionnaire - Villager.

Date ,Time Place

Name

Single/Married

Male/Female Age

1.How long ago was the new handpump/windmill built ?

months

years

2.Who asked for the handpump/windmill to be installed ?

villagers /chief or headman /community worker/

water committee /development committee

nobody asked /don't know /other(specify)

3.Were there village meetings to discuss the project ?

yes-How many?

no don't know

4.Was a village water committee formed ?

yes

no

5.How was the water committee chosen ?

elected at village meeting

chosen by chief or headman

chosen by government /elected themselves

don't know /other(specify)

Questionnaire - Villager.

6.What did the committee do ?

talked to government

talked to Aid Agency

collected money /nothing / other(specify)

7.Who decided what kind of system to install ?

water committee / chief or headman

government / Aid Agency / don't know

other(specify)

8.Who paid for the handpump/windmill ?

government /Aid Agency /villagers

water committee /don't know /other(specify)

9.Who installed the handpump/windmill ?

government /Aid Agency /villagers

water committee /don't know /other(specify)

10.Did people in the village help ?

yes

no /don't know

11.How did they help ?

manual labour /skilled labour

don't know /other(specify)

<u>Questionnaire</u> - <u>Villager</u>.

12.Is it easier or harder to get water now ?

easier /harder

don't know

13.Where did you get your water before the new pump was built ?

protected spring /river /rainwater

unprotected spring /well /other(specify)

14.How many times a day did you fetch water then ?

once /twice /three times /other(specify)

15.How much water did you carry each time ?

16.How long did each trip take ?

minutes

17.Did the old water source ever dry up ?

yes

no /don't know

18.Do you collect water from the handpump/windmill ?

yes

no

19.Is the water you get from the handpump/windmill cleaner or dirtier than from the other source ?

cleaner /dirtier

<u>Questionnaire</u> - <u>Villager</u>.

20.How many times a day do you fetch water from the handpump/windmill now ?

once /twice /three times

other(specify)

21.How long does each trip take ?

minutes

22.Do you ever have to wait in a queue at the handpump/windmill ?

no /yes- For how long ?

23.How much water do you carry each time ?

24.Are there any problems with the handpump/windmill ?

no /yes-What are the problems ?

25.Do you still collect water from the other source ?

no /yes- How often ?

26.Does the handpump/windmill ever run out of water ?

no /yes- How often ?

27.Does the handpump/windmill ever break down ?

no /yes

Questionnaire - Villager.

28.When was the last time it broke down ?

29.What was wrong with it ?

30.Who fixes it if it breaks down ?

government /villager /community worker

chief or headman /don't know

other(specify)

31.How long did it take to be fixed ?

weeks or days

32.Where do you get your water when the handpump/windmill is not working ?

protected spring /river /rainwater

unprotected spring /well /other(specify)

33.Who pays for it to be fixed ?

government /chief or headman

water committee /villagers /don't know

other(specify)

<u>Questionnaire</u> - <u>Villager</u>.

34.Do you think the handpump/windmill operates adequately or well enough ?

no /yes

don't know

35.What things would make the water situation better than it is now ?

Appendix 6.4

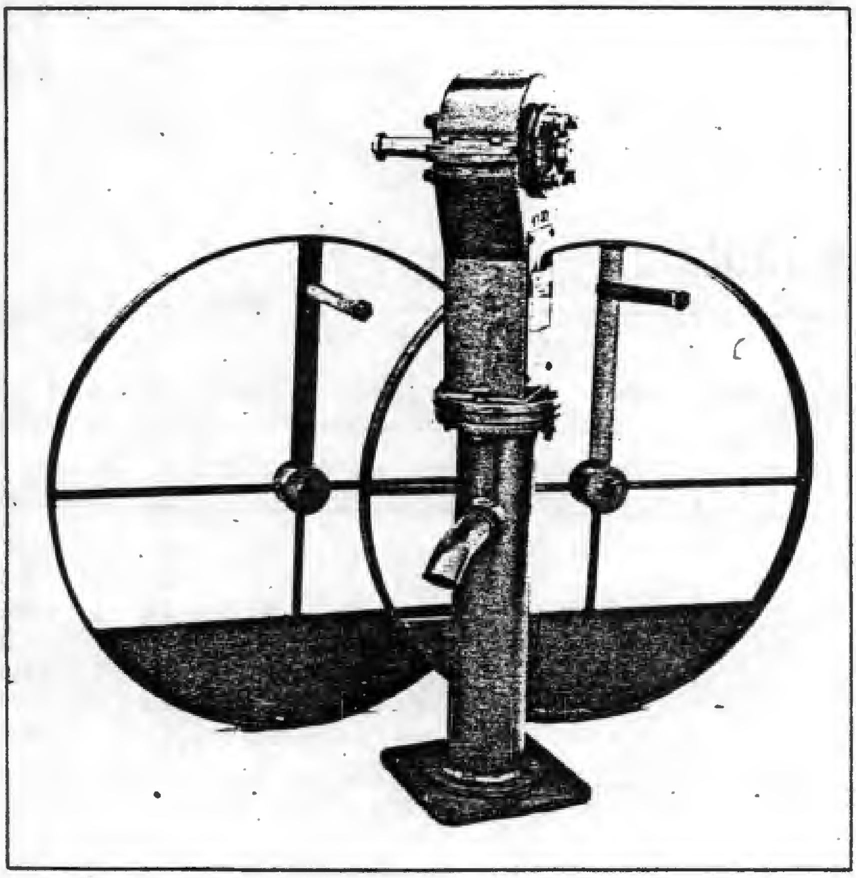
Manufacturer's Data.

Appendix 6.4.1

Handpumps.

Climax

Handpomp
Handpump



Die Climax No. 104 is 'n duursame handpomp wat sy slag onder strawwe toestande op die platteland bewys het.

Dit is 'n draai-aksie eenheid en stel lae onderhoud-vereistes deurdat die draaiende dele met lewenslank verseëlde koeëllaers toegerus is.

Die romp van die pomp is van medium, SABS gehalte pyp vervaardig en die krukkas is van hoë gehalte gietyster.

Die pomp is beskikbaar in beide enkel- of dubbel-handwiel eenhede, met of sonder 'n drukbuis-samestelling.

The Climax No. 104 handpump is a robust unit which has proved itself under arduous rural conditions.

It is a rotary action unit with revolving parts running in self-aligning sealed-for-life bearings. Maintenance is minimal.

The body barrel is of medium quality SABS tube with the crankcase being of high quality cast iron.

The pump is available in either double or single wheel models, with or without a differential tube assembly.

Afmetings

Basis tot middellyn van Handwiel	900 mm	
Basis tot middellyn van leweringsuitlaat	400 mm	
Basis vierkant	330 mm	
Gate vir montering van basisplaat 20 mm op 280 mm sirkeldeursnee		
Leweringsuitlaat	40 mm	B.S.P.
Inlaat vir stygleiding	50 mm	B.S.P.
Slaglengte	100mm	
Handwiel deursnee	100 mm	
	800 mm	

Dimensions

Base to centre line of wheel	900 mm	
Base to centre line of delivery outlet	400 mm	
Base	330 mm	square
Foundation bolt holes drilled 20 mm on 280 mm P.C.D.		
Delivery outlet	40 mm	B.S.P.
Inlet for rising main	50 mm	B.S.P.
Stroke length	100 mm	
Handwheel diameter	800 mm	

Laste Tabel/Load Table

Silinder Grootte Cylinder Size	Maksimum Drukhoogte Maximum Head	liters /min	liters /uur /hr	liters /min	liters /uur /hr	liters /min	liters /uur /hr
m	m	10 spm		20 spm		30 spm	
45	80	1,7	102,0	3,4	204,0	5,1	306,0
51	52	2,0	120,0	4,0	240,0	6,0	360,0
65	39	3,2	192,0	6,4	384,0	9,6	576,0
76	31	4,5	270,0	9,0	540,0	13,5	810,0
90	25	6,3	378,0	12,6	756,0	19,0	1140,0
102	20	9,2	552,0	18,4	1104,0	24,6	1476,0
125	13	12,7	762,0	25,4	1524,0	37,9	2274,0

N.B.

Meganies is die handpomp in staat om teen hoër drukhoogtes te pomp as wat die laste tabel aandui. Die hoogtes per silindergrootte soos aangedui is bepaal in verhouding tot die gemaklike vermoë van die gemiddelde persoon.

N.B.

Mechanically, the pump is capable of higher heads than those shown in the load tables. However, the head per cylinder size has been limited to what can comfortably be coped with by the average person.

REED PRINT S & L 287

"L" HANDPUMP

Load Table

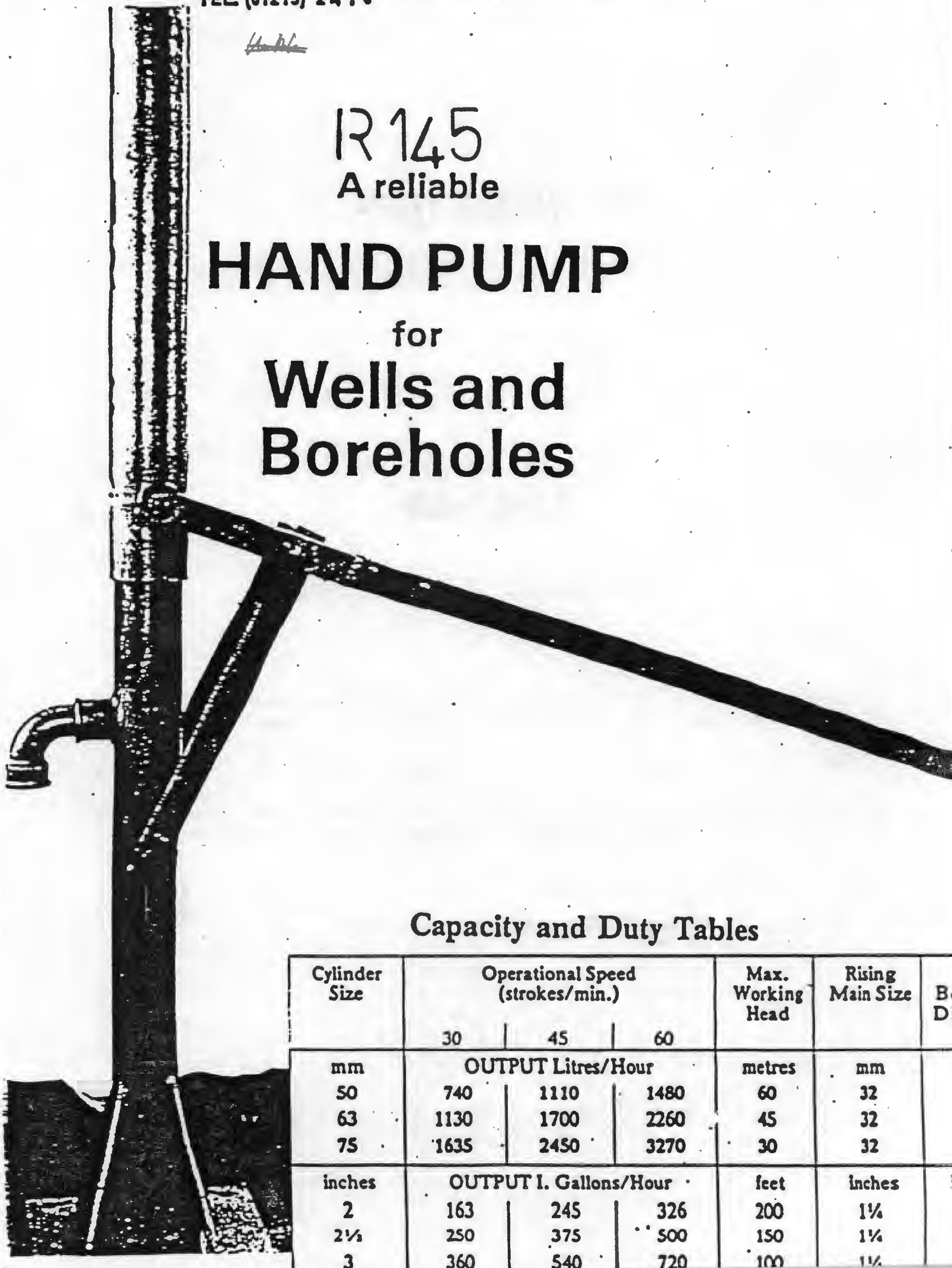
PERFORMANCE AT 30 STROKES PER MINUTE

Cylinder Size (mm)	40	50	65	75	90	100	110	125
Total Lift (m)	90	60	35	25	18	14	12	9
Capacity (ℓ/min)	5,7	8,7	14	19	28	35	42	55

---oOo---

NIMRIC

Posbus/P.O. Box 35 · BELEGGINGS (EDMS.) BPK.
CULLINAN. INVESTMENTS (PTY.) LTD.
TEL. (01215) 2470



R 145

A reliable

HAND PUMP

for

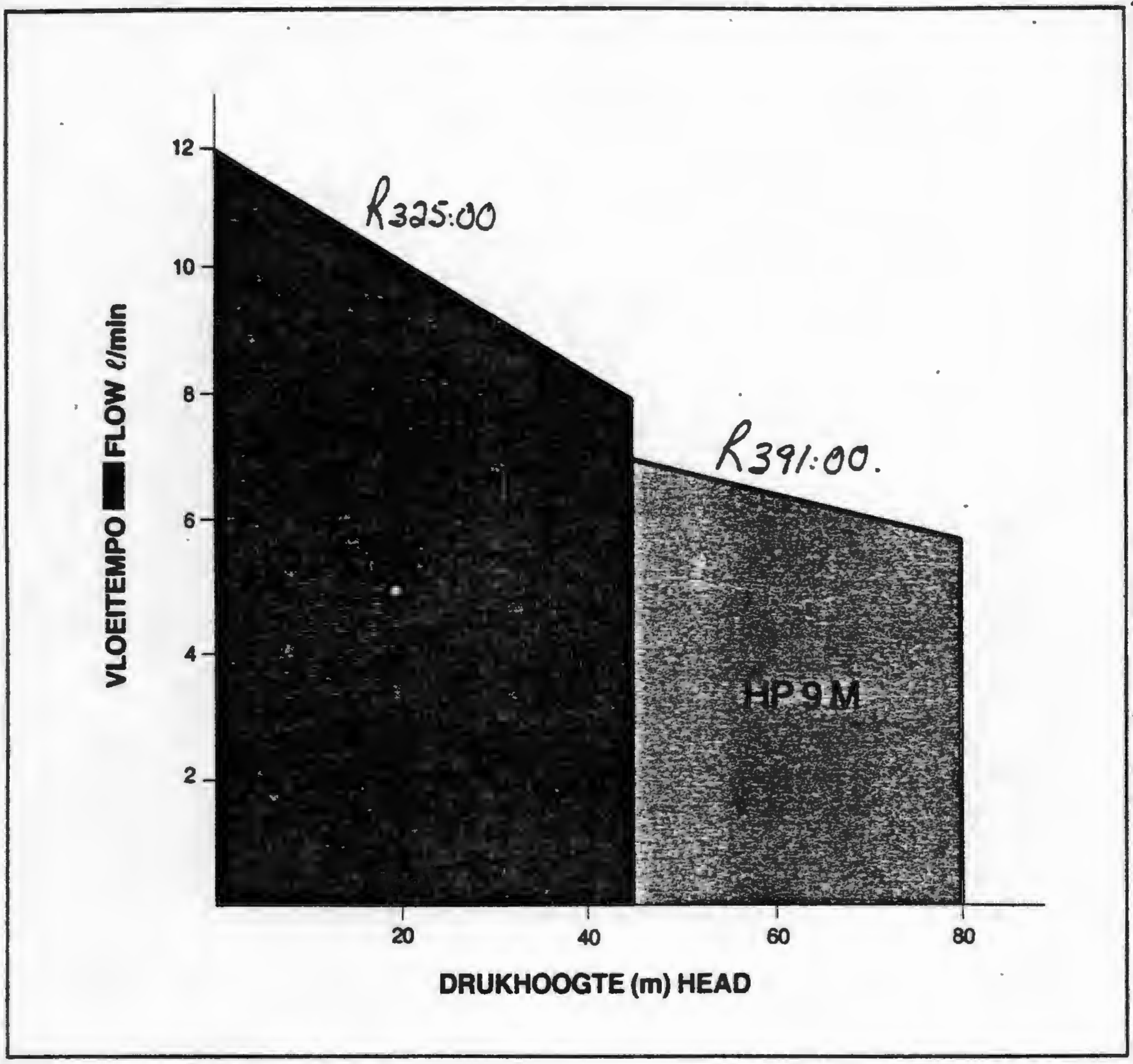
Wells and Boreholes

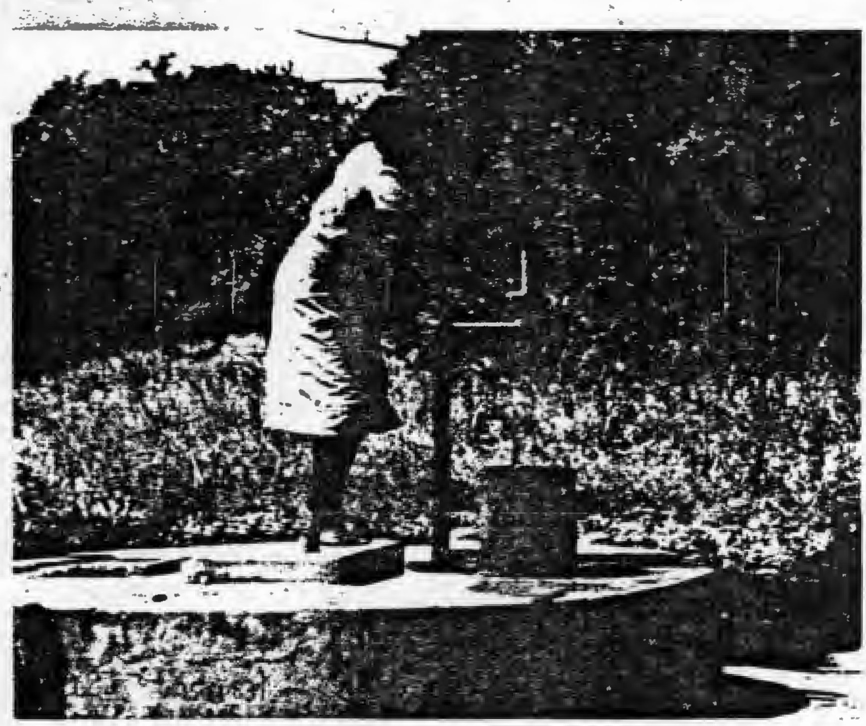
Capacity and Duty Tables

Cylinder Size	Operational Speed (strokes/min.)			Max. Working Head	Rising Main Size
	30	45	60		
mm	OUTPUT Litres/Hour			metres	mm
50	740	1110	1480	60	32
63	1130	1700	2260	45	32
75	1635	2450	3270	30	32
inches	OUTPUT I. Gallons/Hour			feet	inches
2	163	245	326	200	1¼
2½	250	375	500	150	1¼
3	360	540	720	100	1¼

MONO DIRECT DRIVE

Tipiese gemiddelde prestasiegids. Typical average performance guide.





Appendix 6.4.2

Footpumps

Mono Pedal Pump

Mono's Pedal operated pump, designed in conjunction with the Engineering faculty of the University of the Witwatersrand and other authorities for pumping from rivers, dams, reservoirs and ponds, has been engineered for rural Africa.

This pump is a further development in Mono's never ending search for water supply solutions in developing countries. The successful operating for many years of the Hand Operated Rotary Borehole pump and the recently launched Solar Lift Solar Pumping Systems has encouraged Mono to pay attention to surface water.

The unit is robustly constructed of rectangular steel. Ergonomics, comfort and ease of operation have been taken into account.

The use of a simple but robust chain drive in a number of ratios has ensured that a variety of different head conditions may be catered for.

Mono Trappomp

Die Mono Trappomp wat in samewerking met die Ingeneursfakulteit van die Universiteit van die Witwatersrand ontwikkel is, is spesifiek ontwerp vir die pomp van water van uit damme, riviere, kuile of reservoirs in onderontwikkelde Afrika lande.

Hierdie pomp is nog 'n stap verder in Mono se soeke na oplossings vir die waterverplasings probleme wat in ontwikkelende lande ondervind word. Die uiters suksesvolle gebruik van die Mono Draaiskroef Handpomp oor baie jare, asook die onlangse vrystelling van die Solarlift Solar pomp, het Mono genoodsaak om aandag te skenk aan oppervlak water.

Hierdie eenheid bestaan uit 'n taai, reghoekige staalkonstruksie, en baie aandag is aan doeltreffendheid, gerief en maklike hantering geskenk.

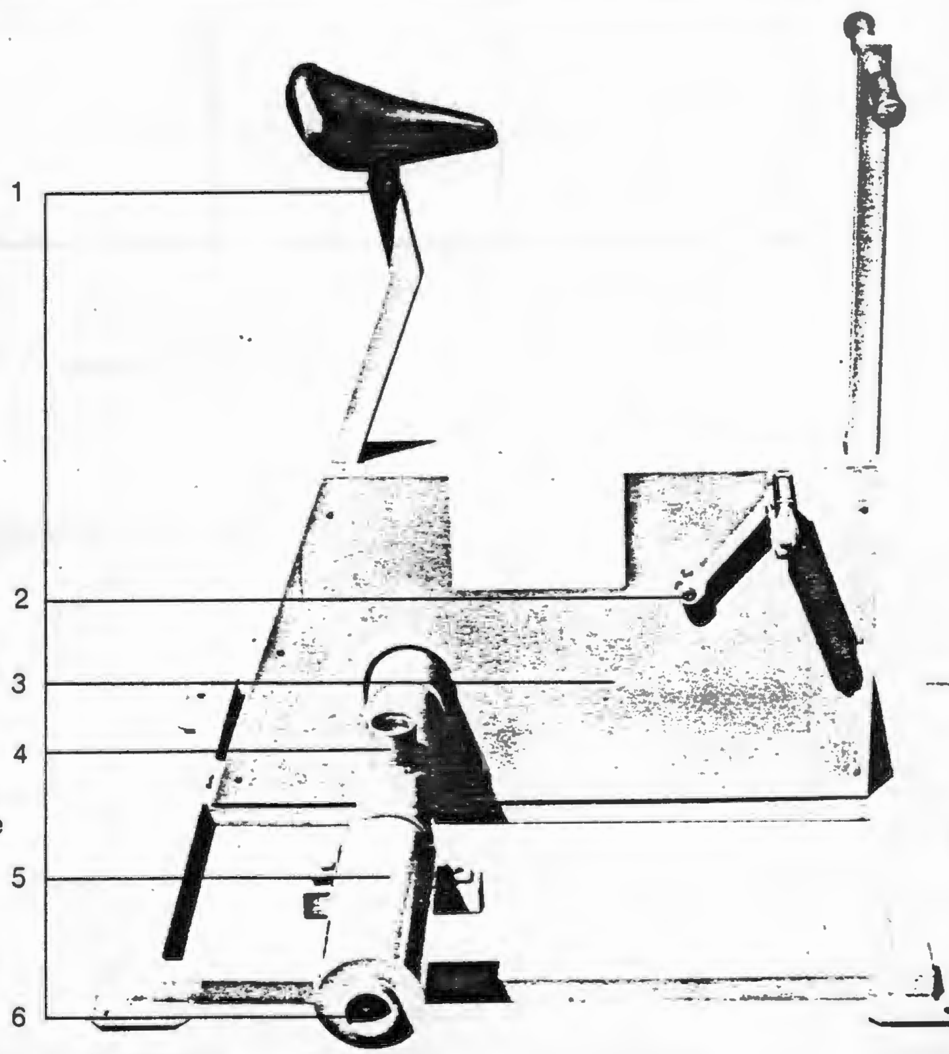
Die gebruik van 'n eenvoudige, dog sterk kettingaandrywing in 'n aantal verhoudings, het verseker dat daar vir 'n verskeidenheid druk toestande voorsiening gemaak is.

Features

1. Adjustable saddle to suit all heights.
2. Robust chain drive — assembled from easily obtainable components.
3. Safe — all moving parts properly enclosed and guarded.
4. Three ratios for differing heads:
   2:1 — 20 metres
   3:1 — 15 metres
   4:1 — 10 metres
5. Proven Mono pump Positive Displacement element.
6. Inherently self priming.

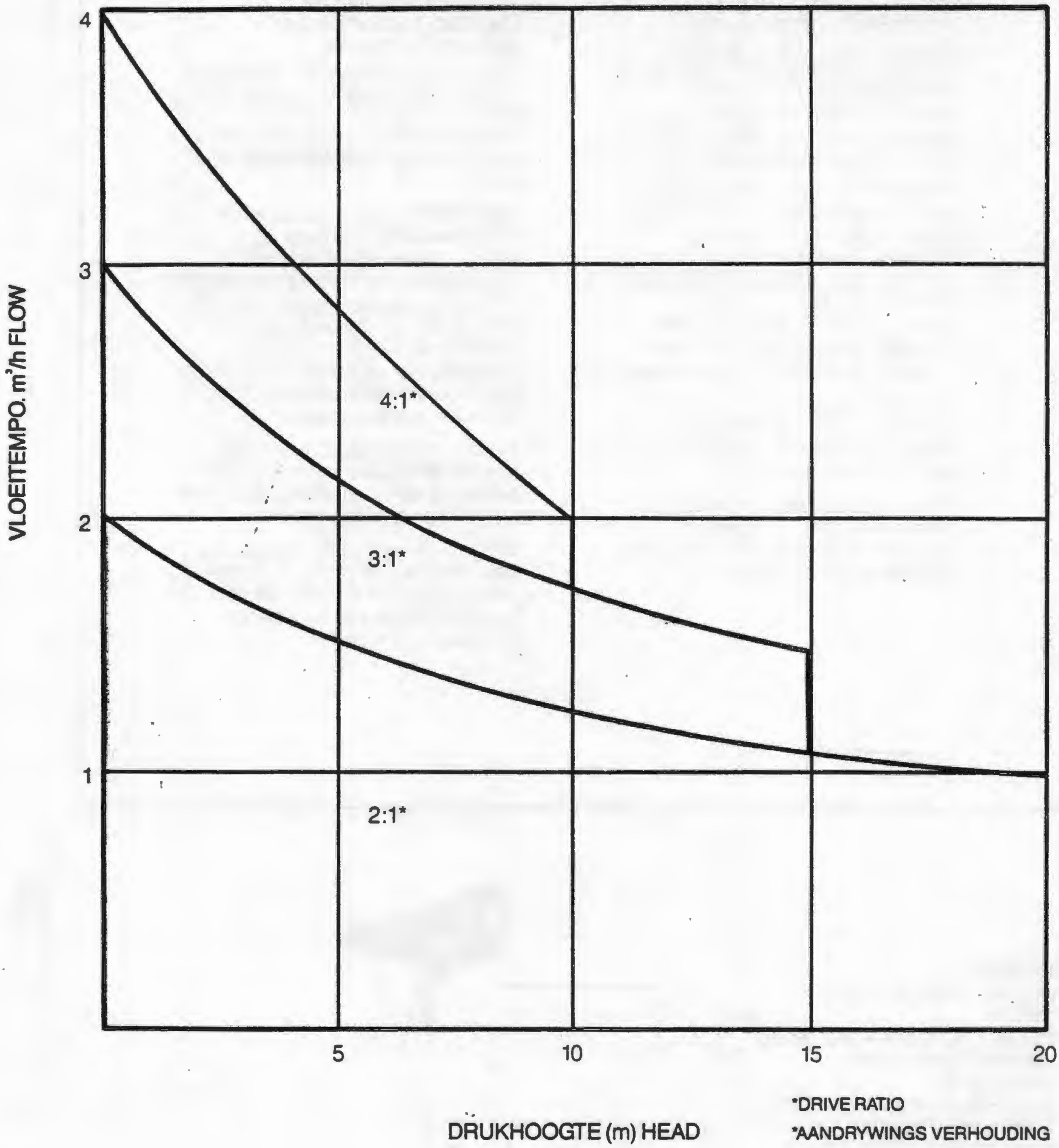
Eienskappe

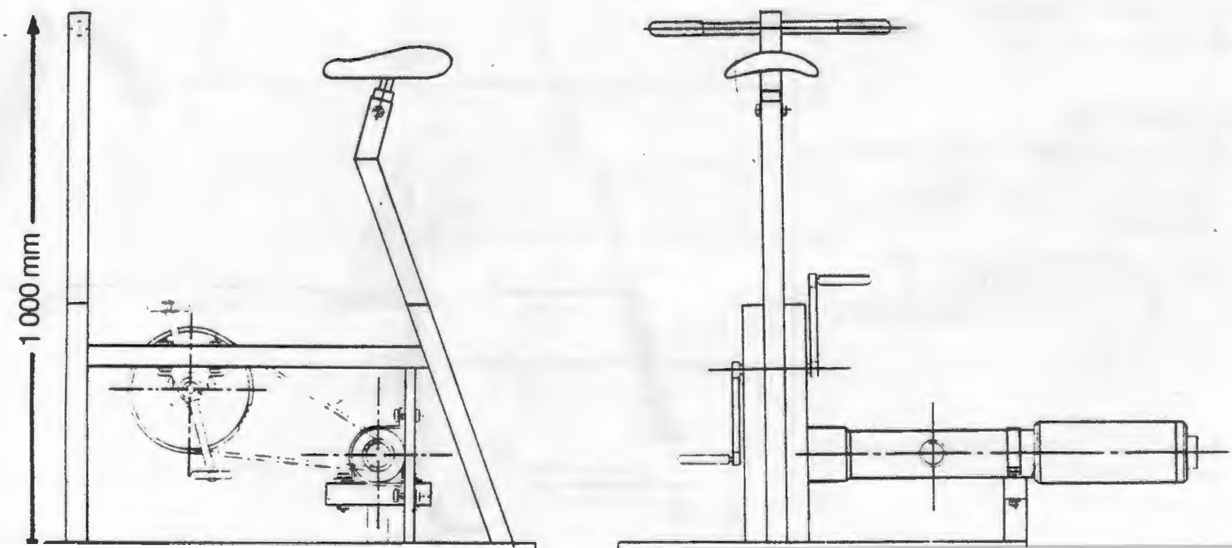
1. Verstelbare sitplek om almal te pas.
2. Sterk kettingaandrywing — saamgestel uit maklik bekombare komponente.
3. Veilig — alle bewegende dele is behoorlik toe en beskerm.
4. Drie ratverhoudings vir verskillende drukhooogtes.
   2:1 — 20 meter
   3:1 — 15 meter
   4:1 — 10 meter
5. Beproefde Mono-pomp positiewe verplasings element.
6. Inherent selfontlugtend.



Typical average performance guide
(Average Pump Speed: 60r/min on the pedals)

Tipiese gemiddelde prestasiegids
(Gemiddelde Pomp Spoed: 60r/min op die pedale)





Appendix 6.4.3

Windpumps

Climax

Nrs. 8, 10, 12, 14

Die Climax-windpomp word deur boere dwarsdeur Suid-Afrika vereenselwig met die mees betroubare pomptoerusting en word vervaardig in die beste toegeruste windpompfabriek in Afrika. Die ervare tegnici met 'n halwe eeuse kennis en ontwikkeling tot hul beskikking, verseker dat 'n topgehalte produk vervaardig word. Voortdurende navorsing en daaglikse kontak met verbruikers maak die vernuwing en verbetering van toerusting moontlik om by veranderende omstandighede aan te pas.
Aldus ons aanspraak dat die Climax een van die beste, indien nie dié mees doeltreffende pomp van sy soort in die wêreld is, wat die maksimum hoeveelheid water lewer met die minimum slytasie. Dié kragtige konstruksie is bestand teen die uiterste weerstoestande.

Treffende Kenmerke van Ontwerp

Ratkas
Die hoofhulsel is in een stuk gegiet en vorm die oliebak en ratkas — geen olie kan dus uitlek nie.
Die tandwiele werk in verstelbare laerdraers — dit vergemaklik die stel van ratte.
Alle ratte is masjiengesny — gladde en geruislose werkverrigting.
Dubbele ratte — dit verseker gebalanseerde vrag en skakel oormatige slytasie weens oorhangende vrag uit.
Oliesmering na boonste meganisme — mees doeltreffende metode om outomatiese smering van die dwarskop te verseker.
Windwielas draai in koeëllaers — gladde maklike draai en duursaamheid.
Weerdigte dop, wat maklik verwyder kan word deur 'n enkele moertjie los te draai — hou stof en reën uit die meganisme.

Ondergeleier
Die kop word gesteun deur 'n koeëllaer in die ondergeleier — verseker doeltreffende werking. Toetse oor 'n geruime tydperk het die voortreflikheid hiervan bewys. Die gladde draai van die kop stel die Climax-windpomp in staat om gou te reageer met verandering van windrigting.

Wiel
Stewige steunarms hou die vlerke teen die rame in posisie — juiste buiging en stand word sodoende verseker.
Die vorm van die vlerk is sorgvuldig ontwerp na deeglike navorsing van windtoestande en boorgatpomp-vereistes in Suid-Afrika.
Outomatiese rembeheer word verkry deur middel van slegs die wind — nadelige skokke en ooreising deur outomatiese aanslaan van die rem is uitgeskakel.

Sterteenheid
Spesiaal ontwerpte buffermeganisme demp en voorkom skokke en beskadiging gedurende onstuimige weer — doeltreffende en outomatiese toevou van die stert word egalig verkry sonder gevaar van beskadiging.
Veerstelsel is ontwerp om die wiel in die wind te hou vir alle veilige windsnelhede — verseker maksimum gebruik van windkrag sonder om die meganisme te oorlaai.

Nos. 8, 10, 12, 14

The Climax is a by-word with farmers throughout Southern Africa, as the acme of thoroughly reliable pumping machinery. It is the product of the largest and best equipped windmill manufacturing plant in Africa, with a staff of highly skilled technicians in close personal contact with users and an accumulated knowledge of over half a century of manufacturing windmills.
This commendation is jealously guarded by constant refinement in the light of changing conditions, backed by continued research into wind conditions and borehole pumping requirements in Southern Africa. Thus we can claim that the Climax is one of, if not the, most efficient machine of its kind in the world and provides the maximum amount of water with minimum wear. Its rugged construction withstands the most extreme weather conditions.

Outstanding design features

Gearbox
One piece main casting forms integral oil sump and gearbox — no leaks.
Main gears carried in adjustable bracket — easy setting of mechanism.
Accurately profiled machine cut gears and pinions — smooth, silent running.
Windshaft carried in ball-bearings — smooth effortless running, long life.
Double gears — balanced load throughout: no undue wear through overhung load.
Oil ring lubrication to upper mechanism — most efficient method of automatically conveying oil to crosshead.
Weather sealing bonnet easily removed by the turn of one nut — keeps mechanism free from dust and rain.

Turntable
Head supported on ball-bearing, quick action turntable — more efficient pumping. Tests over a long period have proved its superiority. Smooth effortless turning enables Climax windwheel to respond quickly to changes in direction of wind.

Wheel
Rigid brackets hold sails in position on rims — correct curvature and alignment are assured.
Sail shape carefully designed after extensive research into South African wind conditions and borehole pumping requirements.
Absolute braking control operated by wind only — damaging shocks and strains caused by brake operation during automatic furling eliminated.

Tail Unit
Specially designed buffer mechanism eliminates slamming of tail and absorbs shocks and damage in gusty weather — results in efficient automatic furling with rising wind without risk of damage and impact noise.
Spring tension designed to maintain wheel in the wind over the full range of safe wind speeds — ensures maximum use of windpower without overloading the mechanism.

Climax

Las-tabelle/Load Tables

Nr. 8 Climax-windpomp/No. 8 Climax Windmill

Wind -snelheid/speed km/h Maks.d'hoogte/Max. head m. Stygleiding/Rising Main mm		10/16 55/110 32 × 12	10/16 43/106 32 × 12	10/16 34/86 40 × 12	10/16 22/56 40 × 12	10/16 16/40 40 × 12	10/16 11/30 50 × 12	10/16 9/23 50 × 12	10/16 7/18 65 × 12	10/16 6/15 65 × 12
Liter/h Litres/h	2·7 m/s 10km/h 16km/h 4·4 m/s	72 126	100 162	130 204	210 330	288 462	390 624	540 840	660 1080	780 1260
Sil. diam./Cyl. diam. mm		40	45	51	65	76	90	102	115	125

Nr. 10 Climax-windpomp/No. 10 Climax Windmill

Wind -snelheid/speed km/h Maks.d'hoogte/Max. head m. Stygleiding/Rising Main mm		10/16 77/110 32 × 12	10/16 57/110 32 × 12	10/16 46/110 40 × 12	10/16 30/78 40 × 12	10/16 22/54 40 × 12	10/16 16/40 50 × 12	10/16 12/32 50 × 12	10/16 9/25 65 × 12	10/16 8/20 65 × 12
Liter/h Litres/h	10km/h 16km/h	84 156	117 200	150 246	246 460	330 540	450 720	650 960	780 1200	900 1460
Sil. diam./Cyl. diam. mm		40	45	51	65	76	90	102	115	125

Nr. 12 Climax-windpomp/No. 12 Climax Windmill

Wind -snelheid/speed km/h Maks.d'hoogte/Max. head m. Stygleiding/Rising Main mm		10/16 92/110 32 × 12	10/16 70/110 32 × 12	10/16 55/110 40 × 12	10/16 37/92 40 × 12	10/16 26/66 40 × 12	10/16 20/48 50 × 12	10/16 14/38 50 × 12	10/16 12/30 65 × 12	10/16 10/24 65 × 12
Liter/h Litres/h	10km/h 16km/h	96 170	132 240	174 300	264 430	375 600	510 830	708 1320	840 1620	1020 1680
Sil. diam./Cyl. diam. mm		40	45	51	65	76	90	102	115	125

Nr. 14 Climax-windpomp/No. 14 Climax Windmill

Wind -snelheid/speed km/h Maks.d'hoogte/Max. head m. Stygleiding/Rising Main mm		10/16 121/110 40 × 16	10/16 96/110 40 × 16	10/16 82/110 40 × 16	10/16 56/110 50 × 16	10/16 40/108 50 × 16	10/16 30/78 50 × 16	10/16 24/60 50 × 16	10/16 18/48 65 × 16	10/16 14/38 65 × 16
Liter/h Litres/h	10km/h 16km/h	80 156	105 210	150 270	230 400	325 520	450 720	570 960	730 1170	960 1500
Sil. diam./Cyl diam. mm		40	45	51	65	76	90	102	115	125

N.B.: Die syfers in die tabelle hierbó is gebaseer op 'n begin-windsnelheid van 10 en 16 km/h met gebalanseerde pompstange. Raadpleeg die Climax-werkverrigtingskurwe vir ander vereistes.

N.B.: The figures given in the tables above are based upon a start windspeed of 10 and 16 km/h and balanced pump rods. For operating performance outside of this assumption, refer to Climax's performance curves.

The S+L No. 18 windmill

1. The No. 18 Windmill is an open type, direct acting, 152 mm stroke mill with 5,5 m diameter windwheel.

2. No lubrication is required as all bearings are sealed for life ball bearings or self lubricating P.T.F.E. bushes.

3. The main frame is a rigid grey iron casting.

4. The head is supported by a P.T.F.E. bush and thrust washer in the tower cap and a P.T.F.E. bush in the lower guide.

5. The windshaft is of high tensile steel revolving in two sealed for life ball bearings with extra steel sealing plates to protect the front bearing from ingress of dust.

6. The crank is of S.G. iron and is keyed and pressed onto the windshaft for extra rigidity.

7. The connecting rod is a rigid grey iron casting fitted with a totally enclosed sealed for life ball bearing at the big end, and two P.T.F.E. bushes at the small end.

8. The windwheel is of all steel construction with eight spokes and three rims for rigidity. Every part is hot-dipped galvanised.

9. The tail carrier is of all-welded tubular construction, hot-dip galvanised after fabrication and fitted with a robust hinge arrangement to simplify erection. The tail vane, of heavy gauge galvanised steel sheet, is securely bolted to the tail carrier.

10. The tower is of four post design and built of heavy rolled steel angle iron, suitably braced and hot-dip galvanised throughout.

Die S+L Nr. 18-windpomp

1. Die Nr. 18-windpomp is 'n oop tipe, regstreekse windpomp met 'n werkslag van 152 mm en 'n windwiel waarvan die diameter 5,5 m is.

2. Dit vereis geen smering nie want al die laers is koeëllaers wat lewenslank verseël, of die busse selfsmerende PTFE-busse is.

3. Die hoofraam is 'n stewige grysystergietstuk.

4. Die kop word gesteun deur 'n PTFE-bus en -drukwaster in die toringdop en 'n PTFE-bus in die onderste leier.

5. Die windas is van hoëtreksterktestaal wat draai in twee koeëllaers wat lewenslank verseël is en wat ekstra staalseëlplate het om die voorlaers teen die indringing van stof te beskerm.

6. Die kruk is van SG-yster en word vasgespy en vir ekstra stewigheid aan die windas gedruk.

7. Die verbindstang is 'n stewige grysystergietstuk wat aan die groot ent toegerus is met 'n geheel ingeslote koeëllaer wat lewenslank verseël is, en aan die klein ent twee PTFE-busse het.

8. Die windwiel is heeltemal van staal vervaardig en het agt speke en drie vellings vir stewigheid. Elke onderdeel is deurgaans warmgegalvaniseer.

9. Die stertdraer is 'n sweispypkonstruksie wat na vervaardiging warmgegalvaniseer is en met 'n stewige skarnierstelsel toegerus is om oprigting te vereenvoudig. Die stertwiek wat van dik gegalvaniseerde staalplaat vervaardig is, is stewig aan die stertdraer vasgebout.

10. Die toring is van die vierstylontwerp en gebou van dik hoekyster van gewalste staal wat behoorlik verspan en deurgaans warmgegalvaniseer is.

No. 18 windmill load tables
Bucket rod loading – 550 kg
Stroke 152 mm

10% allowance for slip

Lastabelle vir Nr. 18-windpomp
Pompstangbelasting – 550 kg
Slag 152 mm

10% toelating vir gly

Cylinder Silinder mm	m Surface pumping Oppervlakpompwerk	m Deepwell pumping Diepputpompwerk	38 S.P.M. l/hr – l/uur	55 S.P.M. l/hr – l/uur
51	269	168	623	931
57	213	144	786	1 145
65	182	124	972	1 422
70	142	108	1 181	1 727
76	120	94	1 408	2 072
83	102	83	1 636	2 417
90	91	73	1 908	2 794
102	67	58	2 499	3 681
108	60	52	2 817	4 158
115	53	47	3 135	4 635
127	43	39	3 908	5 725
152	30	28	5 635	8 225

NIMRIC WINDMILL CAPACITIES

WHEEL SIZES		CYLINDER DIAMETERS 45 mm (1¾")	50 mm (2")	63 mm (2½")	75 mm (3")	90 mm (3½")	100 mm (4")	106 mm (4½")	125 mm (5")	150 mm (6")
2,45 m (N° 8)	Total lift in metres	40	33	23	17	13	11	9	7	5
	Average litre per day	4000	5145	8100	11600	16200	20700	26100	32400	46800
3 m (N° 10)	Total lift in metres	72	60	43	32	25	10	16	13	10
	Average litre per day	4000	5400	7875	11340	15435	20250	25650	31500	45450
3,66 m (N° 12)	Total lift in metres	96	80	58	43	33	26	19	17	13
	Average litre per day	4275	5600	8550	12375	16875	19400	27540	34200	49500
4,3 m (N° 14)	Total lift in metres	130	112	82	60	55	43	32	25	18
	Average litre per day	4100	5750	8700	12420	17100	21400	29600	36000	54200

NIMRIC WINDMILL COMPLETE WITH TOWER

WHEEL SIZE: 2,4 METERS OR 8 FT. (NO. 8)

COMPLETE WITH 6 m TOWER (20 FT) PUMPS FROM 35 m UP
COMPLETE WITH 8 m TOWER (25 FT) PUMPS FROM 35 m UP
COMPLETE WITH 9 m TOWER (30 FT) PUMPS FROM 35 m UP

WHEEL SIZE: 3 METER OR 10 FT. (NO. 10)

COMPLETE WITH 6 m TOWER (20 FT) PUMPS FROM 60 m UP
COMPLETE WITH 8 m TOWER (25 FT) PUMPS FROM 60 m UP
COMPLETE WITH 9 m TOWER (30 FT) PUMPS FROM 60 m UP

WHEEL SIZE: 3,6 METER OR 12 FT. (NO. 12)

COMPLETE WITH 6 m TOWER (20 FT) PUMPS FROM 90 m UP
COMPLETE WITH 8 m TOWER (25 FT) PUMPS FROM 90 m UP
COMPLETE WITH 9 m TOWER (30 FT) PUMPS FROM 90 m UP

WHEEL SIZE: 4,3 METER OR 14 FT. (NO. 14)

COMPLETE WITH 9 m TOWER (30 FT) PUMPS FROM 130 m UP
COMPLETE WITH 12 m TOWER (40 FT) PUMPS FROM 130 m UP
COMPLETE WITH 14 m TOWER (45 FT) PUMPS FROM 130 m UP

WHEEL SIZE: 6,1 METER OR 20 FT. (NO. 20)

COMPLETE WITH 14 m TOWER (45 FT) PUMPS FROM 180 m UP

WEIGHT OF COMPLETE WINDMILL HEADS – NOT CRATED

2,4	METER	=	8 FOOT	197 KG
3	METER	=	10 FOOT	245 KG
3,6	METER	=	12 FOOT	269 KG
4,3	METER	=	14 FOOT	443 KG

Southern Cross

SENESCHAL PATROON DIREKTE AKSIE WINDPOMPE

DIE "ROLLS-ROYCE" VAN WINDPOMPE ...VIR DIE MEES VEELEISENDE WERK

Met die vervaardiging van die "Seneschal" het Suiderkruis 'n windpomp gemaak van hoër ingenieurs-standaarde as wat ooit tevore toegepas is in die vervaardiging van Windpompe.

Modern, doeltreffend en betroubaar. Die aantal wat opgerig is deur grondeienaars en regeringsdepartemente by veestasies, veepaaie, plase en vir oorpsvoorsiening en veral in afgeleë plekke soos in die Kalahari waar hulle enjin-pomptoestelle vervang, getuig van hul betroubaarheid om goeie watervoorrade te lewer.

Die "Seneschal" word gemaak vir groter pompwerke, soos water uit diep boorgate te pomp en ook om water oor lang afstande te pomp.

- KRAGTIGE WINDWIEL
- OUTOMATIESE SMERING
- GLADDE DRAAITAFEL
- ALGEHELE OMHULSEL
- WETENSKAPLIK ONTWERPTE SKEPPERS

UITEENGESETTE SPESIFIKASIE

MOEITEVRYE OUTOMATIESE SMERING: Die smeerstelsel van die Seneschal-windpomp verseker goeie smering van alle werkende dele van die windpomp *sonder dat dit nodig is om op die toring te klim*. 'n Olie-handpomp word aan die toring naby grondvlak gemonteer en olie kan van die pomp na die enjin van die windpomp gepomp word. Olie kan dus vervang word *sonder om op die toring te klim*. Geen ander windpomp het so 'n maklike outomatiese oliestelsel nie.

ALGEHELE OMHULSEL BESKERM ENJIN: Die enjin van die pomp is heeltemal omhul. stof- en waterdig.

POSITIEF GEKOPPEL AAN WIELNAAF: Die wielnaaf word deeglik aan die as vasgesit deur middel van twee spye wat van teenoorgestelde rigtings ingedryf word en dan gesluit word. Sluitmoere word reghoekig aan die spye gepas.

MAKLIKE WERKING OPWAARTSE EN AFWAARTSE MEGANISME: Die krag van die windwiel word deur middel van die hoofas na die kruk- en dryfstang geneem na die dwarskop wat beweeg tussen V-seksiegidse.

KRAGTIGE WINDWIEL: Die struktuur van die windwiel bestaan uit 'n stel Skraagbalkspeke wat dubbel aan die flense van die wielnaaf gebout word. Elke speek is 'n aparte aanmekaar-geklinkte eenheid, en wanneer die wiel aanmekaar gesit is, vorm dit 'n stewige eenheid waaraan die vlerke gebout word.

WETENSKAPLIKE ONTWERPTE VLERKE is gespasieer, gevorm en gebuig om die maksimum pompvermoe te verseker en dat die wiel maklik sal begin draai.

SENESCHAL PATTERN DIRECT ACTION WINDMILLS

THE "ROLLS-ROYCE" OF WINDMIL ...FOR THE MOST EXACTING DU

With the production of the "Seneschal" Southern C built a Windmill to much higher engineering standa than ever previously employed in Windmill manufact

Modern, efficient and reliable, the numbers installe Landowners and Government Departments on Stati Stock Routes, Farms and for Town water supplies particularly in such remote areas as the Kalahari wh they have replaced many engine pumping plants, tes to their dependability in maintaining reliable w supplies.

The "Seneschal" is made for the bigger pumping j such as for pumping big quantities of water from d bores and for pumping water over long distances.

- POWERFUL WINDWHEEL
- AUTOMATIC OILING
- FREE PIVOTING TURNTABLE
- COMPLETELY ENCLOSED
- SCIENTIFICALLY DESIGNED FANS

SPECIFICATION

TROUBLE-FREE AUTOMATIC OILING: The lubricat system of the Seneschal windmill thoroughly oils all working parts of the windmill *without the necessity climbing the tower*. A hand pump is fitted near ground and oil is pumped from there to the mill engi so the oil can be replenished, *without climbing tower*. No other windmill has such a positive automa oiling system.

COMPLETE ENCLOSURE PROTECTS ENGINE: T mill engine is totally enclosed, dust and weather pro

POSITIVELY FASTENED WHEEL HUB: The wheel h casting is securely fastened to the main shaft with t gib head keys driven home in opposite directions a then locked. Locking screws are also fitted at rig angles to the keys.

EASY WORKING RECIPROCATING MECHANIS The power from the windwheel is transmitted from t main shaft through the crank and connecting rod to crosshead which runs between adjustable V-secti guides.

POWER WINDWHEEL: The windwheel structure co prises a set of cantilever girder wheel arms doub bolted to the flanges of the wheel hub. Each wheel a is separate rivetted unit and the wheel arms are co nected to provide a very rigid framework into which t sails are bolted.

SCIENTIFICALLY DESIGNED SAILS are space shaped and curved so as to combine maximu pumping efficiency with easy starting.

SIZE MILL		44 mm	51 mm	57 mm	64 mm	70 mm	76 mm	83 mm	90 mm	102 mm	108 mm	115 mm	127 mm	153 mm	203 mm	254 mm	305 mm	
5,2m "RF"	Total lift in Metres/Totale hoogte in meters	146	126	110	96	84	73	62	53	41	37	32	26	18	10	–	–	
178mm Stroke/ Slaglengte	Avg. Litre/Day/Gem. Liter/dag	5900	8200	10500	12700	15500	18600	21800	25500	33200	37300	41800	51400	74000	132000	–	–	
5,2m "RF"	Total lift in Metres/Totale hoogte in meters	128	110	94	82	73	64	55	47	37	32	29	23	16	9	–	–	
203mm Stroke/ Slaglengte	Avg. Litre/Day/Gem. Liter/Dag	7300	9500	11800	14500	17700	21400	25000	29100	37700	42700	47700	59100	85000	151000	–	–	
6,3m "RG"	Total lift in Metres/Totale hoogte in meter	–	–	175	152	134	119	105	94	73	64	58	47	32	18	12	8	
210mm Stroke/ Slaglengte	Avg. Litre/Day/Gem. Liter/Dag	–	–	10000	12300	15000	17700	21000	24100	31400	35500	40000	49100	71000	126000	197000	283000	
6,3m "RG"	Total lift in Metres/Totale hoogte in meter	–	–	143	125	110	98	87	76	61	53	47	38	27	15	10	7	
254mm Stroke/ Slaglengte	Avg. Litre/Day/Gem. Liter/Dag	–	–	12300	15000	18200	21400	25000	29100	38200	43200	48200	59600	86000	153000	238000	343000	
7,5m "RH"	Total lift in Metres/Totale hoogte in meter	–	–	–	216	194	175	157	140	107	94	85	69	47	27	17	12	
241mm Stroke/ Slaglengte	Avg. Litre/Day/Gem. Liter/Dag	–	–	–	11800	14500	17300	20000	23200	30500	34500	38600	47700	68600	122000	190000	274000	37
7,5m "RH"	Total lift in Metres/Totale hoogte in meter	–	–	–	162	145	130	117	107	85	75	67	55	38	21	14	9	
305mm Stroke/ Slaglengte	Avg. Litre/Day/Gem. Liter/Dag	–	–	–	15000	18200	21800	25500	29500	38600	43200	48600	60000	86000	154000	240000	345000	47

BLOEMFONTEIN
Nuffield Street Hamilton
P O Box 627 Telephone 77001
BLOEMFONTEIN
Nuffieldstraat, Hamilton
Posbus 627 Telefoon 77001

NYLSTROOM
62 Station Street
Tel 3401-2379
NYLSTROOM
Stasiestraat 62
Tel 3401-2379

WORCESTER
18 Abattoir Road
Tel 22257
WORCESTER
Abattoir weg 18
Tel 22257

PORT ELIZABE
2 Algoa Street
P O Box 2090 Tel
PORT ELIZABET
Algoastraat 2
Posbus 2090 Tel

CLIMAX Rotary Drive Windmill

INTRODUCTION

Due to the need for larger capacity wind machines, Climax designed and embarked upon a test program lasting several years, with rotary drive windmills.

These mills deliver more water under certain conditions than conventional mills, and are designed to give many years of troublefree service.

Since the last century, Climax has proven their product by making more than 200 000 windmills a part of the Southern African landscape. This success can be attributed to the Climax policy of QUALITY AND DURABILITY.

Due to the power and speed required to drive rotary screw pumps, it was decided to begin the research on the larger diameter wheels. Extensive factory tests and field trials have proven this right and the initial launch onto the market was with the No. 15, with a 4,57m diameter wheel and the No. 18 with a 5,48m diameter wheel.

OUTSTANDING FEATURES

1. **GEARS**
   The 1:10 gear ratio is achieved with a double set of robust machined gears, which minimise wear and give many years of smooth running performance.
2. **OILBATH**
   The spurgear is partially submerged in a 5ℓ oilbath which splash lubricates the bevel gear and pinion. All bearings are of the durable sealed for life, deep grooved ball type.
3. **OIL SEALS**
   The gearbox was specifically designed to exclude the use of oil seals.
4. **RATCHET**
   The final drive bevel pinion incorporates a simple spring-loaded ratchet which allows the drive rods to stand stationary when the wheel is turned backwards. This ensures that drive rods are not unscrewed.
5. **FURLING MECHANISM**
   To safeguard against damage in gale force and gusty wind conditions, this design incorporates the furling mechanism proven for more than 80 years on our conventional reciprocating windmills. (See sketch on last page.)
6. **DETACHABLE MAST TUBE**
   Due to this feature, a shorter Gin Pole can be utilized, saving valuable erection time.
7. **DRIVE RODS AND COUPLING**
   The drive rods running from the windmill head to the borehole pump are guided by sealed for life flanged bearings, mounted to brackets clamped to the tower construction. A quick release coupling allows the disconnected borehole pump to be driven by exterior power sources.
8. **WHEEL**
   Due to the design of the gearbox, it was necessary to slightly dish the wheel to clear the tower. This was done without affecting the efficiency of the standard wheel which has proven itself over many years of service.
9. **MAINTENANCE**
   It was inevitable that in any machine, parts will eventually have to be replaced. For this reason a lot of thought was given to the replacement of parts without removing the head from the tower.

TECHNICAL SPECIFICATIONS

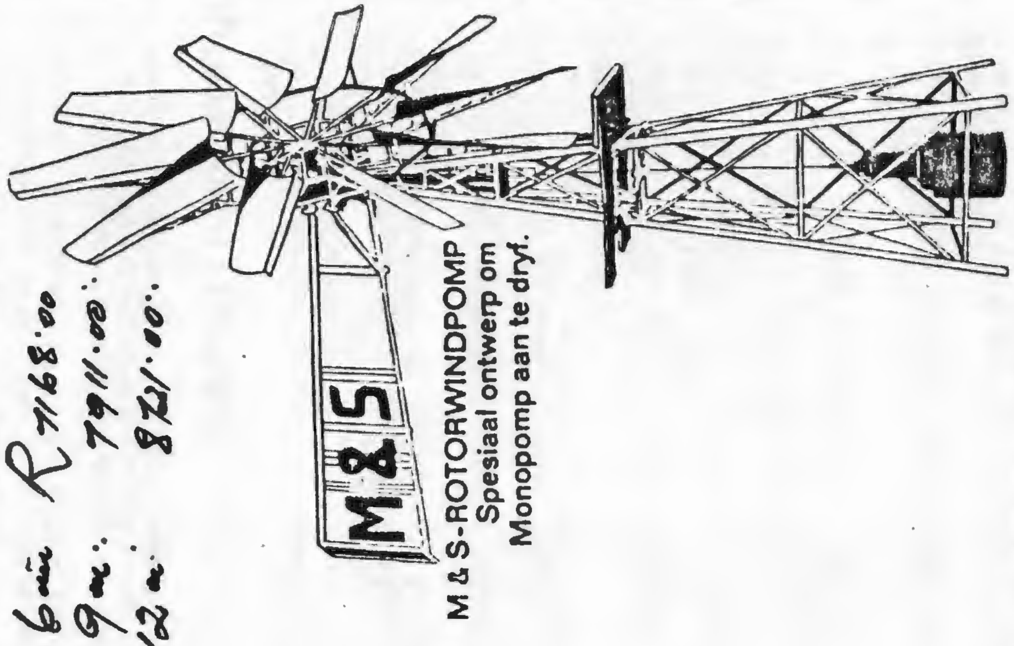
Gear Ratio	No.15	1:10
	No.18	1:10
Oil Capacity	No.15	5ℓ
	No.18	5ℓ
Maximum Pump R.P.M.	No.15	700 R.P.M.
	No.18	500 R.P.M.
Maximum Windwheel Power Output	No.15	8,8 kw
	No.18	12,75 kw
Mass of Gearbox	No.15	169 kg
	No.18	185 kg
Mass of Windmill Head complete	No.15	645 kg
	No.18	949 kg
Furling windspeed	No.15	± 55 km/h
	No.18	± 45 km/h
Wheel Diameter	No.15	4,57 metres
	No.18	5,48 metres
Performance	No.15-600 L/p.h. - 18000 L/p.h. Head up to 150 M.	
	No.18-400 L/p.h. - 24000 L/p.h. Head up to 180 M.	

REED PRINT S/L 855

DIE M. & S. ROTOR WINDPOMP 267

R.S.A. Patent Nr. 77/7269
77/3303
S.W.A. Patent Nr. 79/0137

6 m: R 7168.00
9 m: 7911.00
12 m: 8721.00



M & S-ROTORWINDPOMP
Spesiaal ontwerp om
Monopomp aan te dryf.

Vervaardig deur:
Midkaap Ingenieurswerke
(Edms.) Bpk.
Posbus 48 MIDDELBURG, KAAP
5900
Telefoon 0483-21051

M. & S. ROTOR LEWERINGSTABEL

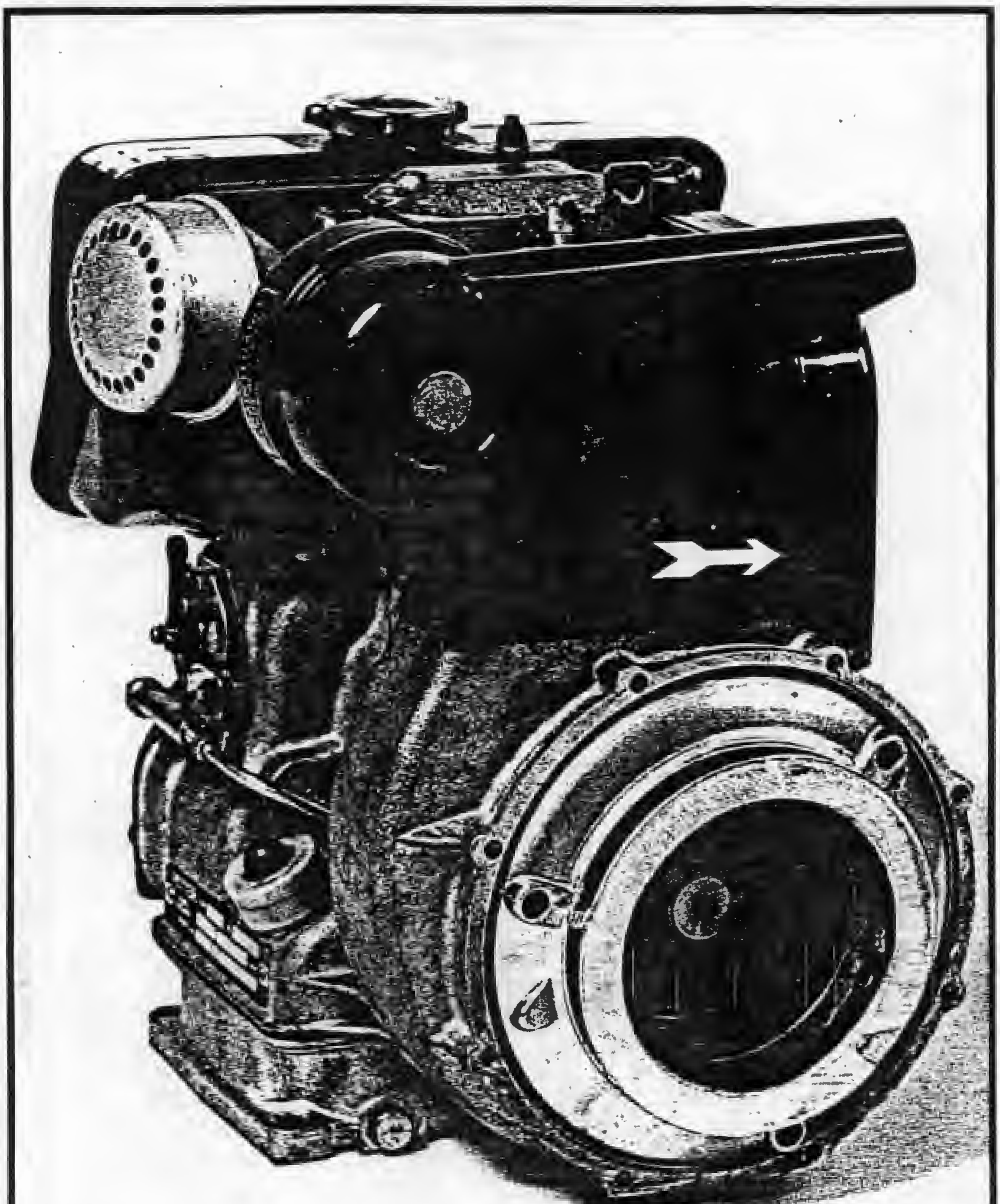
MONOPOMP MODEL	GROOTTE	KOPHOOGTE IN METER	O.P.M. 550 WINDSPOED 20 KM L.P.U.	O.P.M. 400 WINDSPOED 12,8 KM L.P.U.	O.P.M. 260 WINDSPOED 9,6 KM L.P.U.
ES 10 D	40 mm	198	787	572	372
ES 15 D	40 mm	198	1 437	1 044	678
ES 30	50 mm	137	3 365	2 443	1 588
ES 50	50 mm	122	4 930	3 580	2 327
BH 100	50 mm	76	7 204	5 232	3 400
BH 150	65 mm	45	13 312	9 668	6 284
BH 200	80 mm	30	22 160	16 096	10 462
BH 250	80 mm	20	34 200	24 338	15 820
BH 300	80 mm	15	43 000	31 227	20 298
BH 350	80 mm	15	57 300	41 602	27 040

Appendix 6.4.4

Diesel Pumps

'A' RANGE
1,2–4,8 kW

LIGHTWEIGHT AIR COOLED DIESEL ENGINES
LIGGEWIG LUGVERKOELDE DIESELENJINS



MANUFACTURED IN SOUTH AFRICA BY: ● VERVAARDIG IN SUID-AFRIKA DEUR:

Salister Diesels

Specifications

The Petter 'A' Range of engines are all single cylinder, four stroke, overhead valve, air cell system, air cooled compression ignition engines.
This highly successful range of diesels are made of lightweight alloys within compact dimensions. It has been designed to combine easy starting with minimum maintenance and long service life.

Spesifikasies

Die Petter 'A'-reeks enjins is almal enkelsilinder-, vierslag-, kopklep-, lugsel-stelsel-, lugverkoelde drukontstekingenjins. Hierdie besonder suksesvolle dieselreeks word uit liggewig allooie in kompakte vorm vervaardig. Die ontwerp kombineer maklike aansit met die minimum instandhouding en 'n langdienslewe.

Engine Power Ratings

Kraglewering

ENGINE SPEED ENJINSPOED	CONTINUOUS kW DEURLOPEND				
r/min	AAI	ABI	ACI	ACIZ	ACIZS
1000	–	–	–	–	1,15
1500	1,15	–	2,0	1,7	1,85
1800	1,35	2,0	2,45	2,45	2,25
2100	1,55	2,4	3,0	3,0	–
2500	1,85	2,85	3,7	3,7	–
3000	2,25	3,35	4,45	4,45	–
3600	2,60	3,7	4,8	–	–

Technical data

Tegniese gegewens

MODEL		AAI	ABI	ACI	ACIZ	ACIZS
Bore/Boor	mm	69,8	76,2	76,2	76,2	76,2
Stroke/Slag	mm	57,15	57,15	66,67	66,67	66,67
Cubic capacity/Kubieke kapasiteit	Litres/Liter	0,219	0,261	0,304	0,304	0,304
Lub. oil capacity/Smeerolie-kapasiteit	Litres/Liter	1,9	1,9	2,8	2,8	2,7
Mass/Massa	kg	43	45	47	48	63,5

Rated Power

All powers quoted apply to run in engines fitted with air cooling fan, lubricating oil pump, air cleaner and exhaust silencer in accordance with BS 5514/1 (ISO 3046/I). All engines are tested in accordance with BS 5514/2 (ISO 3046/II) Engine Group No. 2. Continuous Power is equivalent to ISO Standard Power. Overload Power is 110% of Continuous Power and available for 1 hour in any 6 hour period of variable load operation, depending on the application.

Aangeslane krag

Alle leweringsvermoëns het betrekking op enjins toegerus met lugverkoelingswaaier, smeeroliepomp, lugsuiweraar en uitlaatdemper volgens BS 5514/1 (ISO 3046/I). Alle enjins word getoets volgens BS 5514/2 (ISO 3046/II). Enjingroep No. 2. Volgehoue krag is gelykstaande aan ISO-standaardkrag. Oorbelading is 110% van Volgehoue Krag en is 1 uur lank uit enige wisselbare vragwerkingsperiode van 6 uur beskikbaar, afhangende waarvoor dit benodig word.

Derating

For non-standard site conditions engine power should be adjusted in accordance with BS 5514/1 (ISO 3046/I). For accurate values of derating consult Salister Diesels. Approximate site service power can be obtained by using the following correction factors:

Altitude: 6½% per 500 m above 150 m.
Temperature: 3% per 10°C above 27°C.

Laer aanslag

In nie-standaard-terreinomstandighede behoort die enjinkrag volgens BS 5514/1 (ISO 3046/I) aangepas te word. Om die akkurate waardes vir laer aanslaning vas te stel, pleeg oorleg met Salister Diesels. Die terreindienskrag kan min of meer bepaal word deur die volgende korreksie-faktore in ag te neem:

Hoogte bo seespieël: 6½% per 500 m bo 150 m.
Temperatuur: 3% per 10°C bo 27°C.

Governing

For general purposes the governing conforms to BS 5514/4 (ISO 3046/IV) Class B1, based on a design speed of 3600 r/min. For fixed speeds of 3000 and 3600 r/min normal governing accuracy to class A2 is obtained.

Reëling

Vir algemene verbruik is die reëling volgens BS 5514/4 (ISO 3046/IV) Klas B1 gestel, gebaseer op 'n ontwerpspoed van 3 600 r/min. Teen 'n vaste spoed van 3 000 en 3 600 r/min word normale reëlingsakkuraatheid in Klas A2 behaal.

Appendix 6.4.5

Solar Pumps

MSP-103 Solar Cell Module

HIGH-QUALITY, HIGH-PERFORMANCE SOLAR CELL MODULE

Highly pure silicon crystals of MSP-103 are product of the most stabilized CZ method, offering unrivaled quality and performance.

Extraordinary Durability under the Severest Outdoor Conditions

MSP-103 package made from tempered white glass, resin, and special films is a highly reputed achievement of out packaging technology with longtime history. This unique packaging method guarantees superb durability under all imaginable stringentest conditions.

High Electric Conversion Efficiency

A special anti-reflection film covering the solar cell front surface and Back Surface Field structure, plus the high purity silicon. All these contribute to attaining the 16.4% or more cell conversion efficiency and module efficiency as high as 12.0%

Lightweight

Use of lightweight aluminum and resin drastically reduced the weight of module.
This means simplified and easy transport and installation.

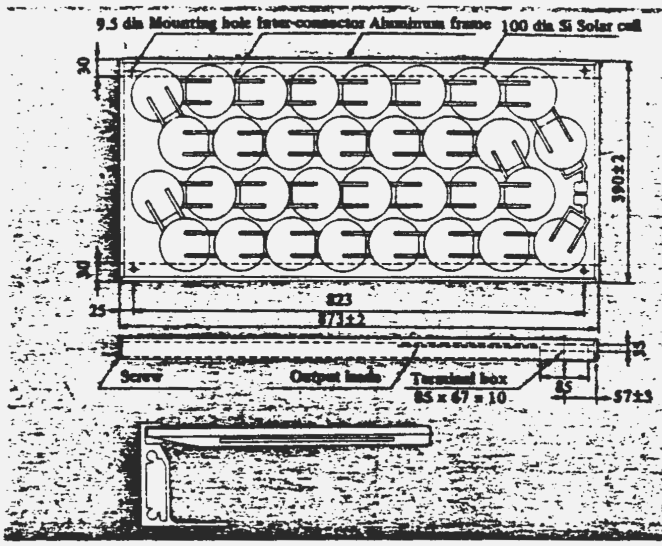


Fig. 1 MSP-103
Current, Power vs. Voltage Characteristics

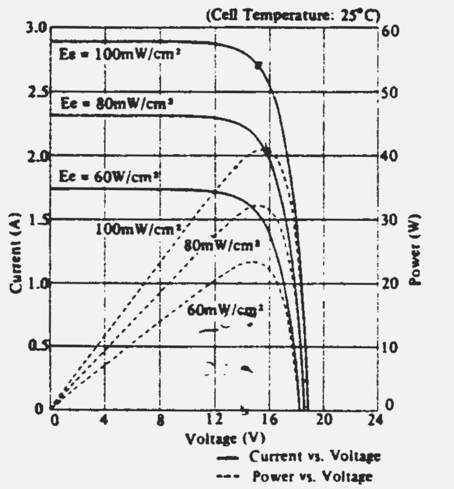


Fig. 2 MSP-103
Open Circuit Voltage, Short Circuit Current vs. Irradiance

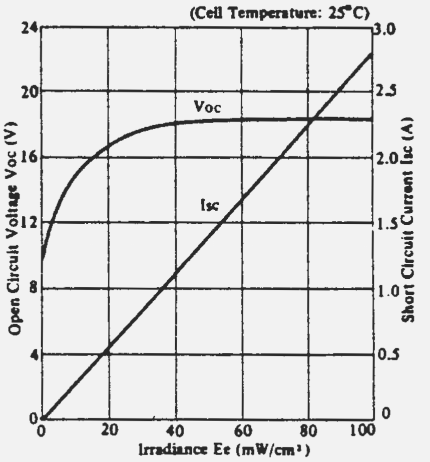
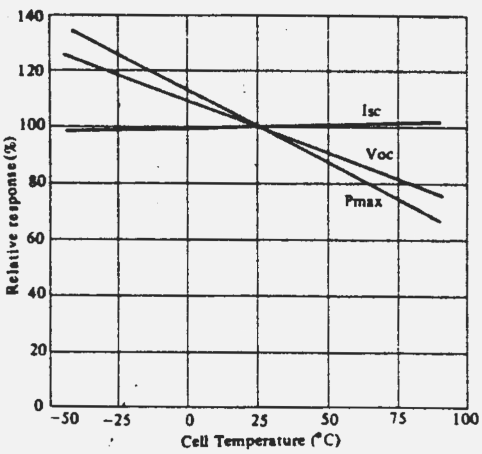


Fig. 3
Temperature Characteristics



Specifications

Element size	100mm dia silicon cell
No. of element	32
Voltage	DC 12V systems
Power output	41W
Dimensions	873(W) x 390(H) x 35(D) mm
Weight	4.7kg

Absolute maximum ratings

Ratings	Symbol	Value	Units
Operating temperature	Topr	−40 ~ +90	°C
Storage temperature	Tstg	−40 ~ +90	°C

Electro-optical characteristics

(Cell temperature : 25°C)

Characteristics	Symbol	Type	Units	Conditions
Open-circuit voltage	Voc	19.0	V	Ee = 100mW/cm²
Optimum operating voltage	Vop	15.3	V	
Short-circuit current	Isc	2.89	A	
Optimum operating current	Iop	2.68	A	
Maximum power output	Pmax	41	W	
Conversion efficiency	η	16.4	%	

*Ee : Irradiance from the sun at sea level

M. SETEK CO., LTD.
HEAD OFFICE/DAIWA BLDG. 6-16, Yanaka 3-chome, Taito-ku,
Tokyo 110, JAPAN
phone 824-3241 TOKYO
TELEX 2637979 MSETEK J

CALCULATION AS PER E.R.I. SPECIFICATION.

E.R.I. SPEC.:

SOLAR PV MAX POWER: 760 W *TOTAL HEAD: 14.5 m.*

PUMP MAX POWER : 1.1 kW

WATER FLOW : 17 m^3/day

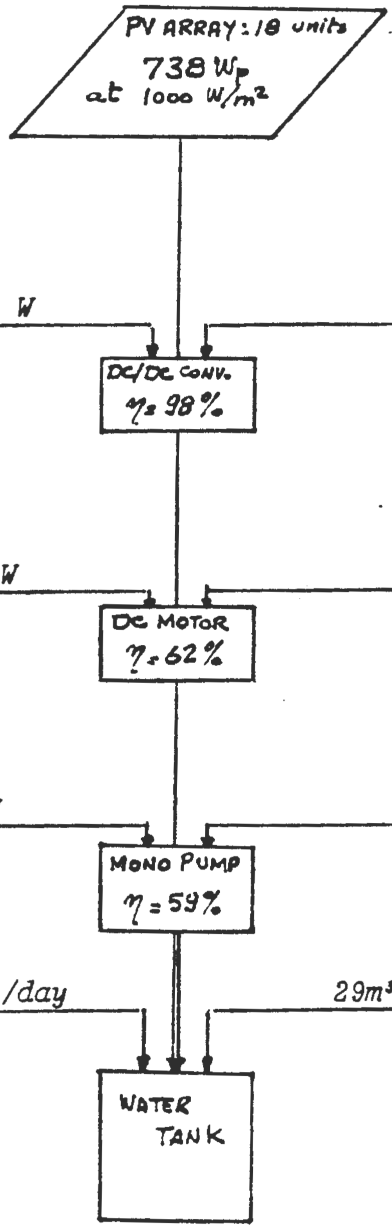
CALCULATION:

1. *No. OF SOLAR PV PANELS:* $\frac{760\ W}{41\ W}$ *= 18.5 units . SAY 18 units*

2. *TOTAL MAX POWER AVAILABLE: 738 W AT 1000 W/m^2.*

3. *SOLAR PV PANELS CONNECTION: 9 series X 2 parallel.*

JUNE *DECEMBER*



4. *POWER TO DC/DC CONVERTER:*

JUNE: $\frac{377 W/m^2 \times 738 W}{1000\ W/m^2}$ = 278 W

DECEMBER: 463 W = $\frac{627 W/m^2 \times 738 W}{1000\ W/m^2}$

5. *POWER TO DC MOTOR:*

JUNE: 278 W X 0.98 = 272 W

DECEMBER: 454 W = 463 W X 0.98

6. *POWER TO PUMP:*

JUNE: 272W X 0.62 = 169 W

DECEMBER: 282 W = 454 W X 0.62

7. *WATER FLOW:*

JUNE: 2.35 m^3/H X 7.7 H = 18 m^3/day

DECEMBER: 29 m^3/day = 3.8 m^3/H X 7.7 H

SYSTEM DESIGN.

DESCRIPTION OF SYSTEM.

THE SOLAR PV POWERED WATER PUMPING SYSTEM IS OPERATED DIRECTLY FROM THE POWER GENERATED BY THE SOLAR PV PANELS AS THE STORAGE BATTERY HAS BEEN ON PURPOSE EXCLUDED FROM THE DESIGN OF THE SYSTEM IN QUESTION.

THE MONO PUMP IS DRIVEN BY THE DC PERMANENT MAGNET MOTOR WHICH GETS THE POWER FROM THE SOLAR PV ARRAY THROUGH THE DC/DC CONVERTER WHOSE PECULIARITY IS TO ASSURE THE MAX POWER TRANSFER TO THE DC MOTOR AT ANY MOMENT OF THE DAY LIGHT ACCORDING TO THE SOLAR RADIATION CONDITIONS PREVAILING AT THAT PARTICULAR MOMENT.

THE SOLAR PV ARRAY WILL BE MOUNTED ON A STEEL STRUCTURE WHICH WILL BE SECURED ON CONCRETE PLINTHS AND WILL BE LOCATED AT AN ESTIMATED DISTANCE OF 30 - 40 m FROM THE PUMP/MOTOR.
THE MOUNTING STRUCTURE WILL BE PROTECTED FROM RUST BY TWO COATS OF PAINT (ONE ZINC CHROMATE AND ONE HIGH GLOSS ENAMEL).
THE MONOSTROOM DISCHARGE HEAD TOGETHER WITH DC MOTOR AND DC/DC CONVERTER WILL BE PROTECTED FROM RAIN AND DUST BY AN ENCLOSED COMMON COVER AS SHOWN ON THE ATTACHED DRAWING 'A4-RD630'.
WHEREAS THE PUMP ITSELF WILL BE PROTECTED BY AN ARTIFICIAL BOREHOLE AND, IF NECESSARY, BY A SUMP DUG INTO THE RIVER BED AS SHOWN ON THE ATTACHED DRAWING 'A4-RD630'.

ASSUMPTIONS.

DUE TO THE PECULIARITY OF THE SYSTEM WHICH PRESENTS A HIGH DEGREE OF FLEXIBILITY IN ITS FUNCTIONING, THE FOLLOWING ASSUMPTIONS HAVE BEEN MADE AS A BASIS OF CALCULATION FOR THE SYSTEM CONCERNED:

1. *WATER FLOW: 17 m^3/day DURING THE MONTH OF JUNE WHICH IS CONSIDERED THE POOREST MONTH IN TERMS OF SOLAR RADIATION.*
2. *EFFECTIVE DAILY OPERATING HOURS: 7.7 HOURS (FROM 8.30 TO 16.12).*
3. *DAILY SOLAR RADIATION FROM 8.30 TO 16.12:*

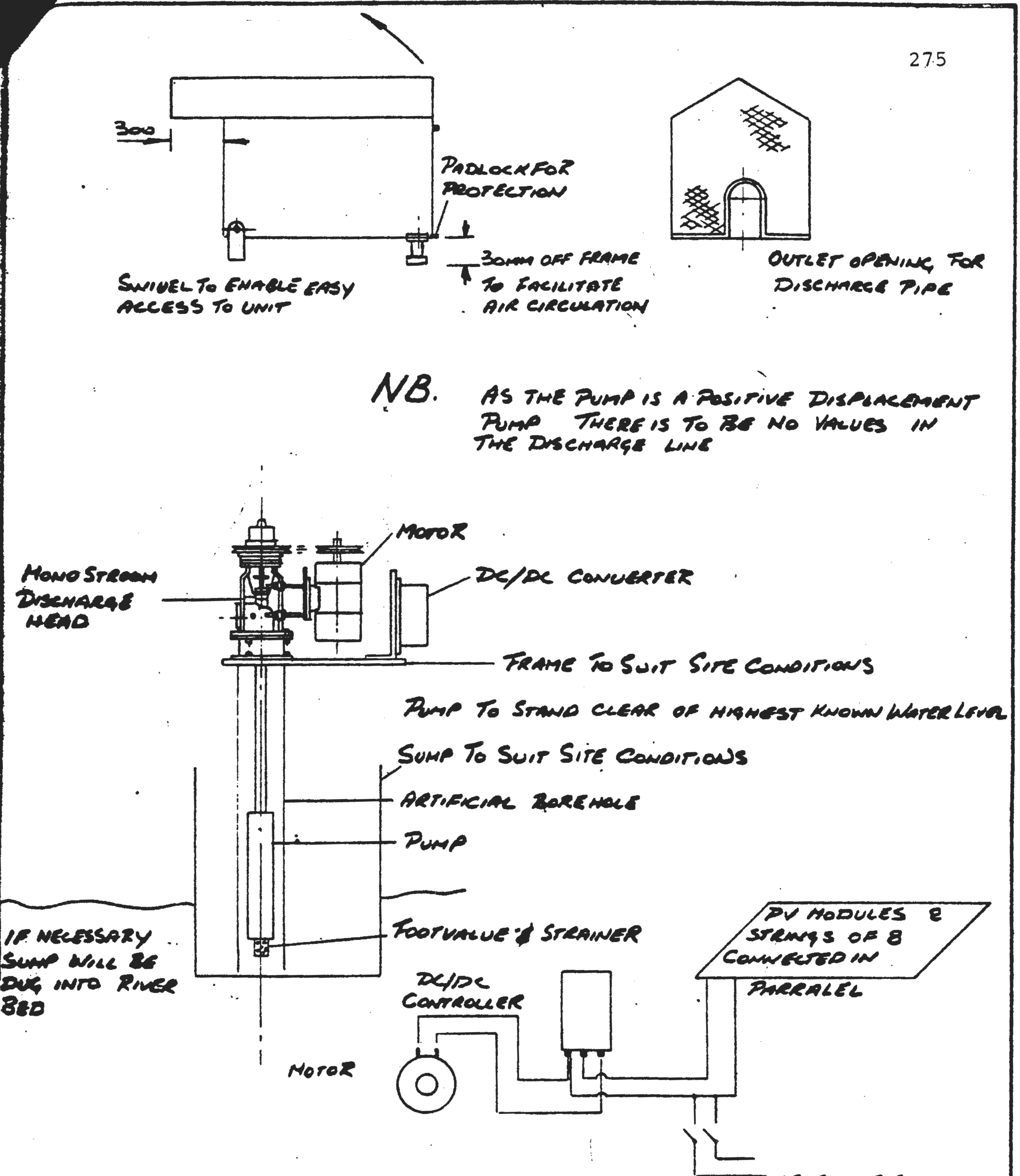
   JUNE : 2900 WH/m^2

   DEC. : 4828 WH/m^2
4. *AVERAGE SOLAR RADIATION OVER 7.7 H:*

   JUNE: 377 W/m^2
   DEC.: 627 W/m^2
5. *AVERAGE POWER FROM SOLAR PV MS-103:*

   JUNE: 15.5 W

   DEC.: 25.7 W
6. *DC/DC CONVERTER EFFICIENCY: 98%.*
7. *EFFICIENCY OF DC MOTOR MP300SCV: 62%.*
8. *EFFICIENCY OF MONO PUMP BP4L: 59%.*
9. *VOLTAGE DROP IN THE CABLE: 0.5 V MAX.*



ALL DIMENSIONS IN MM AND WITHIN A TOL. ± 0.25 U.O.S.

ROUGH M/C	FINISH M/C	GRIND
▽	▽▽	▽▽▽

10 APR 1986

MONO PUMPS (AFRICA) (PTY.) LTD.

EXAMPLE OF THE UTILIZATION OF THE SOLAR PUMP

	DATE	BY	MADE FROM
DRAWN	10-4-86	M.V.	
CH'K'D.			DRG. No
SCALE.	NTS		[illegible]

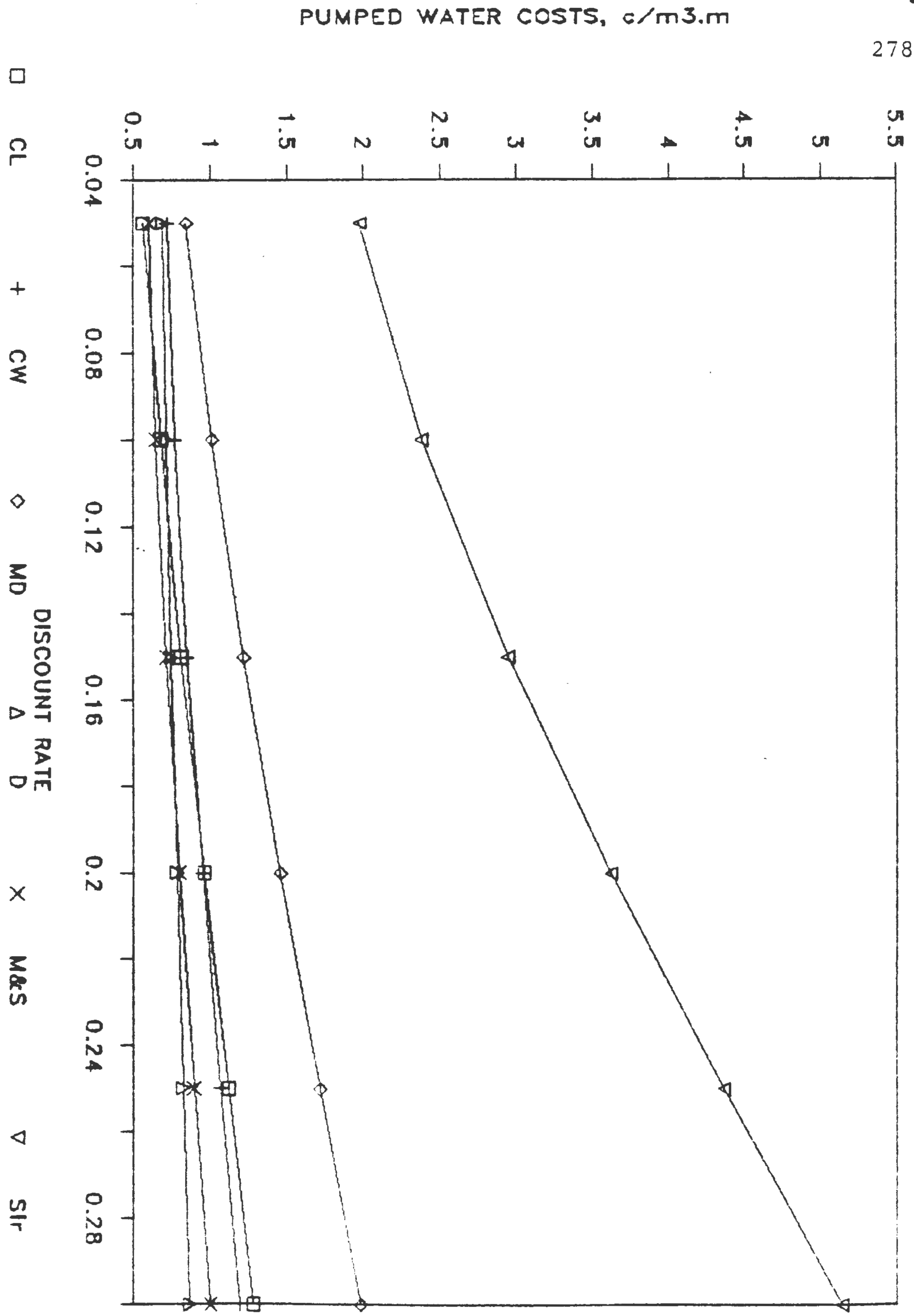
No	DATE	REVISION	BY	CH.

Appendix 6.4.6

Hydraulic Rams

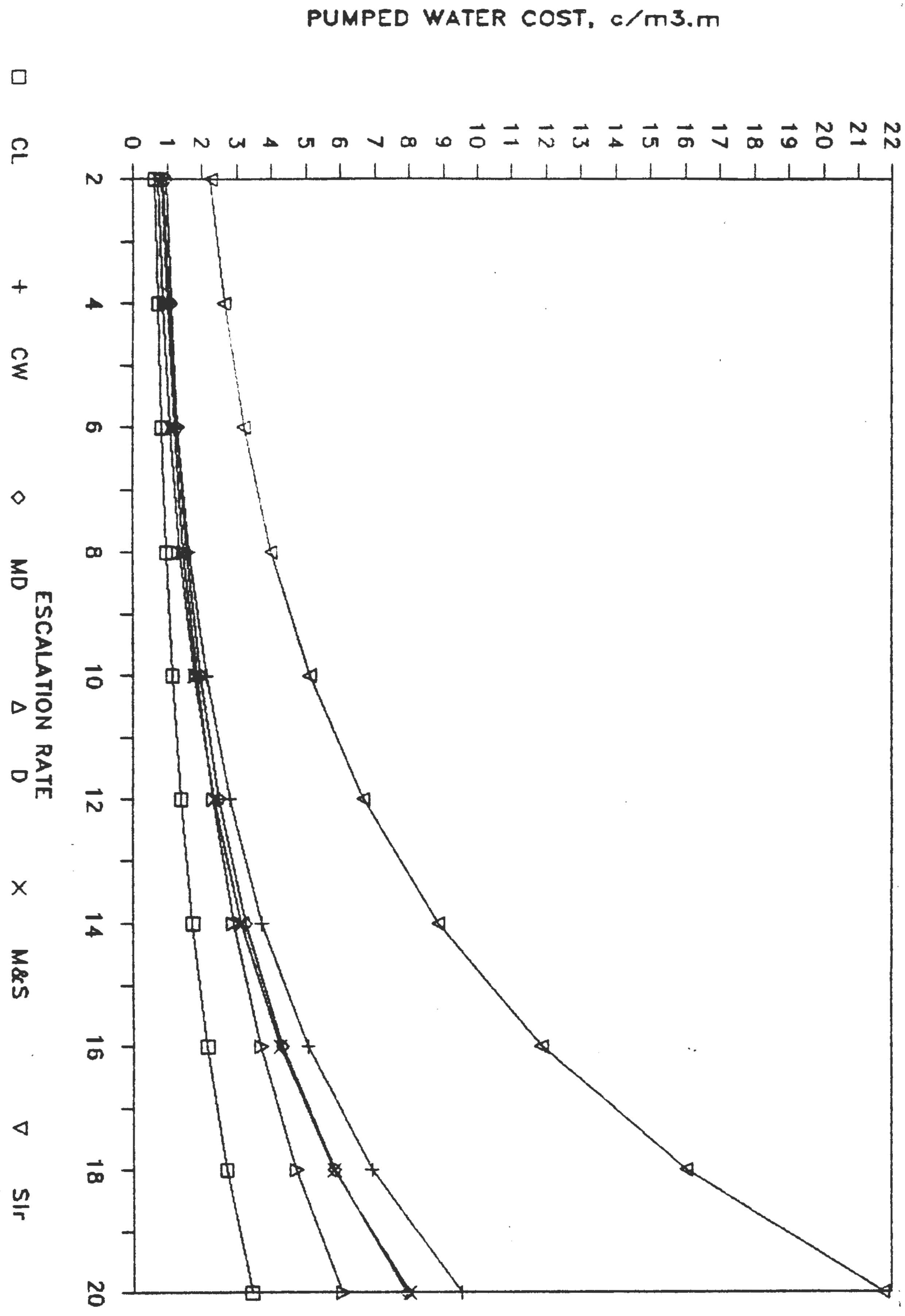
Appendix 6.5

Economic Analysis- Supplementary Graphs



Pumped Water Costs vs Discount Rate.

Graph 3.2.2



Pumped Water Costs vs Escalation Rate.

Graph 3.3.2

Appendix 6.6

References

Appendix 6.6

References

Agarwal, A, 1981, "Supplying Water: Maintenance Problems and Community Participation", *Development Digest*, October, 1981.

Alcock, P, 1985, *A Survey of the Source, Utilisation and Perception of Domestic Water in a Peri-Urban/Rural District of KwaZulu*, Occasional Publication No 3, Dept of Crop Science, University of Natal.

Alcock, P, 1986, *Rainwater Harvesting in the Vulindlela District, KwaZulu*, Occasional Publication No 1, Dept of Crop Science, University of Natal.

Arrestat, G, 1983, "Les Conditions d'une Gestion de Qualite a Faible Cout dans les Pays en Voie de Developpement, *Water Supply*, Vol 1, No 4, p247-252.

Atmore, A, 1986, *It's a Women's Life: The Sondela Community Garden and Photovoltaic Powered Irrigation*, Paper presented to the Energy Research Institute, University of Cape Town, August, 1986.

Babbie, E R, 1973, *Survey Research Methods*, Wadsworth, California.

Barnett, B, Bell, M, & Hoffman, K, 1982, *Rural Energy and the Third World*, Pergamon, London.

Bernard, R, 1983, "A Low Maintenance Solar Pump", *Appropriate Technology*, Vol 10, No 1, London.

Berold, R, & Caine, C, 1981, *People's Workshop-working together to change your community*, Environmental Development Agency, Johannesburg.

Berridge, T, 1986, Pers Comm, Regional Water Supply Technician, KwaZulu Legislative Assembly, Ulundi.

Blanc, G, 1983, "The World of Appropriate Technology", *Appropriate Technology*, Vol 9, No 4, London.

Boyagoda, K B, 1984, "Handpump Applications for Rural Community Water Supply in Sri Lanka, in Tschannerl, G, & Bryan, K, (eds), 1984, *Rural Water Supply Handpumps Project*, UNDP Project Management Report No 5.

Bradley, D S, 1977, "Health Aspects in Tropical Countries" in R Feachem *et al* (eds), *Water, Wastes and Health in Hot Climates*, John Wiley & Sons, London.

Cairncross, S, & Carruthers, I, et al, 1980, *Evaluation for Village Water Supply Planning*, John Wiley& Sons, London.

Cairncross, S, & Feachem, R, 1978, *Small Water Supplies*, ITDG, London.

Carruthers, J, & Browne, D, 1977, "The Economics of Community Supply", in Feachem, R, McGarry, M, & Mara, D, (eds), *Water, Wastes and Health in Hot Climates*, John Wiley & Sons, London.

Casley, D J, & Lury, D A, 1982, *Data Collection in Developing Countries*, Clarendon Press, Oxford.

Charnock, A, 1983, "Malawi's Piped Water Programme", *African Water and Sewage* (Redhill, UK), Vol2, No1.

Chiviya, R M, 1982, "The Need for Alternative Sources of Energy" in *Water Pumping with Windmills* Proceedings of the Symposium, Bulawayo, Zimbabwe.

Churchill, G A, 1983, *Marketing Research: Methodological Foundations*, The Dryden Press, New York.

Cizek, M F, 1982, "The Local Manufacture and Availability of Windmills and Pumping Equipment in Zimbabwe", in *Water Pumping with Windmills*, Proceedings of the Symposium, Bulawayo, Zimbabwe.

Cooper, D, & de Beer, C, 1979, "Underground Water: Where to Look For It", *Link*, Bulletin of the EDA, No 13.

Cuthbert, D L (ed), 1986, *World Vision*, Vol 6, No 2, Florida, South Africa.

CWD, 1984, *Windmills in the Lift*, Consultancy Services-Wind Energy-Developing Countries, The Netherlands.

CWD, 1983, *Cost of Windmill Irrigation*, Consultancy Services-Wind Energy-Developing Countries, The Netherlands.

Davidson, N C, 1984a, *An Analysis of Water Lifting Devices in Botswana*, Botswana Technology Centre, Gaborone.

Davidson, N C, 1984b, *Method for Economic Assessment of Water Lifting Devices*, Botswana Technology Centre, Gaborone.

Dickson, D, 1978, *Alternative Technology and the Politics of Technological Change*, Fontana/Collins, Glasgow.

Dunn, P D, 1978, *Appropriate Technology: Technology with a Human Face*, Macmillan Press Ltd, London.

Eberhard, A A, 1986, *Energy Consumption Patterns in Underdeveloped Areas in South Africa*, Energy Research Institute, University of Cape Town.

Eberhard, A A, 1984, *A Directory and Review of Appropriate Technology Programmes in Southern Africa*, Energy Research Institute, University of Cape Town.

Ewens, M, 1982, "The Scientific Approach to Wind Power and its' Practical Use in Water Pumping", in *Water Pumping with Windmills*, Proceedings of the Symposium, Bulawayo, Zimbabwe.

Feachem, R, et al, 1978, *Water, Health and Development- an Interdisciplinary Evaluation*, Tri-Med Books Ltd, London.

Fraenkel, P, 1986, *Water Pumping Devices: A Handbook for Users and Chosers*, Intermediate Technology Publications, London.

Fricke, T, 1984, *High Impact Appropriate Technology Case Studies*, Appropriate Technology International, Washington DC.

Friedman, I B, 1986, Pers Comm, Deputy Director and Community Medical Officer, Valley Trust, KwaZulu.

Friedman, I B, 1984, *Basic Needs and Health in the Valley of a Thousand Hills*, Second Carnegie Inquiry into Poverty and Development in South Africa, Conference Paper No 150, Cape Town.

Getechah, W, 1980, "The Role of Women in Rural Water Development in Kenya", in *Rural Water Supply in Developing Countries,* Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980.

Gray, K D, 1984, "Working Towards Village-Based Handpump Maintenance-- UNICEF's Approach in India", *Waterlines,* Vol 3, No1, New York.

Haile, T, 1980, Community Participation in Rural Water Supply Development, in *Rural Water Supply in Developing Countries,* Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980.

Hawkins Assosiates, 1984, *Development Proposals for the South Western Region of Transkei,* (2 vols), National Planning Committee, Umtata.

Hawkins Assosiates, 1980, *The Physical and Spatial Basis for Transkei's First Five Year Development Plan,* National Planning Committee, Umtata.

Huisman, L, *et al*, 1981, *Small Community Water Supplies,* International Reference Centre for Community Water Supply and Sanitation, Technical Paper No 18, The Hague, Netherlands.

ITDG's Water Panel, 1982, "Water for Rural Communities- the Choice Between Pumping Methods", *Appropriate Technology,* Vol 9, No 1, London.

Jorgensen, K, 1984, "African Rural Water Supply: Where Have All the Women Gone?", *Waterlines* (London), Vol 2 No 3.

Kashoro, Y N, 1980, "Shallow Wells Project, Shinyanga Region", in *Rural Water Supplies in Developing Countries*, Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980.

Kauzeni, A S, 1984, "Promotion of Villagers Mobilisation and Involvement in Rural Water Development Programmes- The Case of Rukwa Region, Tanzania", *Aqua* (London, U K), Vol 5, 1984 pp296.

Kenna, J, & Gillet, B, 1985, *Solar Water Pumping: A Handbook*, Intermediate Technology Development Group, London.

Kennedy, W K, & Rogers, T A, 1985, *Human and Animal Powered Water-Lifting Devices: A State-of-the-Art survey*, Intermediate Technology Publications , London.

Krone, A, 1984, *Water and Development in Transkei*, Specialisation Project, Department of Urban and Regional Planning, University of Cape Town.

Lea, J D, Alcock, P, & Ellis, R J M, 1985, *Water Supply and Crop Improvement in Peri-Urban KwaZulu: A Community Approach*, Occasional Publication No 2, Department of Crop Science, University of Natal.

Liebenow, J G, 1984a, "Malawi: Clean Water for the Rural Poor. Part 1- Organisation and Preparation", *Waterlines*, Vol 2, No 3.

Liebenow, J G, 1984b, "Malawi: Clean Water for the Rural Poor. Part 2- Construction and Maintenance", *Waterlines*, Vol 3, No 1.

de Moll, L, & Coe, 1979, *Stepping Stones: Appropriate Technology and Beyond*, Marion Boyars, London.

Mammo, A, 1980, "Shallow Wells and Handpumps", in *Rural Water Supply in Developing Countries*, Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980.

Mann, C, 1985, *The Valley Trust: Water and Sanitation Projects*, Valley Trust, Botha's Hill, South Africa.

Mara, D, 1982, "Sanitation Alternative for Low Income Communities- A Brief Introduction", *Appropriate Technology for Low Income Communities*, Vol 1b, World Bank, Washington D C.

Munyimbili, A W C, 1980, "Community/Household Participation", in *Sanitation in Developing Countries*, Proceedings of a workshop on training held in Lobatse, Botswana, 14-20 August, 1980.

McNellis, B, 1982, "The ITDG Experience of Building Windpumps in Developing Countries", in *Water Pumping with Windmills*, Proceedings of the Symposium, Bulawayo, Zimbabwe.

Mueller, A M, 1983, *Farm Economics of Water Lifting Windmills*, CWD, The Netherlands.

Muller, N D, 1984, *Aspects of the Political Economy of Drought and Water in Transkei*, Second Carnegie Inquiry into Poverty and Development in South Africa, Conference Paper No 149, Cape Town.

Munthali, L W C, & Kamwanja, G A, 1980, "Operational Maintenance in Malawi", in *Rural Water Supplies in Developing Countries*, Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980

Mzee, A, 1980, "The Role of Operation and Maintenance in Community Rural Water Supply Training", in *Rural Water Supplies in Developing Countries*, Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980

O'Hea, A, 1983, "Performance Index for Man-Powered Pumps", *Appropriate Technology*, Vol 9, No 4, London.

Pacey, A, 1977, *Hand Pump Maintenance in the Context of Community Well Projects*, Intermediate Technology Publications, London.

Payne, S, 1986, *Harnessing Human Energy Potential in the Provision of Water in Rural Areas*, Paper presented to the Conference on Renewable Energy Potential in Southern Africa, University of Cape Town, 8-10 September, 1986.

Robertson, L H, 1980, "The Development of Self-Help Gravity Piped Water Projects in Malawi", in *Rural Water Supply in Developing Countries*, Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980.

Rod, M G, Marcus, R D, & Kitsoff, S, 1983, A Foot Powered Water Pump for Use in Rural Areas, in *Selected Papers in Development Technology*, University of the Witwatersrand.

Rosenhall, L, & Hansen, L, 1979, "Evaluation of Rural Water Supplies in Eastern and Southern Africa", *Progress in Water Technology*, Voll 11, No 1, London.

Roy, S, 1984, "A One-Tier System: The Tilonia Approach to Handpump Maintenance", *Waterlines*, Vol 2, No 3, New York.

Sadzik, P, 1986, *Catalogue of Equipment for Small Water Supplies*, CSIR, Pretoria.

de Satge, R, Herschel Project Report No 2, *EDA Field Reports*, Vol 3, South Africa.

Shaker, A. 1986, *Pers. Comm.*, Director, Transkei Department of Agriculture and Forestry.

Shikwe, R C, 1980, "The Planning and Organisation of Training for Water Development in Kenya", in *Rural Water Supplies in Developing Countries*, Proceedings of a workshop on training held in Zomba, Malawi, 5-12th August, 1980.

Smulders, P T, & Schermerhorn, R E, 1984, *The Design of Fast Running Water Pumping Windmills*, CWD, The Netherlands.

Spence, S M, 1982, "Water Pumping in Zimbabwe: A Cost Comparison", in *Water Pumping with Windmills*, Proceedings of the Symposium, Bulawayo, Zimbabwe.

Stone, A, 1984a, *A comparison of Domestic Water Use Between Black and White Communities in the Eastern Cape*, Second Carnegie Inquiry into Poverty and Development in South Africa, Conference Paper No 147, Cape Town.

Stone, A, 1984b, *A Case Study of Water Sources and Water Quality of the Chalumna/Hamburg Area of Ciskei*, Second Carnegie Inquiry into Poverty and Development in South Africa, Conference Paper No 148, Cape Town.

Transkei Appropriate Technology Unit, not stated, *How to Protect and Develop Springs into Permanent Rural Water Supply Systems*, TATU Media and Information Branch, Umtata.

Transkei Appropriate Technology Unit, 1986, *Progress Report*, TATU Media and Information Branch, Umtata.

Watt, S B, & Wood, W E, 1976, *Hand Dug Wells and their Construction*, Intermediate Technology Publications, London.

Whibley, M, 1986, "Clean Water- No Longer a Pipe Dream" in *World Vision*, Vol 6, No 2. Florida, South Africa.

Williams, A T, 1985, *The Potential for the Production of Biomass Energy in Southern Africa*, Report No 82, Energy Research Institute, University of Cape Town.

Williams, P G, 1986, "Improving the Health of Rural Communities", *South African Journal of Science*, Vol 82, January 1986.

WMO, 1981, *Meteorological Aspects of Solar Radiation as an Energy Source*, World Meteorological Organisation, Technical No 172, Geneva.

REPORT NO. GEN 121

TECHNICAL, ECONOMIC AND SOCIAL ANALYSIS OF ALTERNATIVE WATER PUMPING TECHNOLOGIES FOR UNDERDEVELOPED RURAL AREAS

K WISEMAN
A A EBERHARD

AUGUST 1987

SPES BONA