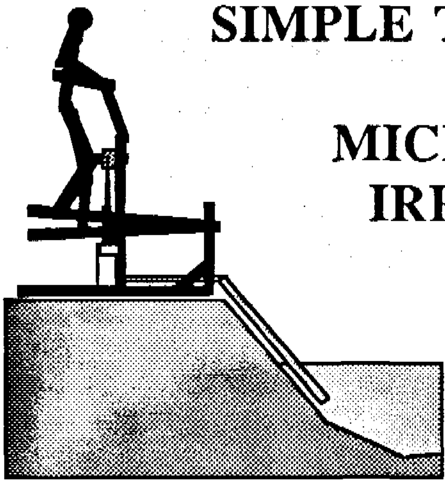
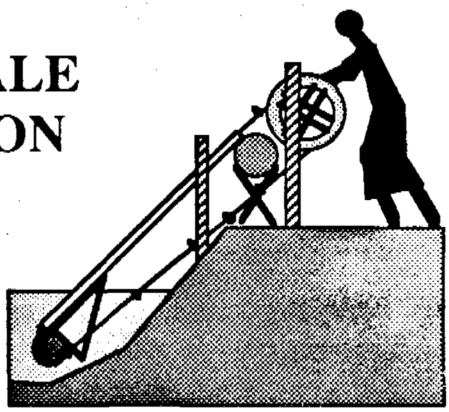
SIMPLE TECHNOLOGY for MICRO-SCALE IRRIGATION





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SIMPLE PUMP TECHNOLOGY
for
MICRO-SCALE IRRIGATION

by

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FINAL REPORT OF ODA PROJECT R 4434

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SUMMARY

This report presents the results of a research and development project funded by the Overseas Development Administration (ODA) of the UK, and carried out by the University of Loughborough in collaboration with the University of Zimbabwe, over the period 1987 to 1991. The project represents a progression from an earlier ODA funded project, which was concerned with the scientific and socio-economic feasibility of irrigation on dambos in Zimbabwe. This work, therefore, moves from investigation to implementation.

The feasibility of micro-scale irrigation on dambos was established in the previous work. The main problem in expanding this form of cultivation is in the method of lifting water from shallow wells. At the start of the project only buckets and watering cans were available to the majority of rural farmers. The initial analysis indicated that there was a large gap between the simplest technology available to small-scale farmers and "modern" technology such as the petrol or diesel driven pump. The capacity of poor farmers to bridge this gap is severely limited by their access to capital and by the size of the land-holdings needed to justify such comparatively large investments.

Manually operated pumps offer the possibility of bridging this gap, but have long been overlooked by project planners. Additionally, the technical and economic superiority of motorised pumps is not clearly established, and obtaining spare parts is difficult in most parts of Africa. When considering the high economic risks involved with motorised pumps, the case for manually powered systems becomes much stronger. Alternative energy sources, such as wind and solar energy, are attractive, but are also much more capital intensive. Animal powered systems that have been developed to date have not been widely adopted, probably because the capital cost is still high. Furthermore, poorer farmers may not own or have access to the draught animals required to power such pumps.

Laboratory and field tests show that simple irrigation systems, using human powered pumps, are feasible for micro-scale irrigation. Four pumps were initially selected for testing, and two of these have been developed further. These are the rope-washer pump, which can be made by artisans or farmers, and the treadle pump, which can be made by the artisans with basic welding

equipment. The rope washer pump is very low cost, and is capable of lifting water from depths in excess of 20 metres and to heights of 4 metres or more. It is particularly suited to wells and ponds, but can be used on streambanks too. The pump can be made and installed in one day by a trained pump maker for a cost of £30-£60. The treadle pump is more expensive, costing about £150. It is suited to areas where a high overhead lift is required and water is available close to the surface. It is capable of sucking water from depths of 6 metres and discharging to heights in excess of 20 metres. Such conditions are common in the alluvial water resources found in the drier lowveld areas of Zimbabwe.

Although the main aim of this project was research and development, considerable dissemination of the technology has already taken place in Zimbabwe. This has been done through the informal artisan sector, the government agricultural extension services and through non governmental organizations (NGOs). Invitations have been received to extend the technology to other countries, including Kenya, Botswana, the Gambia and Bangladesh.

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1 INTRODUCTION

1.1 Crop water shortages

One of the major constraints on crop production in Africa is the availability of water. In many parts of the continent there is a long dry season, when rainfed crop production is not possible. As an example, Figure 1 illustrates the long term pattern of rainfall and evaporation for two stations in Zimbabwe, Grasslands on the wetter Highveld and Buffalo Range on the drier lowveld. From April to October there is a clear deficit of rainfall against evaporation.

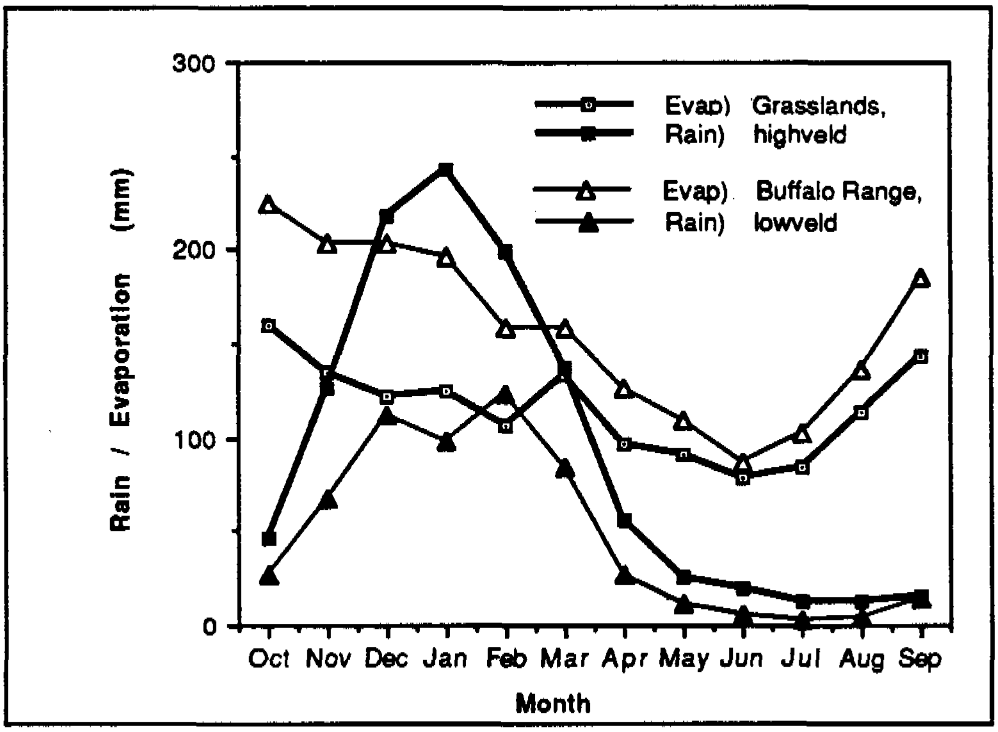


Figure 1
Long term rainfall and evaporation data from two stations in Zimbabwe

In addition to the problems of producing crops in the dry season harvests may be reduced and sometimes may totally fail in the rainy season because the rains don't arrive in sufficient quantity or at the right time. In the case of Zimbabwe, this unreliability of rainfall has been identified as the single most critical uncertainty facing the Zimbabwean farmer today (Mupawose, 1984). This is especially true in the less well endowed natural regions[1] of the

1 Zimbabwe is divided into Natural Regions principally on the basis of rainfall. These range from Natural Region 1, which ample and reliable rainfall, through to Natural Region 5, which has low and erratic rainfall

country. These mid season droughts have been described by Hussein (1988) who found that in some parts of the country 53% of rainy seasons were insufficient for crop production, either because rains were inadequate over the whole season or because of the occurrence of a mid-season drought (Table 1). In addition, the length of the rainy season in Natural region V, at 96 days, is insufficient for the growth of maize whose minimum growing period is recommended to be 110 days (Hussein, 1988).

Table 1
Lengths of crop season and occurrence of poor rainfall seasons in semi-arid regions of Zimbabwe.

Natural region	Mean median length of season (days)	% occurrence of poor season
III	131	23
IV	121	32
V	96	53

Source: Hussein, 1988.

The actual deficit of water has been calculated over a period of 20 years for various stations in Zimbabwe using a soil water balance model. Figure 2 shows the return period of crop water deficits for different natural regions in the country. It can be seen that in natural region III a crop water deficit of about 100mm occurs with a return period of about four years while in region V a deficit of 200mm occurs almost every second year. There are significant variations around the mean values, especially in the driest region, region V.

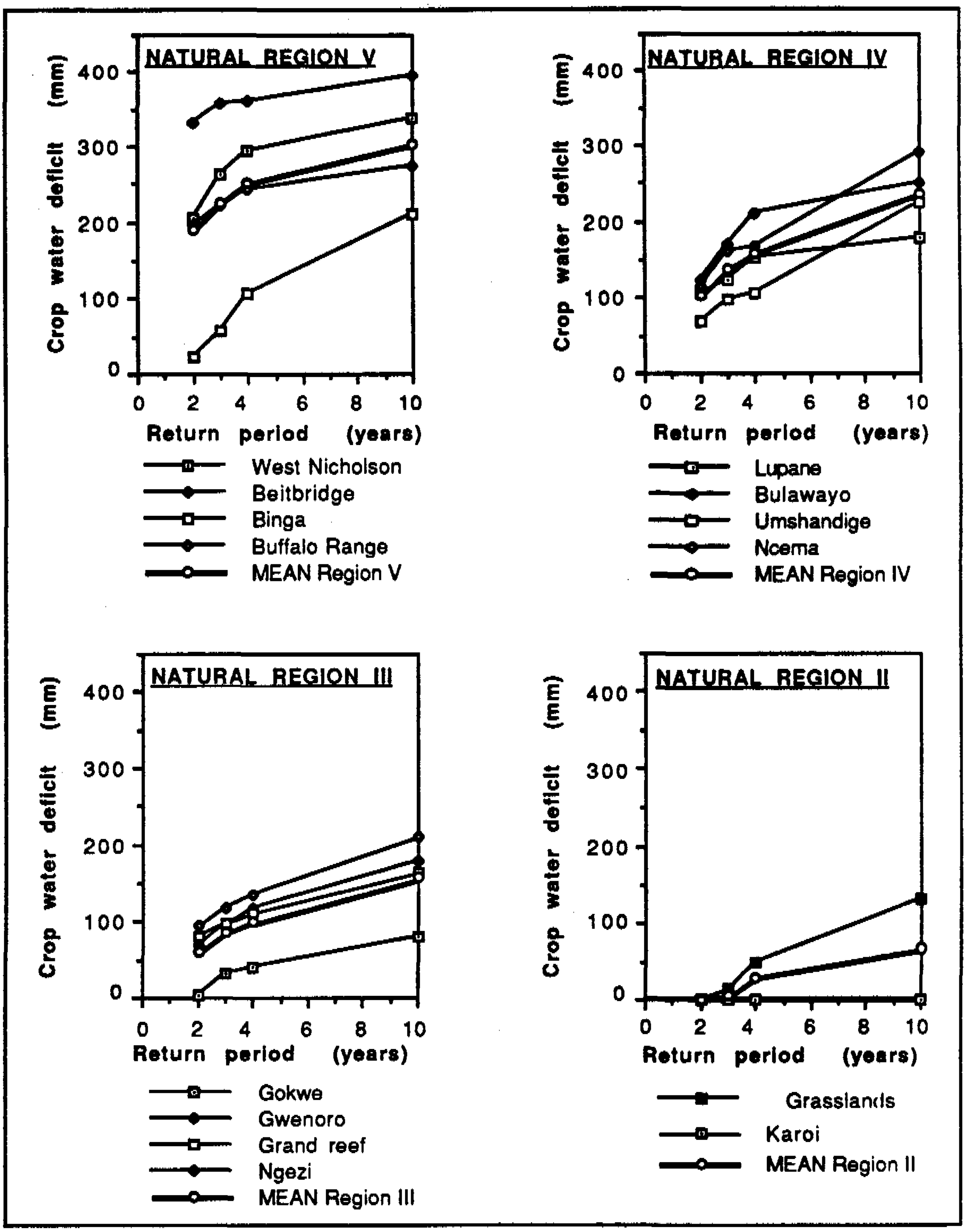


Figure 2
Return periods of crop water deficits according to natural region in Zimbabwe

1.2 Irrigation in Africa: failures and successes

In order to mitigate the effect of crop water shortages, various forms of irrigation have been proposed. Irrigation has been seen as the means of overcoming problems of low yield or total crop failure and to the production of high value crops in the dry season. Partly as a result of the relatively successful introduction of large scale irrigation schemes to countries such as India, large schemes were promoted in many parts of Africa.

However there have been many problems with development of such schemes (Moris & Thom, 1990). The Bakalori scheme in Nigeria and the Bura scheme in Kenya exemplify the problems: flooding of fertile land by the dam water, displacement of local population and massive capital investment. In the Bura scheme in Kenya project costs in 1986 were reported to be between US$40,000 and US$50,000 per hectare (African Business,1986). Much of this cost relates to unproductive but necessary infrastructural development associated with the remoteness of the project and the need to relocate almost all of the people who were supposed to be the beneficiaries. In some cases, such unproductive facilities may cost more than the actual irrigation development. In an extreme example, Biswas (1986) notes that for the Tshovane project in Zimbabwe out of the total development cost of US$10,000/ha only US$750 was for the engineering works directly associated with the irrigation development, the rest being for agricultural buildings, machinery and road networks.

However the cost of such schemes is only part of the problem. Large scale schemes require sophisticated management and highly skilled staff. Commenting on the Kano River project in Nigeria, the FAO (1986) stated that:

> "It has been estimated that a single project, the Kano river project, will absorb all the agricultural graduates from Kano State for the next twenty five years ... this could jeopardise the management of the whole of the state's agricultural sector for the foreseeable future."

In addition there is a growing realisation that the large dams built for such schemes are likely to have a much shorter life-span than was anticipated at the planning stage (Pearce, 1991).

The problems associated with large-scale schemes have prompted an increasing degree of interest in small-scale schemes. However in many such schemes, the only small-scale element is the size of the plots allocated to individual farmers. A scheme extending over as little as 80 hectares may require effective co-ordination among 200 farmers (Lambert et al, 1987). Such small-scale irrigation is often "the usual thoughtless bureaucratic large scale development in little chunks" (Adams and Anderson, 1988).

The sudden transition from traditional agriculture,which was essentially a household activity, to a modern, alien form of agriculture requiring the adoption of a completely new form of social organisation has all too often presented insuperable problems. Even when the scheme succeeds in producing crops, the problems of marketing, both within the country and to outside markets, remain. In Tanzania, food surpluses in some parts of the country very commonly go hand in hand with near famine in other parts.

With the failure of much of Africa's planned, formal schemes it is interesting to look at what has been happening in the unplanned informal sector. Underhill (1984) discusses the main features of this type of irrigation and outlines why it has been successful in so many cases. Bell et al (1987) report that there are 20,000 hectares of dambo garden cultivation in Zimbabwe, an area far greater than the country's 3,000 - 5,000 hectares of government small-scale schemes. In Nigeria, fadama cultivation rose seven-fold in the period 1958 -1978 (Turner, 1984) and according to Moris and Thom (1990) produced over five times as much rice as the modern irrigation sector in 1982.

Much of the successful irrigation in Africa takes place on plots covering as little as 0.1 hectares - hence they are frequently overlooked in national surveys of irrigation although taken together they may aggregate to a very significant area. In order to clarify this problem of definition and scale the term "micro-scale irrigation" has been proposed (Lambert et al, 1987). Central to the idea of micro-scale irrigation is the concept of farmer control, which is exercised by the individual, family or small group that does the work. Because of the lack of attention paid to this important sector, little has been done to address its many needs, of which the technological needs are but one part. For example the problem of providing small amounts of financial credit to peasant farmers with little collateral remains largely unsolved. From the technical point of view, the need to develop appropriate water lifting and distribution systems has been identified (FAO, 1986; Bell et al 1987).

1.3 Resources for irrigation

There is a growing appreciation of the potential of groundwater for irrigation (e.g. Wright, 1986). Two recent studies, funded by the ODA and carried out in Zimbabwe identified significant groundwater resources, dambos and alluvium.

Dambos. The Dambo Research Unit concluded that up to 100,000 ha of dambo land could be cultivated by small-scale farmers in the communal areas. In dambos groundwater lies close to the surface for much of the year and irrigation is generally not necessary during the rains although drainage may be needed in the wet season. However, as the dry season progresses and groundwater levels drop, manual irrigation of the dambo garden becomes essential. This usually involves collection of water by bucket from shallow wells dug in or near the crop area. The depth to water in these wells varies through the year but is typically between two and three metres, rarely in excess of 5 metres. However, in many cases, wells are located at the lower end of the garden, which means that for piped irrigation water must be lifted into a header tank to give command of the upper areas.

Alluvium. Owen et al (1989) estimated that alluvial water resources in Zimbabwe's communal areas could irrigate a minimum of 12,000 hectares. Much of this area, 8450 ha, could be irrigated through the exploitation of channel deposits in sandy river beds, with the rest from wells dug in alluvial plains. Most of this potential occurs in the lowveld areas of the country (Regions 4 & 5) which are particularly prone to drought (see Figure 2 above).

Lifts from wells dug in alluvial plains could be as much as 20 metres, although shallower lifts are common. With channel deposits, a shallow well of 1 to 2 metres may be dug to abstract the water which must then be pumped over the river bank. For these situations a pump with a suction lift of up to 5m and a delivery head of up to 20m is required (Owen et al, 1989).

Others. Groundwater resources are not confined to dambos and alluvium and in Zimbabwe many families use hand dug wells for domestic use and for household gardens. Firm data on these resources are not available, although recently a programme to upgrade family wells has started in Eastern Zimbabwe (Mtero and Chimbunde 1991).

1.4 Labour resources

During the dambo study (Bell et al, 1987) data were collected on the number of months during the year spent on irrigation of gardens. A summary of these results is presented in Figure 3. It can be seen that most households are involved in irrigation for 4-6 months of the year.

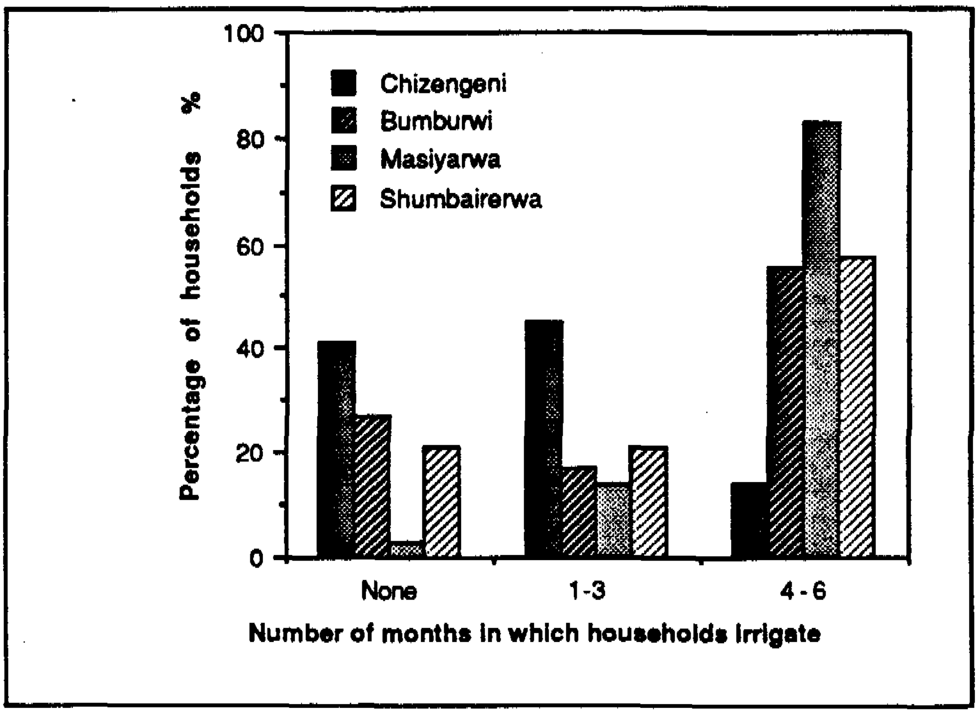
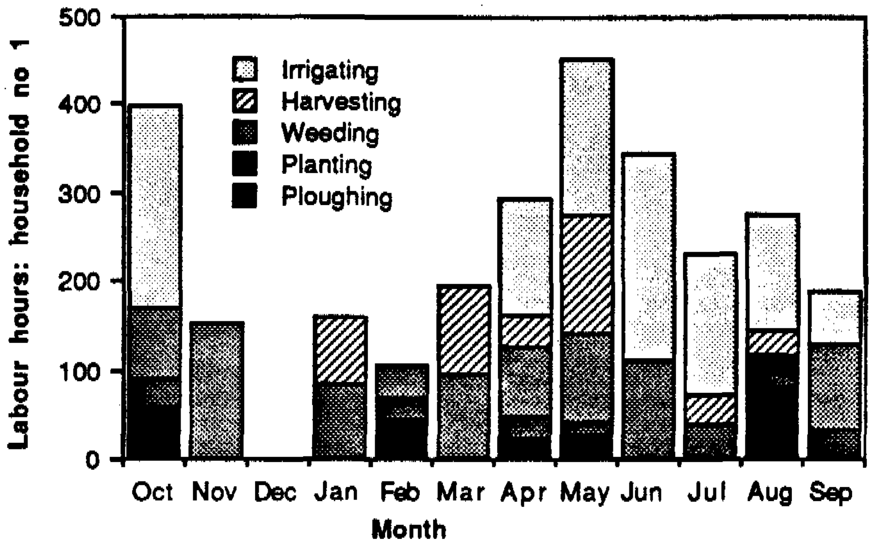


Figure 3
Monthly irrigation by households

During the present study interviews were carried out with selected households to determine the breakdown in labour time between various agricultural activities on the dambo gardens. Figure 4 shows the pattern of activity through the year for two households, excluding activities such as processing. The garden of household no 1 was estimated to be about 1.8 ha while that of household no 2 was just under 1.0 ha. Not all of the area of the garden would have been cultivated or irrigated at any one time. Activities on the dry fields are not included.



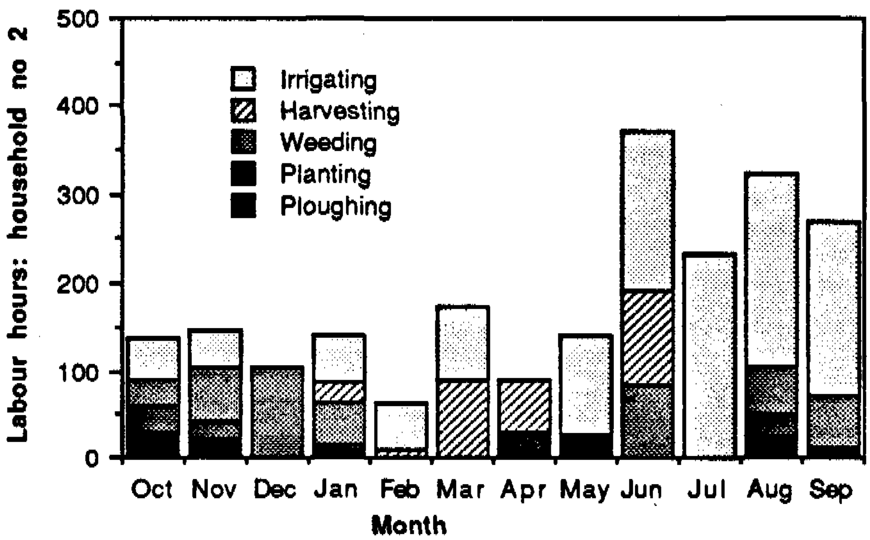


Figure 4
Labour hours per agricultural activity

The absolute amount of time involved has been estimated by the householders during interview and so must be regarded as a fairly crude approximation. As can be seen from Table 2, labour time excluding irrigation varied from 932 hrs/ha to 1080 hrs/ha. Kotschi (1988), quoting work done in Rwanda, suggests that the total labour time per hectare is 3,000 hrs for maize. Estimates made in the course of this project suggest that, with ox ploughing and harrowing, a figure of 1,500 hrs/ha might apply. These estimates suggest that the data reported by the householders are in the correct order of magnitude. Whatever the precise number of hours involved, the breakdown does indicate the degree of importance each activity plays in the perceptions of those interviewed. Clearly, for these households, irrigation forms the most significant part of the activities on the dambo garden at 40 and 56% of the total activities on the dambo garden.

Table 2
Irrigation time as % of total time on dambo gardens for two households

		Labour time						
House hold	Plot size ha	Total hrs/ plot	hrs/ ha	Irrigation hrs/ plot	hrs/ ha	%	Other hrs	hrs/ha
1	1.8	2795	1553	1117	621	40	1678	932
2	0.9	2194	2438	1223	1359	56	971	1080

For both these households over 1000 hours per year and in some months, in excess of 2000 hours, were spent irrigating. This is the equivalent of one person involved in that activity on a full time basis for significant periods of the year.

Irrigable area. The area that can be irrigated using manual systems has been calculated and is shown in Figure 5 below. The maximum irrigable area depends on:

- The amount of labour time devoted to pumping and hence the amount of energy going into the system. In this analysis a daily energy input of 250Wh and a system efficiency of 50% was used. This gives an equivalent hydraulic output of 45 m^3m/d (15 m^3 over a 3m lift or 5 m^3 over 9 m). Tests carried out during this project (Lambert and Faulkner, 1991) indicate that sustainable outputs of 15 m^3m/hr are possible with the hand operated rope-washer pump, implying that an output of 45 m^3m/d could be achieved with three hours pumping per day.

- The lift from the water to the cropped area.

- The crop water requirements. In Zimbabwe, the dry season is also the cool season and so the daily crop water requirements are low in comparison with the warm wet season. Values ranging from a low of 2.0 mm/d up to 4.5 mm/d are used, reflecting the fact that a mixed cropping system will have crops at various stages of maturity and hence crop water demand.

It can be seen that the area that can be irrigated is critically dependent on the depth from which water must be lifted. For lifts in excess of 10 m areas in excess of 0.2 ha require more than 5 hrs/day for one person. It is difficult, however, to estimate the lift at which manual irrigation becomes uneconomic because an increasing depth to groundwater may imply an increasing scarcity of vegetables and may be reflected in a higher price for those irrigated vegetables.

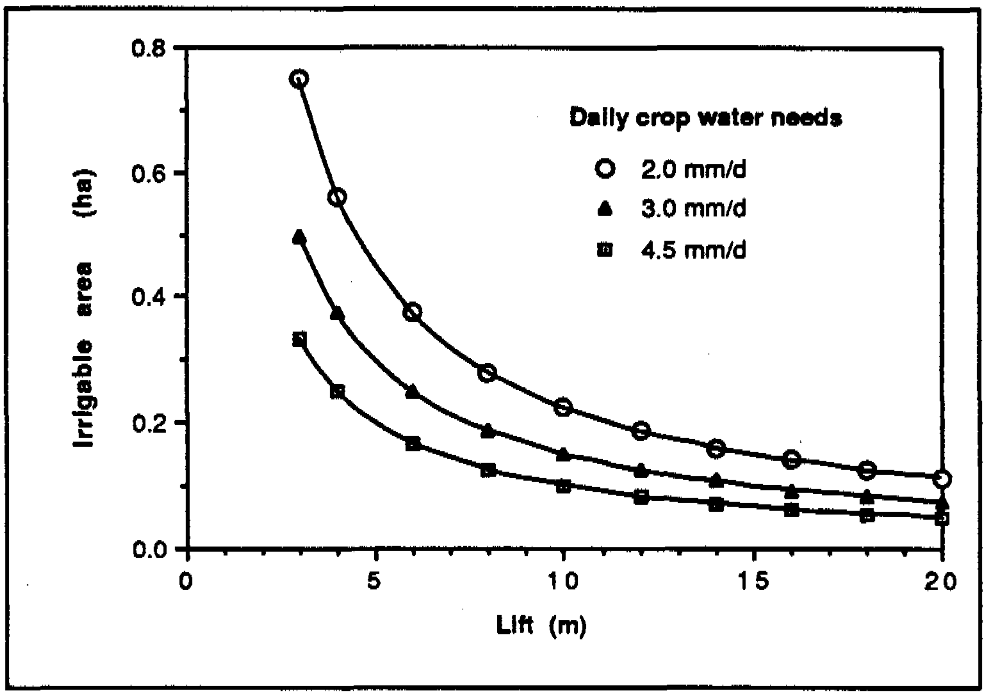


Figure 5
Area irrigable with manual pumps for varying daily crop water needs

1.5 Supplementary irrigation

When rainfall fails to arrive in sufficient quantity or at the right time crop yields may be drastically reduced. In addition, the element of risk involved in rainfed crop production may induce farmers to reduce the amount of money spent on inputs such as fertiliser which would ensure a high yield. (Mackenzie, 1988). Thus, even if the rains are good, the yields may not be as high as they could be. Anecdotal evidence from farmers growing maize on dambo gardens indicates that yields of up to 10 tonnes/ha are possible. This is equivalent to the best yields obtained in the commercial farming sector. By comparison yields on dry fields in the communal areas are often under 1.0 t/ha.

The time required to supply a crop water deficit of 100mm has been calculated for various crop areas and pumping lifts and is shown in Figure 6. In this analysis a conservative hydraulic output of 10 m^3m/hr (27.3W) was assumed. For an area of 1.0 ha the labour time to supply 100mm varies from 400 to 2000 hours for lifts of 5 to 20 metres respectively.

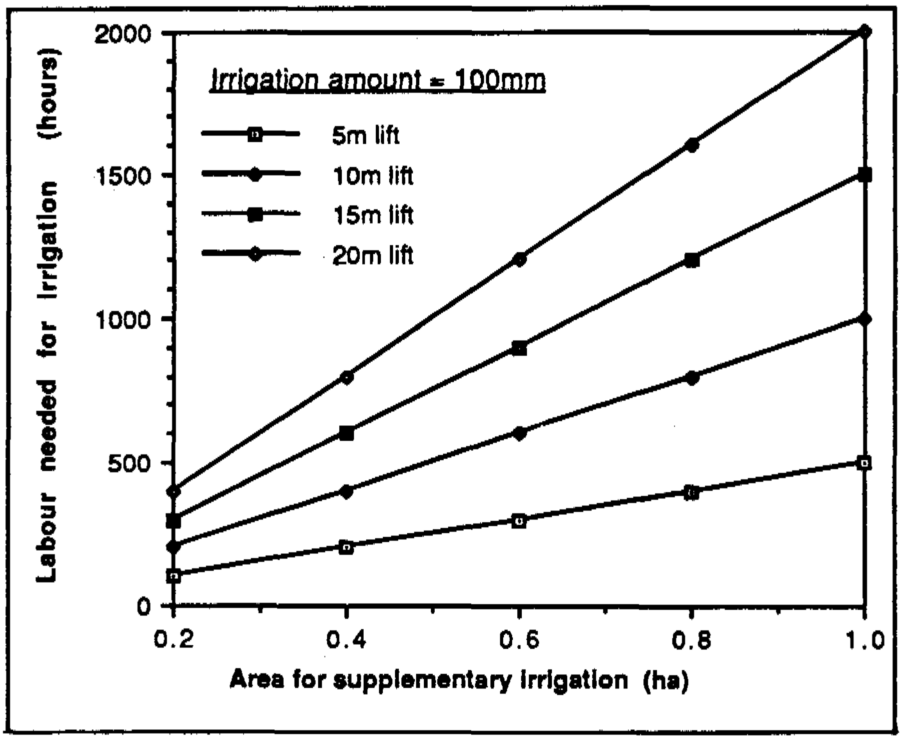


Figure 6
Labour needs for supplementary irrigation

To accurately assess the costs and benefits of providing supplementary irrigation is a very complex task and beyond the scope of this report. However a crude approximation can be made and is useful to assess the viability of such irrigation. Given a labour expenditure of between 1,500 and 3,000 hours/ha on growing unirrigated maize then a further expenditure of up to 2000 hours/ha may be justified if there is a significant increase in yield. At a 20 m lift an increase in yield of from 67 to 133% would be needed to justify the increase in labour for 100mm of irrigation. There are many areas where water is found at depths far less than 20m. Such an increase in yield may well be feasible. Mackenzie (1988) reports an increase in yields of up to 41% for sorghum and 55% for cotton through the adoption of water conservation practices such as "ridge and cross tie". A summary of variations in yields between drought and favourable years is given below in Table 3, adapted from Mackenzie (1988). This summary indicates that very large increases in yield are possible if crop water needs are satisfied. There seems to be considerable potential for low-cost technology that could facilitate such supplementary irrigation.

Table 3
Maize yields in wet and dry years (t/ha)

Natural region	Master Farmers		Non-master Farmers	
Season	dry	wet	dry	wet
II/III	2.5	3.2 (28)[1]	1.7	2.3 (35)
III/IV	1.3	3.2(246)	0.8	1.6(100)

[1] % increase from dry to wet year.

1.6 Technical possiblities: choice of power source

One of the first decisions to be made in the selection of an appropriate irrigation technology was the choice of power source for pumping. Diesel or petrol internal combustion (i.c.) engines were not considered as it was felt that technological development of these sources was not the major factor limiting their dissemination. Farmers who didn't use this technology were influenced by considerations of capital cost, access to the product and to spare parts and the need for considerable skill to maintain and repair the equipment.

Solar or wind operated devices have received much attention in the last 10 to 15 years and considerable technical advances have been and are being made. However such technologies remain outside the reach of small-scale farmers, primarily bacause of their high capital cost.

Animal driven pumps have been widely tested in Zimbabwe, Botswana and Ethiopia although very few have as yet been adopted by farmers. Even the cheapest animal driven pumps developed to date seem to be beyond the reach of most small farmers. Conversations with farmers in Zimbabwe indicate that there is often a reluctance to use valuable cattle to turn pumps - there seems to be a cultural resistance in addition to a funding problem. However the use of donkeys seems much more acceptable. It remains to be seen how strong the resistance to using animals would be if there were a possibility of significant economic returns. However even if a cheap and effective animal driven pump were designed, many poorer farmers would still have the problem of getting access to draught animals. Therefore, such devices would be likely to benefit better off farmers and have little relevance to the poorer farmers.

Human power. Engineers and planners have been reluctant to consider human powered pumps for irrigation pumping. This reluctance seems to be based on both moral and technical/economic grounds: it is immoral to propose solutions that force people into hard physical labour and in any case the technical and economic justification is very poor. These are important arguments and must be addressed by anyone involved in the development of simple irrigation technology.

The morality of using human power and involving people in physical drudgery is best decided by the farmers themselves. Much agricultural activity in crop production in developing countries involves hard physical labour and could theoretically be done using modern machinery at a much lower cost per unit energy, but with a higher total energy expenditure and with a greater negative effect on the environment. Resource poor farmers don't have the option of using such capital intensive equipment - they use what they've got: their labour. Designing technology that uses human energy efficiently is arguably a more effective means of reducing drudgery than promoting technologies that farmers can't afford.

Water is heavy and a lot of energy is required to raise the quantities required for irrigation. Figure 7 shows the relationship between flow rate and discharge for a range of feasible continuous hydraulic power outputs. The type of power source capable of each level of output is indicated. No account it taken of system efficiency, which is treated below. It can be seen that manually operated pumps are capable of comparatively small outputs.

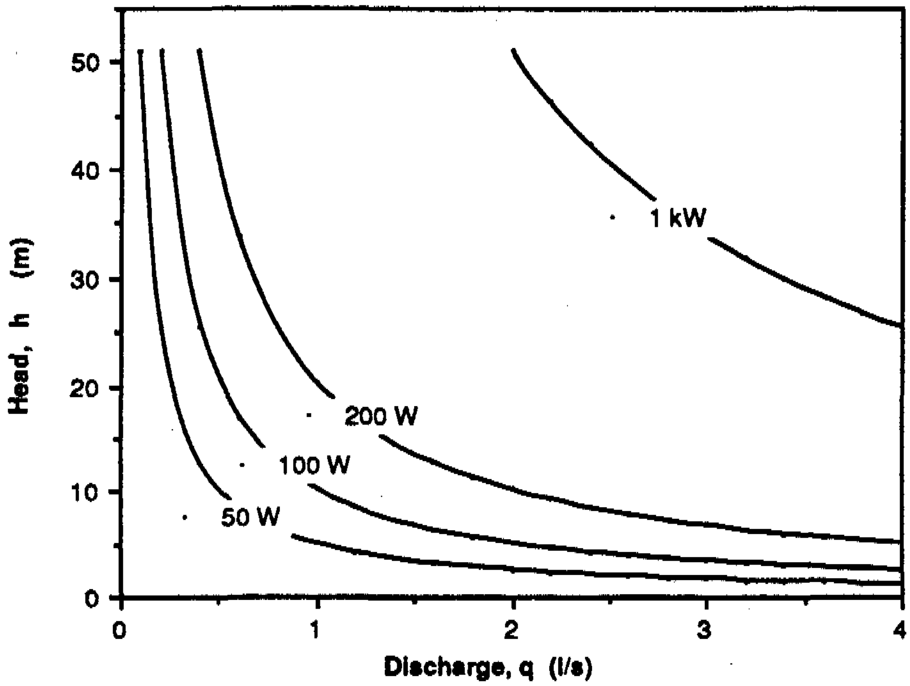


Figure 7
Head discharge relationships for a range of power outputs

The technical limitations of humans as power sources make a strong economic argument. Humans are capable of only relatively small power outputs of about 250Wh/day (50W for 5 hours/day). A donkey can give an output of two to four times and a cow up to ten times this amount. At 250 Wh/day, it takes a human 4 days to deliver 1.0 kWh, the output of a fairly small petrol engine in one hour (Fraenkel, 1986). The unit cost of human power is high: in Zimbabwe at the 1991 minimum agricultural wage of Z$120/month (approx £25/month) 1.0 kWh costs about £4.00, compared with, for example, a unit cost of electricity in the UK of £0.065/kWh. These are very strong economic arguments and have convinced most engineers involved in irrigation development.

However the economics of using fossil fuels deserve deserve closer examination. Fraenkel (1986) estimates that the total efficiency of a fossil fuel powered irrigation system in converting energy from fuel into the hydraulic energy to deliver water to a crop is in a wide band, varying from 0.5% up to 27%. Losses occur throughout the cycle, from the storage of fuel to leakage and pressure losses in the pipes delivering water to the crops. On the other hand, human energy goes directly into the pump, where efficiencies of at least 60% can be be expected. With the low pressures and flow rates achievable with human energy, pipe losses are likely to be very low and efficiencies in the order of 95% could be expected in the distribution system. The efficiency with which the water is applied to the crops in relation to their needs is known as the field application efficiency of the irrigation system. Excess irrigation is much more likely in a motorised system than in a manual system where every drop of water delivered demands hard physical work. According to Doorenbos and Pruitt (1977), even the more efficient sprinkler systems have field application efficiencies in the range of 60-80%. Thus the overall efficiency of a motorised system may be in the range of 0.3-22%. Taking higher values of field application efficiencies for the manual systems, the overall efficiency is likely to be in the order of 50%.

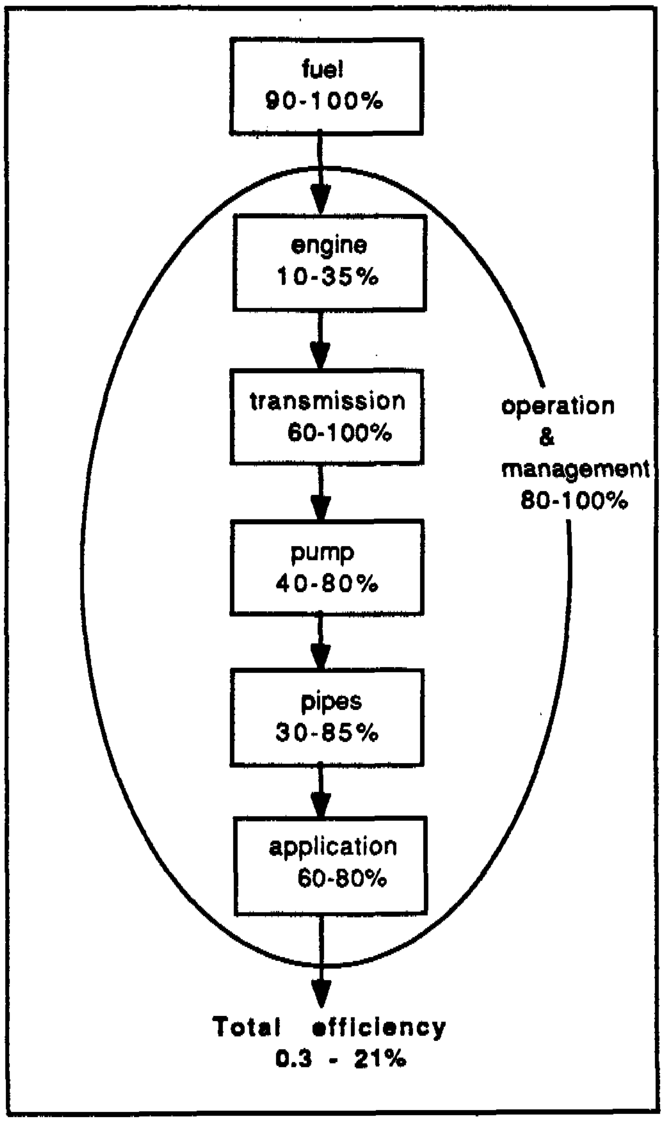


Figure 8
Energy efficiencies of a motorised irrigation system
(adapted from Fraenkel, 1986)

Based on this analysis, and a fuel price of £0.50/litre, the cost of 1.0 kWh of output in the form of water delivered to the plants may vary from as little as £0.20 for a very efficient system up to over £11.00 for a poorly run system (Table 4). The most efficient systems are likely to be those using well maintained and bigger engines, operating for long periods of time. This implies the use of a skilled mechanic and the availability of a large irrigable area. For poorly trained farmers operating with small machines on small plots, efficiencies are likely to be low. At low system efficiencies human energy may become competitive even on the basis of energy running costs alone. Many small scale farmers have complained to the authors about the high cost of fuel, complaints that are often regarded as ill-founded compared with the cost of labour. This analysis lends support to these complaints, especially where the overall system efficiency is low.

Table 4
Comparative costs of hydraulic energy ouptut in irrigation:
human and fossil fuel

Efficiency[1] %	Fuel input for1kWh output amount, litres(2)	cost,£(3)
0.3	37.5	18.75
0.7	16.0	8.00
10.0	1.1	0.55
22.0	0.5	0.25
Cost of human labour @ £25.00/month and 50% efficiency		8.00

[1] Efficiency of total irrigation system
[2] Energy content = 8.9 kWh/l
[3] @ fuel cost: £0.50/litre

These energy costs form only part of the recurrent costs borne by farmers. Other recurrent costs include those for repairs, maintenance and the cost of security for the pump. Security is very important and often overlooked. The recurrent costs must be considered in conjunction with the fixed costs of the various options open to the farmer. It is no use pointing out that it would be much cheaper to use petrol at £0.50 per litre if the engine costs £200 and is not available for two years. The capital costs and the availability and cost of spare parts are significantly higher for i.c. engines than for manual pumps. For high powered pumping systems to be viable, a reliable and adequate source of water is needed. Motorised pumps are capable of removing large amounts of water, may require the drilling of deep boreholes and could result in depletion of small aquifers. In addition to large amounts of water, farmers must have access to large plots of land - many small-scale farmers do not have access to such plots.

1.7 Cost analysis of irrigation system

A cost analysis of a variety of irrigation systems was carried out in the first phase of this project . The analysis considered the fixed and variable costs of the whole irrigation system, for five options from the watering can to a diesel pump. In the simplest system, that of the watering it is assumed that irrigation is carried out by fetching water from a shallow well and carrying it by hand to the crop to be irrigated. In a bucket and tank system, a small tank, such as a 200 litre oil drum is filled by bucket and the water conducted to the crops by pipe. With the remaining systems the tank is filled with a manual, animal or diesel powered pump. For the animal powered pump, only a proportion (30 to 40%) of the capital value of the animal was used as it was assumed that the animal could be used for other purposes when not powering a pump. The cost of labour has been included, from the lowest value of $1.00/day for family labour to $4.00/day for hired labour. The analysis was carried out with high and low estimates for a range of plot sizes. The results are presented in Table 5.

The total costs are estimated on the assumption that the irrigation system will operate over a period of 5 years. While it would be expected that the equipment in the high capital cost systems would still be functioning after 5 years there would be uncertainty over the viability of the markets at that time in the future. With high capital systems, the farmer must be confident of the markets for a number of years in order to repay the large amount of capital invested. With low capital and high recurrent costs, the farmers are free to decided from one year to the next whether or not to incur the recurrent costs. If market prospects look good then the it may be reasonable to incur the costs.

The calculation of present values uses a discount rate of 10%. For many small farmers such low discount rates are not practicable as the opportunity costs of capital may be much higher. For example, when farmers buy a piece of capital equipment, such as a plough, they expect an annual return on their capital far in excess of 10%, perhaps in the order of several hundred percent. Increasing the discount rate would result in a lower present value for future recurrent costs and would therefore reduce the overall cost of the low capital systems. It is clear that even with the low discount rate of 10%, for irrigation systems involving diesel powered pumps on plots smaller than 1.0 ha, the unit cost becomes high and on plots smaller than 0.5 ha animal powered pump systems become expensive. The high recurrent costs and low plot size of the simplest system, that of the watering can imply high overall unit costs. The ratio of fixed costs to annual costs gives some idea of the risk associated with each system. A low ratio means that most of the costs only occur if the system is being operated and a high ratio that costs are incurred whether or not the system is operating.

Table 5
Cost analysis of irrigation systems
(1988 prices Z$1.00 = £0.35)

Irrigation system 1	Plot size (ha) 2	Fixed costs 3	Annual costs 4	PV(1) of fixed & annual 5	Fixed/ annual ratio(2) 6	Total PV unit costs Z$/ha 7
Watering can (3)	0.01(hi)	20	21	101	1.0	10,100
	0.01(lo)	30	32	153	0.9	15,300
	0.03	20	63	262	0.3	8,733
	0.03	30	96	399	0.3	13,300
Bucket & tank	0.04	50	44	219	1.1	5,475
	0.04	180	136	703	1.3	17,575
	0.09	80	72	357	1.1	3,967
	0.09	230	220	1,076	1.1	11,956
Manual Pump	0.10	135	47	316	2.9	3,160
	0.10	870	272	1,916	3.2	19,160
	0.25	135	80	443	1.7	1,772
	0.25	970	445	2,682	2.2	10,728
Animal Pump	0.50	2,770	165	3,404	16.8	6,809
	0.50	10,900	502	12,831	21.7	25,662
	2.00	4,270	300	5,424	14.2	2,711
	2.00	13,400	1,258	18,238	10.7	9,119
Diesel Pump	1.00	7,000	462	8,772	15.2	8,777
	1.00	21,000	856	24,292	24.5	24,292
	5.00	11,000	2,310	19,885	4.8	3,977
	5.00	25,000	4,280	41,461	5.8	8,292

1 Present value of annual costs over 5 years @ 10% discount rate: PV factor = 3.85, added to fixed costs (column 5 = column 3 + 3.85 x column 4).
2 Ratio of fixed costs to annual costs (column 3 / column 4).
3 High (h) and low (l) estimates for each plot size.

The analysis demonstrates that a system based on manual pumps has the potential to be a bridge between the low capital and high recurrent costs of the simplest watering can system and a high capital cost diesel pumped system.

2 THE PROJECT

2.1 Aims of the project

The aims of the project, as defined in the proposal submitted to ODA were as follows:

> to design and test simple but effective water lifting devices for the exploitation of small scale groundwater sources, such as dambos, for irrigation. Such a device, or devices, must be technically appropriate and acceptable to the user, and meet the economic and social constraints. The objective is that the pumps can be constructed and maintained using skills and materials available locally. The work is predominantly concerned with field testing and involves collaboration principally between members of the Water, Engineering and Development Centre (WEDC, Department of Civil Engineering) at Loughborough University and the Department of Civil Engineering at the University of Zimbabwe. The initial activities will concentrate on human powered pumps whilst keeping the options open for animal power.

2.2 Methodology

The methodology employed during the project was a combination of literature research, laboratory and field testing of equipment, farmer evaluation of products and design improvements in conjunction with manufacturers.

The literature search was carried out in Phase 1 of the project. A review of the results of that research and subsequent work is given below.

2.3 Experience with manual systems of water lifting

Considerable effort has gone into the development of manually operated pumps for community drinking water supply, notably in the 1980's, declared by the UN to be the decade for the provision of clean water and sanitation to all. Great progress has been made in the design of pumps and the criterion of village level operation and maintenance (VLOM) is now widely accepted (Arlosoroff et al, 1987). A programme of pump testing was undertaken in the UK to evaluate the technical performance of a wide selection of pumps used in rural water supply (Consumers Association, 1984). Most of the pumps tested, having been been designed primarily for community use, were not suitable for irrigation by individual households. The principal problems were the cost of the units, operation and maintenance problems, poor availability of pumps and spare parts to private purchasers and the need for a costly well head. Despite the advances that have been made in handpump design, the problem of community level maintenance and repair remains severe, and is unlikely to be solved in many countries where local government institutions are chronically weak and underfunded.

As has been noted by Kennedy and Rogers (1985), there has been much less effort devoted by institutional researchers to the development of manually operated pumps for irrigation although in areas where farmers use such systems farmer innovation continues. Recently such research has been advocated by Arlosoroff in an influential publication on community water supply (1987). In addition to the dearth of institutional research, there is relatively little documentation on the extent to which manually powered systems are currently being used.

The notable exception is in Bangladesh where since the mid 1970s there has been a continued and documented expansion in the use of manually operated irrigation systems (Allison, 1986; Biggs and Griffith, 1987). Allison (1987) estimated that more than 50,000 Treadle pumps and 25,000 Rower pumps were in use specifically for irrigation. In addition Allison (1986) estimates that over 400,000 pumps are privately owned and used for some irrigation in addition to domestic supply. Bangladesh is particularly suited to the development of such systems for a number of reasons:

- The high groundwater table means that simple suction pumps can be used and that relatively large quantities of water may be pumped by hand.
- Permeable alluvial soils allow cheap and easy installation of tube wells and can provide a sufficient flow rate for the pumps.
- A high density of population and services facilitates mass production of equipment and ensures a labour surplus.
- Low agricultural wages and/or small plot sizes mean that manual systems can compete with motorised systems.

In India, there has been a massive growth in the use of private wells for irrigation. While much of this is due to the use of motorised pumps, whose number has expanded rapidly since the 1960s, manually operated systems make a significant contribution to the overall area of irrigation in the country.

Traditional designs for human and animal powered water lifting devices are described by Kennedy (1985) and Fraenkel (1986). These include the *shadouf* or counterpoise lift, the *picottah* (a variation on the shadouf) and the *dhone* for human operation and the *mohte*, the persian wheel, the *sakia* and the *zawafa* for animal power. The *shadouf* is widely used in North Africa and is a very cheap and efficient device, capable of lifts of up to 7 metres. In fact in one research project in Chad it was found that the *shadouf* performed at least as well as all other manually operated pumps, including the rope-washer pump (Mirti & Ittah). The principle limitations of the *shadouf* compared with the rope-washer pump are its limited lift and the impracticability of adapting it to animal power.

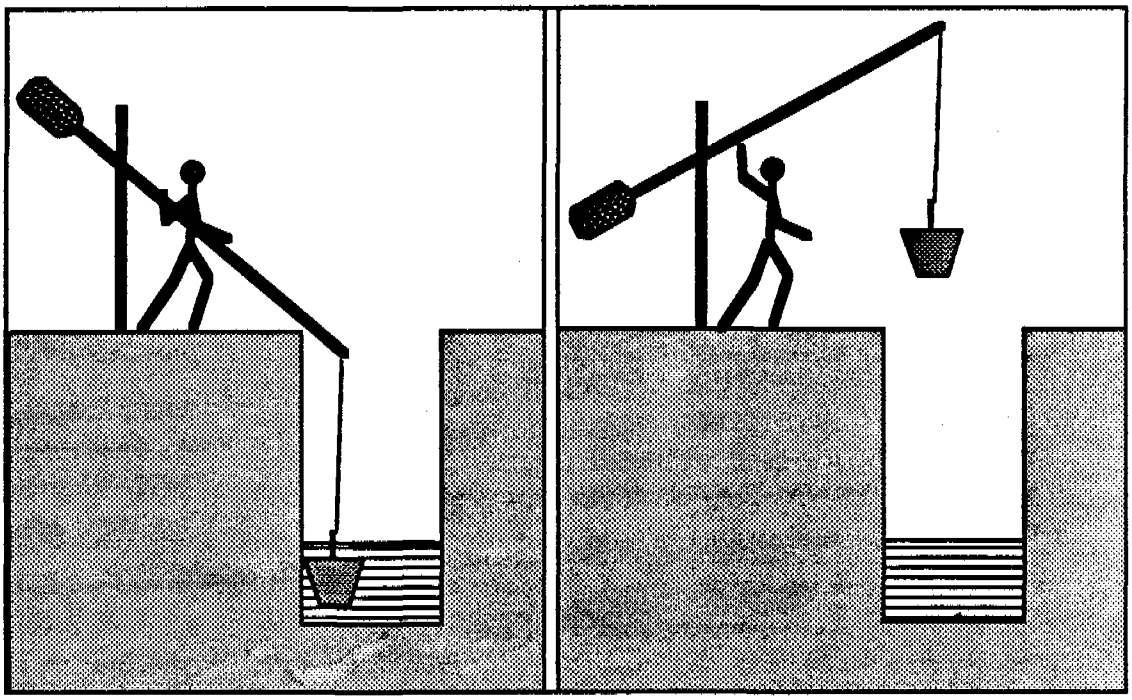


Figure 9
The shadouf

In Africa there have been relatively few attempts to introduce manual pumps suitable for private use. The main emphasis in the provision of rural water supply has been on village water programmes for domestic use and for livestock. However in many cases where such village wells have been installed small gardens have sprung up to use the small amounts of water for vegetable production. As a result of this interest by local communities, in 1988 the Zimbabwean Ministry of Health commissioned a study to explore the possibilities of encouraging nutrition gardens at domestic well points. The results of that study have not yet been produced. During a study on the use of dambos for micro-scale irrigation (Bell et al, 1987), a number of rope-washer pumps were installed to gauge farmers interest. It was clear from the positive response that there was a lot of interest among Zimbabwean farmers in such simple pumps.

A comparison of various types of water lifting devices is given in Table 6. The lift indicated is the maximum for each device, with the lift from the water level up to the pump indicated by "below" and the height to which the pump can discharge water above itself indicated by "above". The *dhone* has a very limited lift and is not suited to most African conditions. The *shadouf* has a better lift, comparable with that of the Rower, although the maximum lift of 7 metres renders both unsuitable in many situations. Only the Bumi pump was capable of discharging water above itself, and then only to a limited height.

Manufacturing requirements are indicated by the letters V, A and F with simple devices such as the *dhone*, the *shadouf* and the rope-washer capable of being made by farmers or artisans. The degree to which operation and maintenance, a critical factor in pump selection, can be carried out is also indicated, with the letter V indicating that for the rope-washer and the *shadouf* repairs and maintenance are possible at village or farm level. The mode of operation, whether by hand or foot and by one or two people, is indicated under "operation" with the Rower pump operated by hand and by a maximum of one person. The treadle pump is foot operated and can accommodate two people, so allowing an increased output. Finally a range of cost estimates are given for the various devices.

From the literature search and past experience, four existing pump designs, illustrated in Figure 10, were identified for further investigation.

- **The rope-washer pump** is a hand cranked water lifting device suitable for village manufacture. It is capable of lifting water to the height of the cranked pulley but is not capable of discharging water under pressure above itself. Unlike the other three pumps it has no valves and is capable of handling weeds, mud and silty water. The pump is operated by hand-cranking a rubber pulley (A) which pulls a rope (B) with washers attached up through a pipe (C). The rope and washers are guided into the pipe by a rope-guide (D).

• **The Bumi pump** is a hand operated reciprocating diaphragm pump manufactured in Zimbabwe. It is capable of taking in water under suction, with a maximum lift of about 6 metres and of discharging water under pressure through a pipe. Somewhat similar designs have been manufactured in other countries, including the Netherlands. The diaphragm (A) is operated by a lever (B). Water enters through a suction pipe (C) and is discharged through a delivery pipe (D) which moves up and down with the diaphragm.

Table 6
Comparison of selected manual water lifting devices at start of project[1]

Device	Lift (m)		Manufacture	Repair[2]	Operation		Cost
	Below	Above	Farmer, V Artisan, A Factory F		Leg/Foot	1 or 2 person	(£) estimate
Bucket	> 50	0	V A F	A	H	1	4 - 6
Windlass	> 50	0	V A	A	H	1&2	10 - 60
Dhone	1.5	0	V A	V	H	1&2	3 - 10
Shadouf	7	0	V A	V	H	1	3 - 10
Rower	6	0	A F	A	H	1	50 - 100
Bumi	6	2	F	A	H	1	120 - 150
Rope-washer	70	0[1]	V A	V	H	1&2	5 - 70
Treadle	6	0[1]	A F	A	F	1&2	20 - 160
Nsimbi	30	0	F	A	H	1	120 - 150
Bush	50	0	F	A	H	1	150 - 250

1 At the start of this project. Modifications have been introduced during the project.

2 Indicates at what level all repairs are possible. Artisans include anyone with training in repair and maintenance.

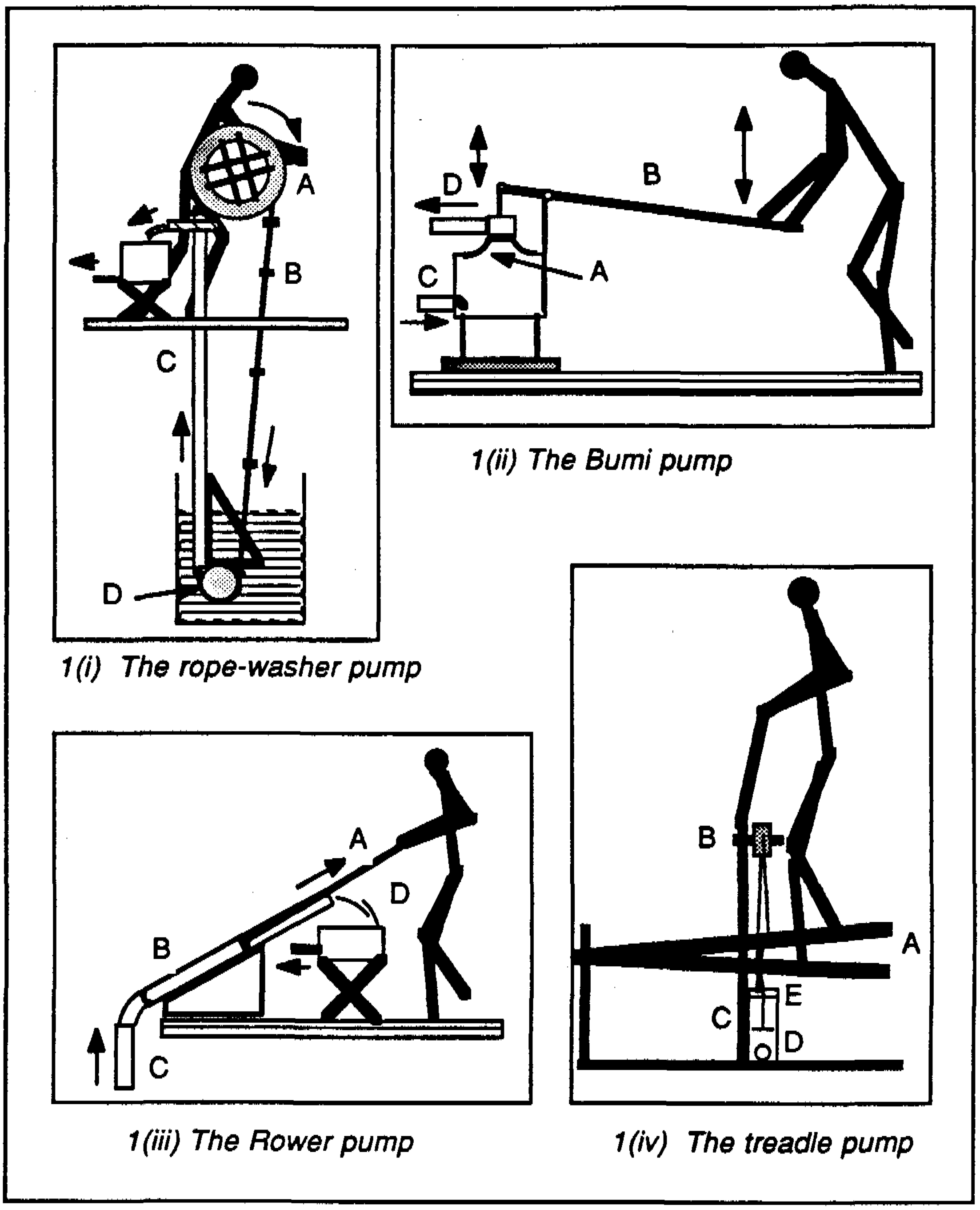
• **The Rower pump** is a hand operated single cylinder reciprocating suction pump. It is capable of lifting water from a maximum of about 6 metres and cannot discharge above itself. The Rower pump is mainly used in Bangladesh, although some manufacture has begun in other countries, including the UK. A number of Rower pumps were produced on order for the project by a local Zimbabwean manufacturer, Prodorite. The pump is not generally available to private purchasers in Zimbabwe. The piston rod (A) is directly operated by hand with the cylinder (B) set at an angle of 30° to the horizontal. Water is drawn in through the suction pipe (C) and discharged at the top of the cylinder (D).

- **The treadle pump** is a twin cylinder foot operated reciprocating pump widely used in Bangladesh. The Bangladesh design is a suction pump, capable of raising water from a maximum depth of about 6 metres. Water is pumped by means of leather or plastic cup seals moving in a steel cylinder. Simple rubber flap valves are used. The pump is activated by alternately depressing each of the two treadles (A) which are linked by a rope which passes over a pulley (B). Each treadle is connected to a piston moving in one of the two cylinders (C). Water enters through the inlet pipe (D) and is discharged at the top of the cylinders (E).

Laboratory and field tests were carried out on all four pumps (Lambert & Faulkner, 1991; Faulkner & Lambert, 1990). Details of these tests are given in Chapter 4 of this report.

A prototype *shadouf* was demonstrated to farmers in the project area, but the response was quite negative. This may be due to the fact that it takes some time to get the knack of using the *shadouf* and that the device looks very inefficient and "old-fashioned" - an appearance which is belied by its performance. Due to the negative response of the farmers and the limit of 6-7m on the lift of the *shadouf* it was decided not to include it in further testing and dissemination.

Based on the results of the laboratory tests, farmer evaluation and a consideration of the technical requirements for pumps which could suit the available water sources both in Zimbabwe and in other parts of sub-Saharan Africa, two pumps, the rope-washer and the treadle were selected for redesign and dissemination.



1(i) The rope-washer pump

1(ii) The Bumi pump

1(iii) The Rower pump

1(iv) The treadle pump

Figure 10
Schematic diagram of the four tested pumps

3 THE TECHNOLOGY

3.1 Design philosophy

The design of the simple technology for agriculture and the choice of production methods are dependent on the assumptions made about farmers' abilities to maintain and repair this type of equipment. It is frequently pointed out by producers of agricultural equipment that farmers or their families, and especially small farmers, are capable of great ingenuity in finding out how to break such equipment. What can go wrong, even if it can't, does go wrong. What is less frequently pointed out is the ingenuity farmers show in keeping old equipment functioning. If they can fix it, they will - if they really want to. It is almost inevitable that farmers will want to modify a machine to suit their particular needs. In the case of manual pumps, each farmer will have a unique combination of lift and discharge requirements and of people to operate the pump. Any successful pump must have a large element of flexibility built in. Therefore, in this project, the underlying design philosophy underlying can be summarised as: "fixability and flexibility".

In the case of the rope washer pump different pumping lifts and human power capabilities can be accommodated through the choice of pipe and pulley sizes. A large pulley or pipe will give a high flow of water but will require quite a lot of effort. Pipe sizes ranging from 20mm to over 80 mm internal diameter have been used successfully, giving a 16-fold range in maximum pump output. Pulley diameters varying from under 30 cm to over 50 cm can be chosen. With the twin axle overhead rope-washer pump, the gearing range is even wider as there are three pulleys involved. The pump can be operated by one or two people. Finally the speed at which the pump is operated can be controlled to a certain extent, although laboratory tests indicated that there was a strong preference for speeds in the range 30-50 rpm (Lambert & Faulkner, 1991). The rope-washer pump exemplifies the principle of "fixability" - as the pump can be made at farm level every component can be repaired or replaced by the farmer.

With the treadle pump flexibility is achieved by allowing for a choice of cylinder sizes. Large cylinders give a higher output but with more effort. The cylinder unit can be moved along the pump frame, so adjusting the length of the piston stroke and the amount of leverage available. Close to the treadle pivot gives a high leverage, a small piston stroke and a reduced volume of flow but with a higher discharge pressure. Further flexibility is achieved because the pump can be operated by one or two persons. The part most likely to be difficult to repair is the manifold unit, which is made from mild steel and will therefore be subject to corrosion. However it has been designed so that it can be easily repaired by a metal working artisan with a welding unit. The valves are simple and easy to remove, repair and replace.

3.2 The rope-washer pump

3.2.1 History and original design

The principle of the rope-washer pump is very old, possibly dating back to ancient China (Needham, 1965). Sketches of the pump, known also as the chain pump, the chain and washer pump or the rag and chain pump, appear in several compendia of pumping and field machinery (e.g. Longland, 1948 and Westcott, 1932). Westcott mentions the work of Agricola (1556) "De re metallica" wherein the rag and chain pump is described as one of the favourites for draining deep mines. This pump was superceded in the mining industry by the reciprocating piston pump in the seventeenth century.

The traditional design of the rope-washer pump, illustrated in Figure 11, involved a chain or rope pulled through a pipe by a cast iron or wooden gear wheel (Watt, 1976). At intervals on the rope were washers made of leather or cloth bundles and occasionally of steel plate. These washers act in a similar fashion to pistons in a cylinder and draw water with them as they move up the pipe. In addition the washers were gripped by the teeth of the gear wheel in order to pull the rope up and then released on the downward side of the wheel. According to Westcott (1932) lifts of over 70 metres (240 ft) were possible with an animal driven version. Cast iron versions of the pump may still be seen in old farmyards throughout Britain where they were used until relatively recently for lifting animal slurry from tanks.

In the late 1970s a Dutch organization called Demotech introduced the pump to some villages in Niger and to Indonesia (Demotech, 1986). They reported that hundreds of rope-washer pumps are now in use in Java, although there are no other reports of this in the literature. Five years after a pilot project visits were made to 128 of the pump owners and it was found that two thirds of the pumps were still in use. It seems that many of the pumps that were out of use had been given away free or that a government irrigation scheme had been installed. Demotech seems to have also been involved to some extent in Peru. During this project several attempts have been made to contact Demotech but without success. Some work has been carried out in Sri Lanka on the development of the rope-washer pump (Pieters et al, 1988) and there are reports of ongoing work in Nicaragua.

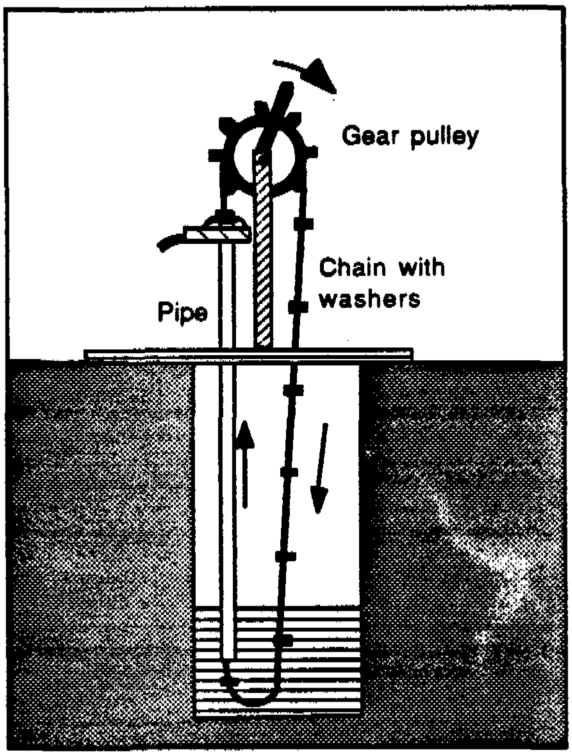


Figure 11
Schematic diagram of traditional design of rope-washer pump

Working in Tanzania in 1981, one of the authors of this report, Robert Lambert, installed a number of rope-washer pumps. These were well received on a local level but there was no time to initiate field trials, demonstrations or dissemination of the technology. In the course of research carried out by the Dambo Research Unit (1984-1987) a number of prototype rope-washer pumps were installed with farmers in the study areas.

There has some interest recently in using the pump for more "high-tech" applications, for example in conjunction with a vertical axis V-type wind turbine (Kersey, 1987). Of particular interest for wind turbines is the pump's low starting torque. With many reciprocating pumps the starting torque may be higher than the operating torque. However because the riser pipe in a rope-washer pump drains down when the pump is not in operation, the amount of torque needed to get the pump started is low and increases gradually as the rope draws water up the pipe.

3.2.2 Recent modifications

In the late 1970s a design appeared, believed to have been invented by Demotech (1986), which greatly simplified the construction of the pump through the use of modern materials. This involved the construction of a pulley from an old car tyre to replace the toothed gear wheel. This pulley could pull a wet rope under considerable tension without slippage, yet release the rope freely on the slack side of the pulley. Tests carried out during this project indicated that ratios of forward to back tension on this pulley were frequently greatly in excess of 20. During this project, a very simple method of making the pulley was developed, using steel bars or strong wooden laths. Figure 12 illustrates two of the common pulley designs used in this project. Various operating arrangements are shown in Plate 1.

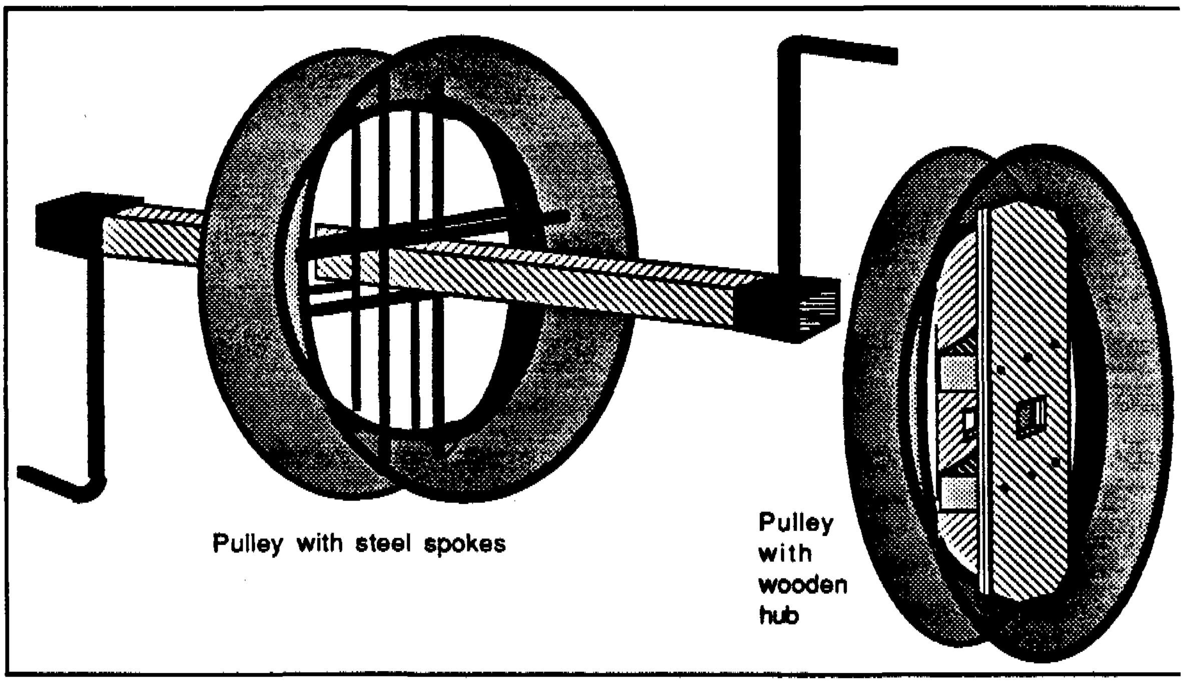
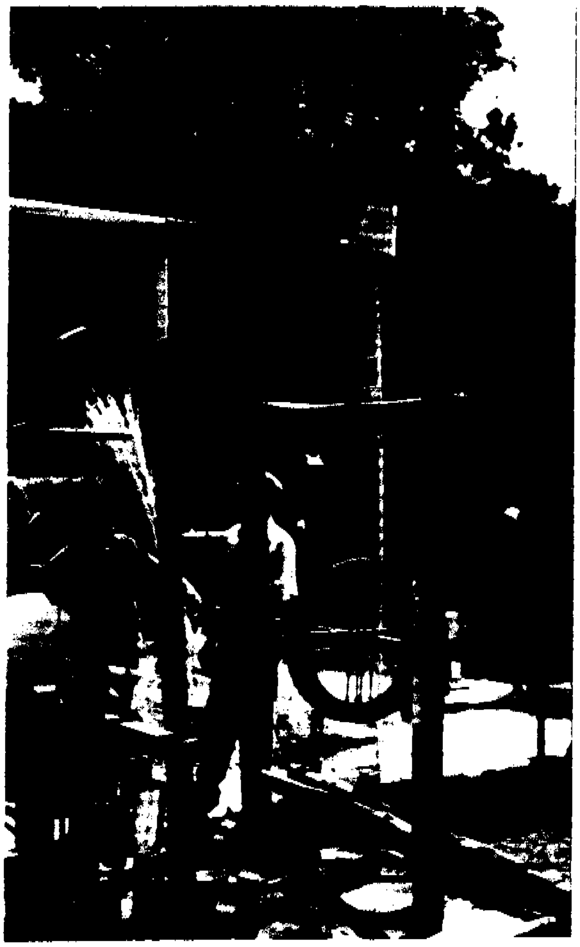


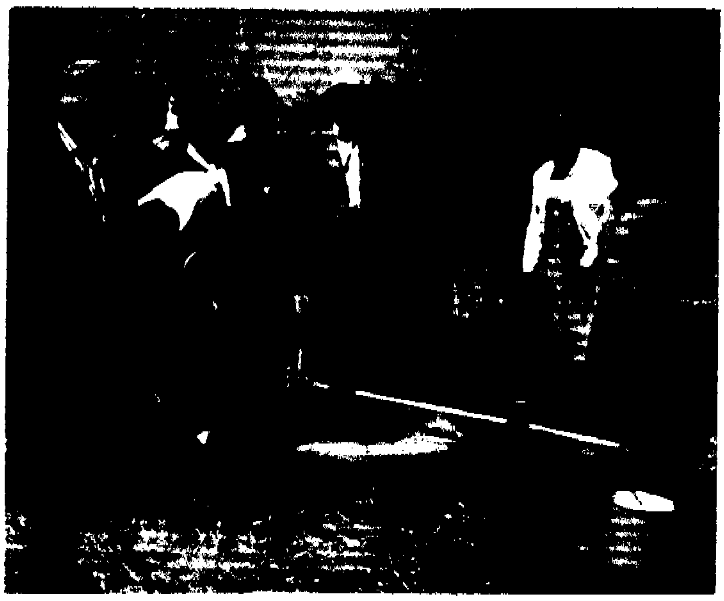
Figure 12
Car tyre pulley wheel for rope-washer pump

Plate 1
Operational modes for rope-washer pump

Inclined operation for pond



Overhead operation



Vertical operation for well

Having been pulled up through the pipe, it is vital that the rope can return freely to the bottom of the well and enter the pipe without snagging on the pipe lip. With a steel or wooden pipe and steel chain with washers this isn't a problem because the pipe mouth could be belled out and the chain, being heavier than water could descend below the pipe and approach the pipe mouth vertically. However a nylon rope, which is much cheaper than a chain, is much lighter and will not perform in this way. A guide is necessary to ensure that the rope enters the bottom of the pipe smoothly. Several types of rope-guide have been used in this project, two of which are shown in Figure 13. In some places farmers using the pump in the inclined position have substituted a bottle for the log which acts as a rope guide.

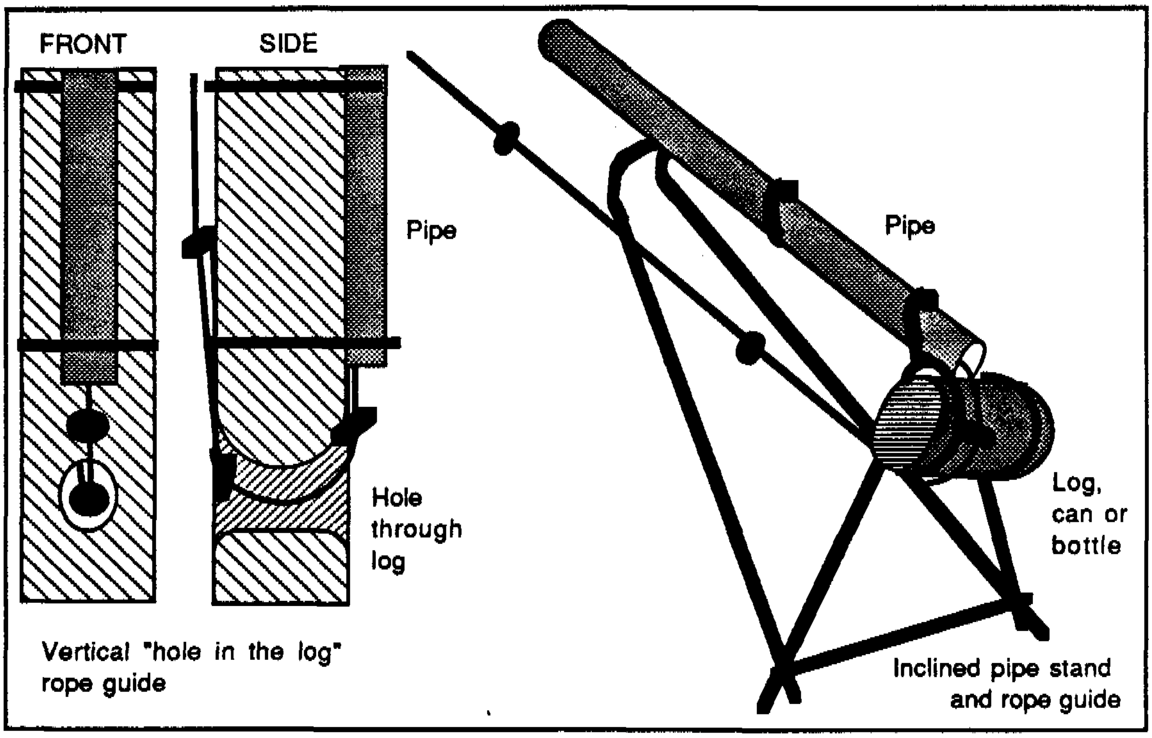


Figure 13
Rope guides for the rope-washer pump

Plate 2
Treadle pumps

Pressurised treadle

Bangladesh treadle

Treadle detail

The Demotech design was for vertical use and was unwieldy to erect over unlined ponds or beside streams. Figure 14(i) shows this vertical arrangement. In response to this problem, Lambert, working in Tanzania in 1981, modified the design to cope with unlined ponds or streams as ilustrated in Figure 14(ii). In Zimbabwe, many farmers interested in using the pump had their wells situated at the lower end of their gardens. In order to lift the water high enough to command the plot area, an earthen platform was built to raise the outlet of the pump the requisite height. However building such platforms higher than about one metre is impracticable. Faced with this problem one of the pumpmakers trained during this project, Mr James Mukorera, devised a double axled arrangement so that water could be raised up to 5 or 6 metres above groundlevel. The arrangement was modified to give the set-up shown in Figure 14(iii) - the practical limit is the height of the poles needed to support the upper axle.

The rope-washer pump in its present form is not suitable for small diameter wells, such as tube-wells. At present, installation on a well requires that a person must be able to descend into the well to secure the pipe at the bottom. This limits the pump to hand dug wells, which are in any case overwhelmingly the most common well built by rural households. In areas where aquifer permeability is low, and this is the case in most parts of Zimbabwe, large diameter wells have the advantage of greater storage capacity and less drawdown during pumping. However with the development of simple tube well technology there may be a need for a modification that allows installation on these wells.

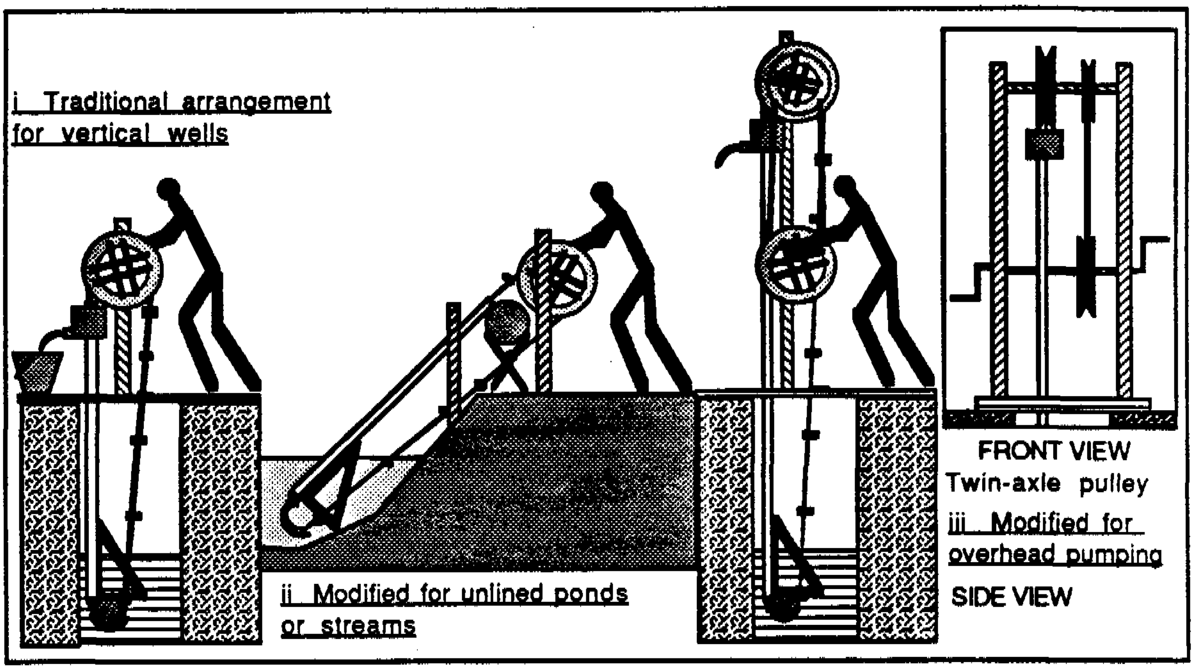


Figure 14
Various arrangements of the rope-washer pump

3.3 The treadle pump

3.3.1 The Bangladesh suction design

The treadle pump was developed by RDRS/LWF in Bangladesh during the early 1980s (Barnes, 1984) and is widely used in that country with an estimated 50,000 in operation in 1985 (Allison, 1986). The pump has been introduced to a number of other countries, including Tanzania and the Phillippines (Stickney et al, 1985) although the full extent of its current use is unknown. The Bangladesh design has two single acting reciprocating pistons in steel cylinders. The pump is installed directly over a shallow tube well and water is drawn into each cylinder from a single inlet pipe through a manifold. The water discharges at the top of each cylinder and overflows into an earthen channel that is built around the pump unit (Figure 15).

As the pump raises water by suction the lift is limited to about 7 metres depending on altitude above sea level. In Bangladesh farmers purchase only the cylinder unit which, being mass produced is quite cheap, so their cash outlay is low. Stickney (1985) claimed that the cost of the treadle cylinder unit was $10.00 in Bangladesh in the early 1980s. Using local timber and bamboo for piping they are shown how to erect a treadle mechanism on a tube well.

A number of the Bangladesh models were imported to Zimbabwe for testing during this project. It quickly became apparent that a number of modifications would be necessary. Due to the permeable nature of the soil in many parts of Zimbabwe, unlined earth channels have unacceptably high infiltration losses. Therefore the pump was modified by the addition of a spout to allow discharge into a small tank, from which water could be piped to the crops (see plate 2). The type of permanent field installation used in Bangladesh was unpopular with farmers in the study areas of this project because the pump could not be taken back to the house at the end of each day for safe keeping. Many of the shallow aquifers used by farmers in Zimbabwe have a low permeability so it is necessary to have a number of wells and a pump that can be moved from one to another. Therefore a portable unit was designed, incorporating a self standing frame (Figure 16). This frame allows the cylinder units to be set at the most comfortable position for the operator. For high lifts, greater leverage and hence a higher lift, can be achieved if the cylinder unit is moved close to the treadle pivot at the front of the frame. This will shorten the piston stroke length and reduce the volume of water delivered.

3.3.2 The pressurized discharge treadle

It soon became apparent that in many situations a pump was required that could discharge water under pressure through a pipe. This is of particular importance if the channel deposits of alluvial water resources described by Owen et al (1989) are to be utilized. Accordingly the cylinder unit was redesigned to incorporate pressurized discharge. In addition, the type of steel tubing used in the Bangladesh cylinders is not available in Zimbabwe so the cylinders were made from lengths of thick walled uPVC pipe. A special clamping device was designed to secure the plastic cylinders to the steel manifold. This clamping system allowed a wide range of cylinder sizes to be used. Small cylinders allow high-lift (and low-flow) and large cylinders permit high-flow (and low-lift). The pistons utilise leather cup seals, two in each cylinder, each facing in opposite directions, one for suction and one for delivery. The pressurised discharge cylinder unit is shown in Figure 17.

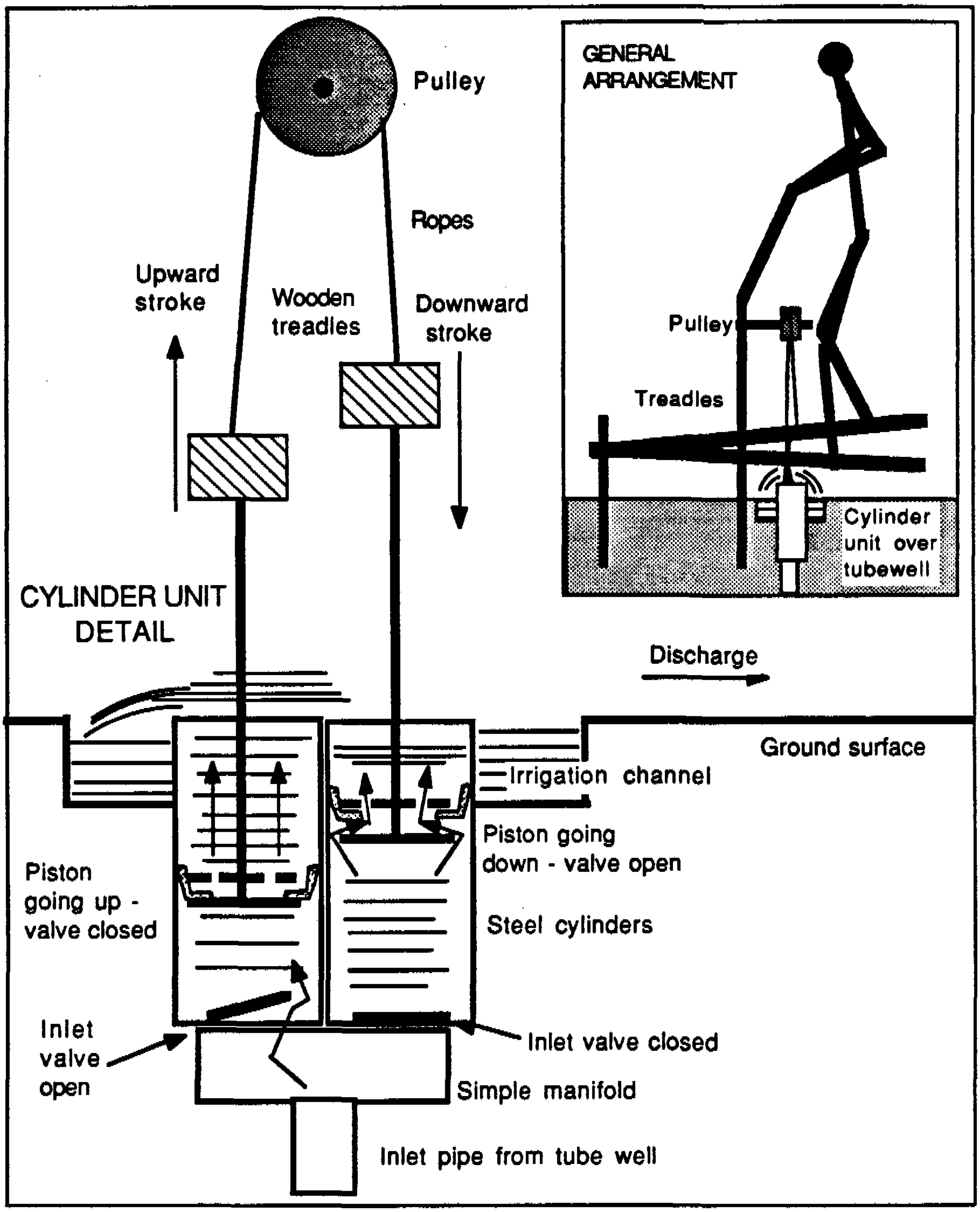


Figure 15
Bangladesh suction treadle

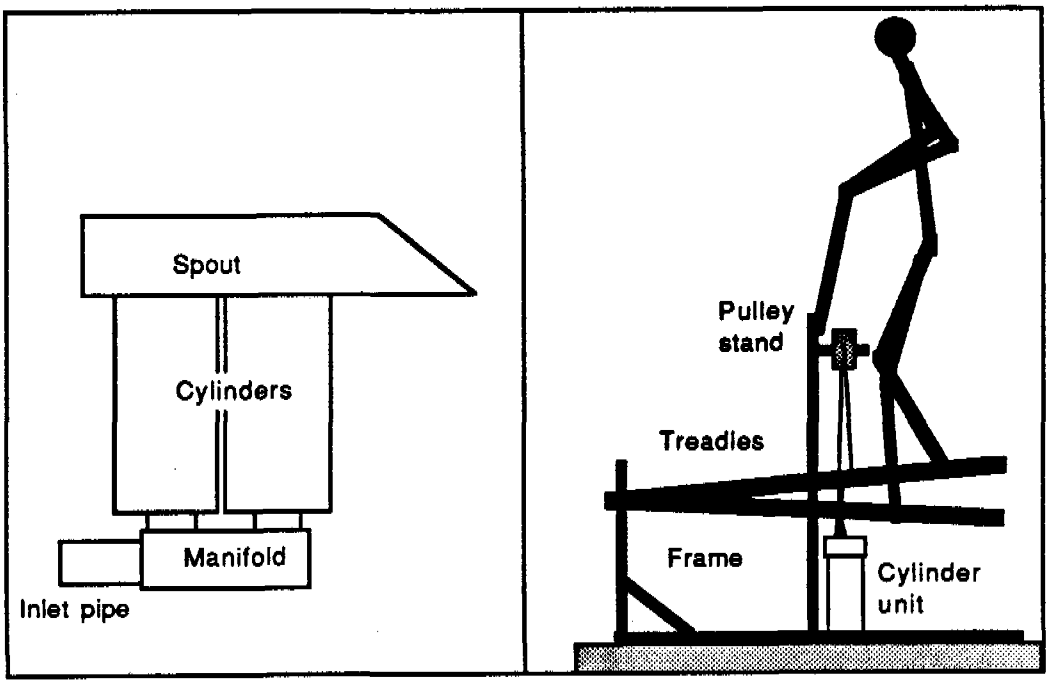


Figure 16
Portable suction treadle pump on frame

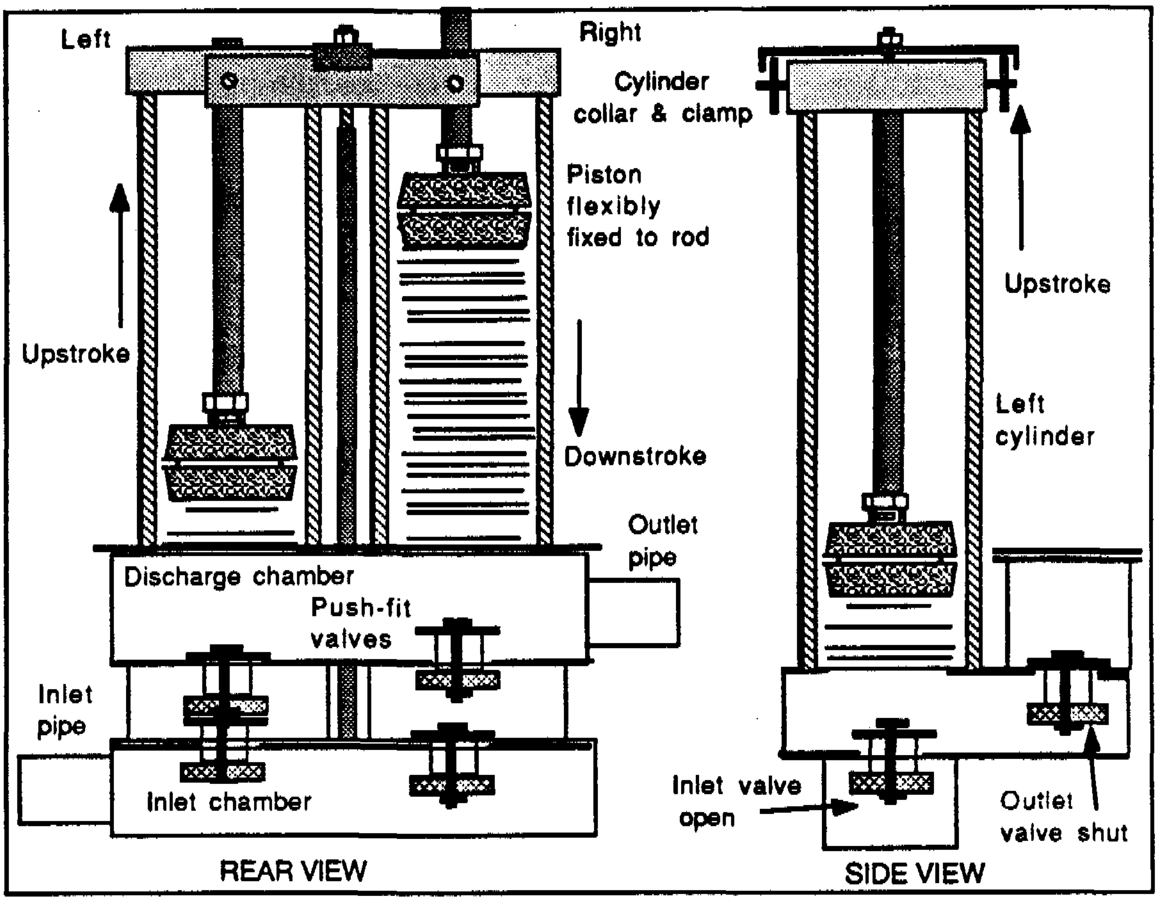


Figure 17
Pressurized discharge cylinder unit

An important objective of the redesign was to facilitate manufacture by small-scale artisans working in the informal sector who had access to only very basic metal working equipment, such as welding machines and drills. Production using lathe or foundry work was not considered. Considerable attention was given to the problems faced by the farmer in operating and maintaining the pump. This is particularly relevant in the design of the valves, which can be fouled by silt or leaves in the pumped water. A silt trap was designed for use with the pump and push-fit valves designed to be easy to remove and repair. Where possible nuts and bolts which could rust and seize were avoided.

It was found that due to the radial movement of the treadle during operation, the piston is deflected from the vertical and some leakage can occur between the leather cup seal and the cylinder wall. This is particularly important on the suction stroke because if air enters and gathers in the cylinder the pump will fail to operate. It is not so important on the discharge stroke as the consequence is a small amount of leakage but the pump continues to function. In order to counter this problem, the piston is attached to the piston rod using a "wobbly" connection (a knuckle joint) that allows limited movement by the piston on the end of the rod. The geometry of the piston ensures that it remains in contact with the walls of the cylinder.

Small-scale production and sale of the treadle pump by an artisan working in the informal sector has been underway for over a year now. Two units have been shipped to the UK for further testing and evaluation.

3.4 Distribution and application

Irrigation of crops involves lifting water from the well or stream, distributing over the irrigated plot and applying it to the crops. A good field distribution and application system can save as much effort as the introduction of a manual pump.

Stern (1979), in a useful field book, describes a range of distribution systems suitable for small scale irrigation the simplest of which is the open channel. However unlined channels are unsuited to the small plot sizes and light soils common in micro-scale irrigation in many parts of Zimbabwe and other parts of Africa. For light soils it is necessary to line channels with concrete or brick which is expensive and difficult for an individual farmer to do correctly. Without proper maintenance cracks can develop which result in high losses of water. Even on heavy soils where seepage losses may not be so high, the accurate layout of earth channels is a skilled task. Such channels, lined or unlined, are very inflexible and may impede drainage in the wet season, especially in low lying areas such as dambos where much micro-scale irrigation is practised.

Because manual systems are low energy systems, sprinkler application is not feasible due to the relatively high hydraulic energy losses in the sprinklers. Drip irrigation, although economical with energy, requires a considerable amount of piping and needs a fairly permanent installation - at least over one season. There can be problems with particulate matter in the water supply - a likely occurrence when taking water from open unlined ponds or streams. In order to store enough water for continuous trickle feed a reservoir to hold at least one day's supply is needed.

Some work has been done on buried pipe irrigation (van Bentum and Smout, 1991) but although it offers potential for small-scale irrigation, it seems unlikely to be more attractive than the low pressure surface pipe system described below for micro-scale irrigation.

Low pressure surface pipes. Some farmers have already introduced a simple distribution system, using plastic pipe to carry the water from a small tank filled by bucket. Such a tank and pipe arrangement is a simple, flexible, efficient and cheap distribution system. With the correct size of pipe there is very little head (and energy) loss in the system. Low pressures also mean that the lightest duty pipe may be used. If a pipe is damaged, it can be easily repaired with strips of rubber.

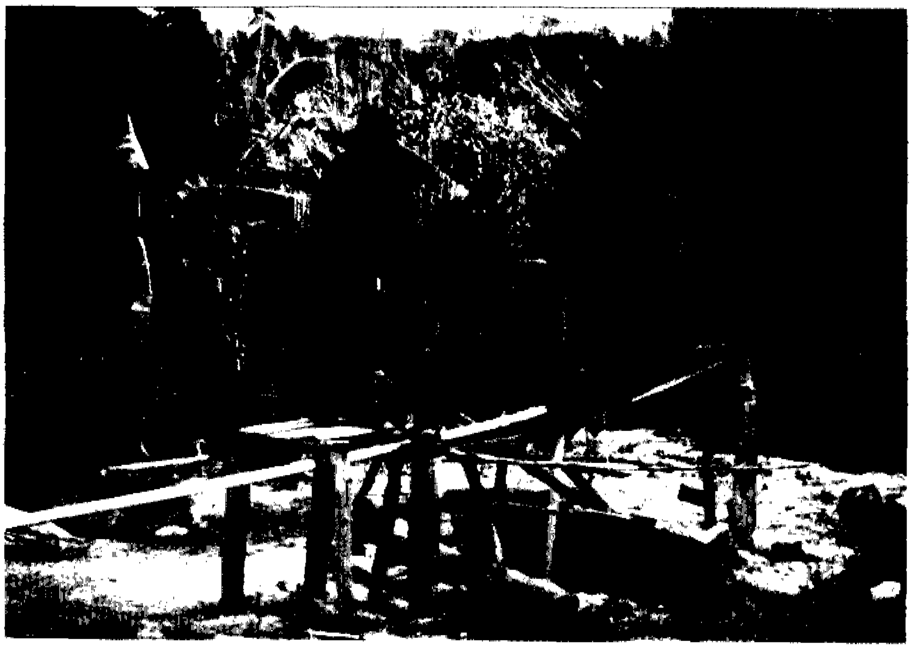
To minimize head loss, the velocity of flow in the pipes should be kept under one metre per second. It is important to choose a pipe diameter that is large enough to take the output of the pump. In practice, this means a minimum of 40mm internal diameter. With such diameters the tank, into which water is discharged from the pump, needs to be raised no more than one metre above the plot to be irrigated. Smaller pipes or a lower tank elevation may mean that the distribution system cannot cope with the flow from the pump. The pipes may be easily moved from one plot or well to another and lent or rented to a neighbour. If the farmer decides to give up irrigation, the pipes may be sold, so retrieving some of the original investment.

A 50 metre length of 40mm ID pipe when full of water weighs over 60kg and is difficult to move around a field full of fragile crops. For simple field operations it is desirable to have pipes in shorter lengths, of say 5 metre. Short lengths of rubber hose can be used to quickly connect these lengths of pipe. These connections are flexible and, due to the low water pressures involved, leakage is very small.

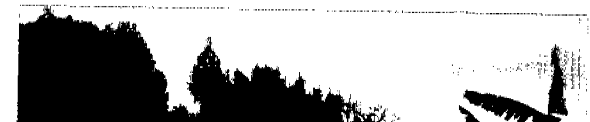
Having conveyed the water by pipe to the crops, application of the water to the crops may be by furrow irrigation. Small furrows may be dug beside each crop row to carry the small amounts of water needed in the early stages of growth with larger furrows being dug when the crops mature. Cross ties may be built across the furrows to aid infiltration and to reduce the risk of erosion during rainfall.

Some farmers have designed their own application system. An example is the use of a "sprinkler" pipe fitted at the end of the distribution line. Holes are made using a nail in a length of plastic pipe at intervals of 0.1m. One end of the pipe is blocked and the other connected to the distribution line. The "sprinkler" pipe is laid alongside the crop bed and water is pumped into the tank at the head of the distribution line, flows down the pipe and emerges in a spray onto the crops. Such a low head sprinkler system ensures a uniform application on the crop bed and minimises the risk of erosion. An example of a field system is illustrated in plate 3.

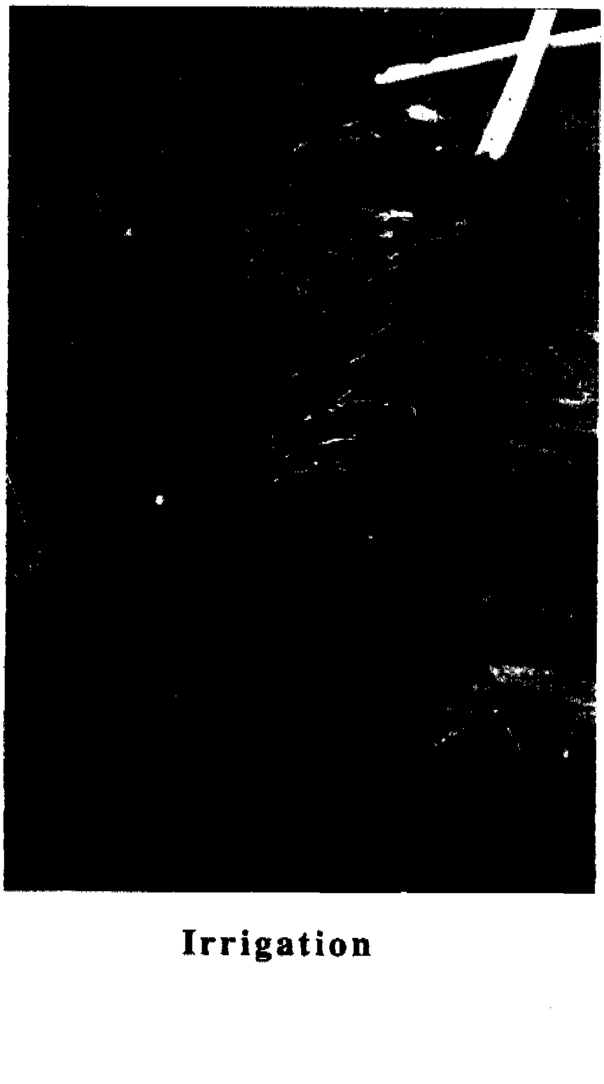
Plate 3
Field irrigation system



Pump



Delivery



Irrigation

4 PERFORMANCE

4.1 Laboratory tests

The objective of the tests was to evaluate the performance of the pumps during sustained operation, and to establish the performance characteristics in terms of the normal parameters of head, discharge and efficiency. It is also important to evaluate the their effectiveness in converting human energy into hydraulic discharge. Conventional analysis would consider the mechanical efficiency of each machine in converting human power into useful hydraulic output. However, the muscle groups utilised are also a major factor in the output from a human powered pump. A pump which utilises a number of more powerful muscles, can result in a greater hydraulic output than a more efficient pump which uses weaker muscle groups.

The pumps need to be able to deliver a sustainable flow of 1 l/s over a fifteen minute period, against relatively low heads of up to about 5 m. Testing was carried out both in Zimbabwe and Loughborough, and the principal results are given below.

4.1.1 Tests at Loughborough University

A conventional series of tests was run using a rope-washer pump rig set up over a large sump. The pump was driven mechanically to enable a wide range and diversity of testing to be carried out. The tension in the drive chain was measured to facilitate the evaluation of the efficiency (Faulkner and Lambert, 1990).

For the test rig, the rope was 8mm diameter nylon with plastic washers of 69mm diameter and the vertical pipe was UPVC of 71mm internal diameter. The pulley wheel was made up from two 650mm diameter wooden discs held 150mm apart by steel rods which were indented slightly to give a shallow Vee shape. The washer spacing was 1.0 m.

Figure 18 shows a plot of the volumetric efficiency against the rope speed for four pumping heads. It can be seen that as the as the speed and hence discharge increases then the volumetric efficiency also increases. The maximum value obtained was 95% at a head of 2.4 m. A rope speed of between 0.6 and 0.8 m/s appears to be optimal.

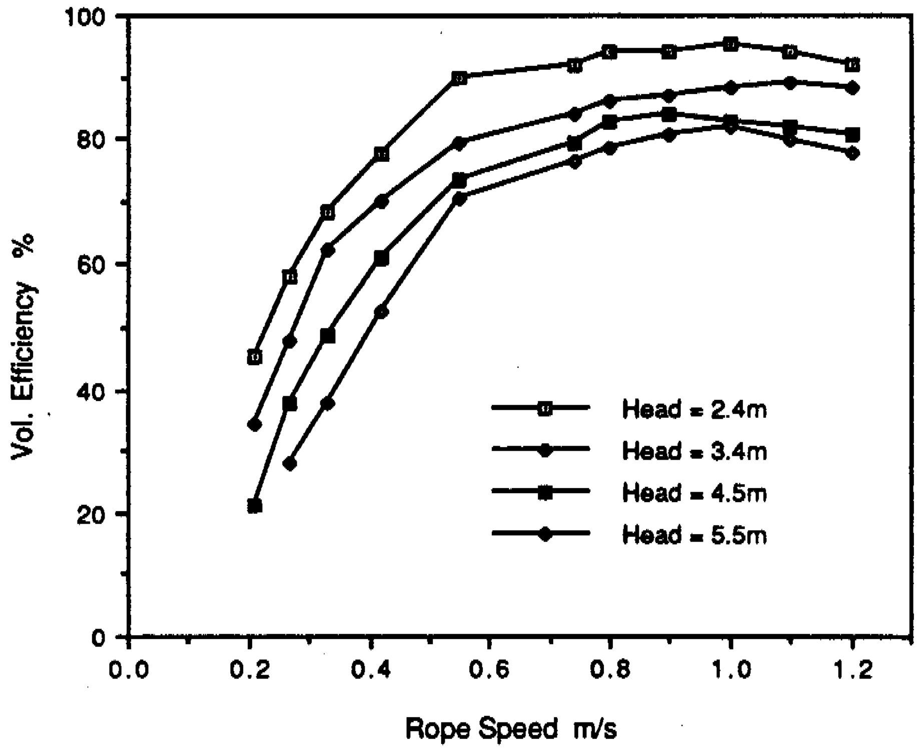


Figure 18
Volumetric efficiency-RWP

Figure 19 shows a plot of the mechanical efficiency against the rope speed. The peak values occur at a rope speed similar to that for the volumetric efficiency. The maximum value obtained was 62% at a head of 5 m. Initial tests carried out with several volunteers indicated that a sustainable output of human power is 50-75 W, which would give flows of around 1.5 l/s up to 3 m head. The optimum rope speed of 0.6-0.8 m/s corresponds to a field version of the pump with a top pulley wheel 300-500 mm diameter, being operated at the preferred speed of 30-50 rpm.

It was found that reducing the washer spacing resulted in increased flowrate down to 0.75 m, with little difference between 0.75 m and 1.0 m. The influence of the gap between the washer and the pipe was also investigated, using rubber washers, and it was found that only a very slight reduction in discharge occurs as the gap is increased from 0.5 mm to 1.5 mm. However, at 2.0 mm gap the reduction in the discharge became significant.

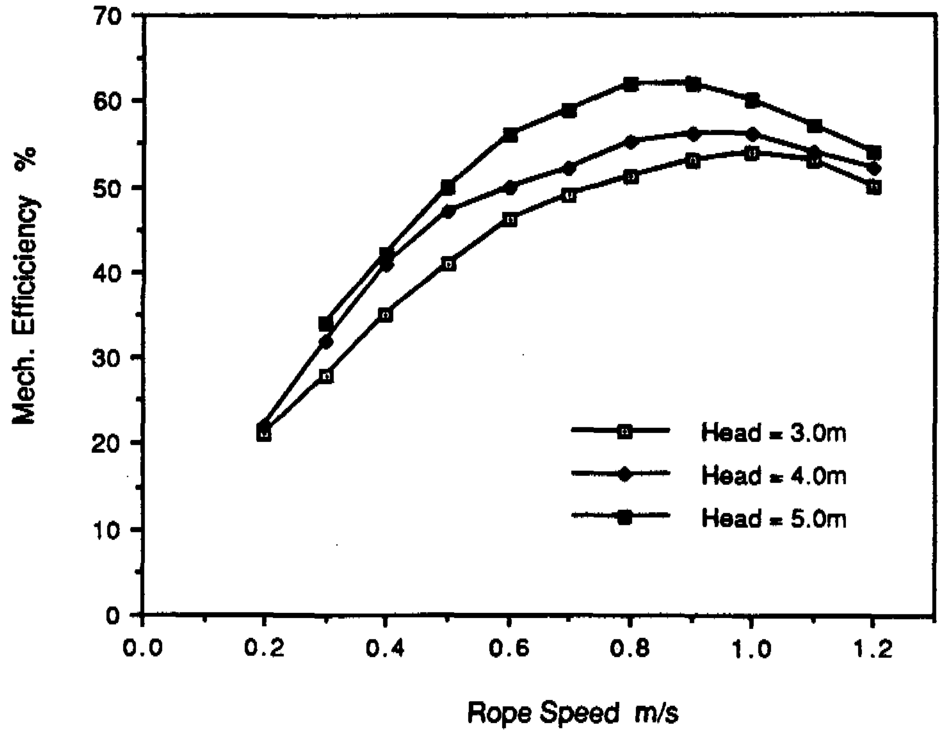


Figure 19
Mechanical efficiency-RWP

A number of tests were carried out in the laboratory using the field version of the pump, with the pulley made from car tyres, including one where a flow of 0.4 l/s was obtained over a short period from a 14 m lift. The field pump has a slightly smoother operation than the test rig, due to the improved movement of the rope and rubber washers over the car tyre pulley.

These laboratory tests were later justified in the field operation of the pumps, where the actual performance slightly exceeded that predicted by these results. For example, a flow of 1.1 l/s was sustainable at 4.8 m head and 0.74 l/s at 6.1 m head with the field pump operated by one adult male, implying an input power of about 75 W.

4.1.2 Tests at Zimbabwe University

These tests concentrated on the performance utilising human power only, and a methodology was devised which uses heartrate as a measure of human power input to the pumps (Lambert and Faulkner, 1991). Tests were carried out on the field versions of the rope-washer, treadle, Bumi and rower pumps.

The Bumi pump did not compare well with the others, being almost impossible to operate at heads over 4 m. The efficiency of the rower was 40-60%, but this pump simply did not achieve the necessary discharge of 1 l/s at heads in excess of 1.0 m. The rope-washer and treadle pumps consistently achieved efficiencies over 50%, with the rope-washer having a maximum value over 70% and the treadle about 60%. However, it can be seen from Figure 20 that the performance of these two pumps is very similar. The stronger leg muscles utilised in the treadle being offset by the higher efficiency of the rope-washer pump. This implies that the optimum, or maximised, utilisation of human power would be a rope-washer pump operated using the leg muscles. This is the topic of further research following on from the present project.

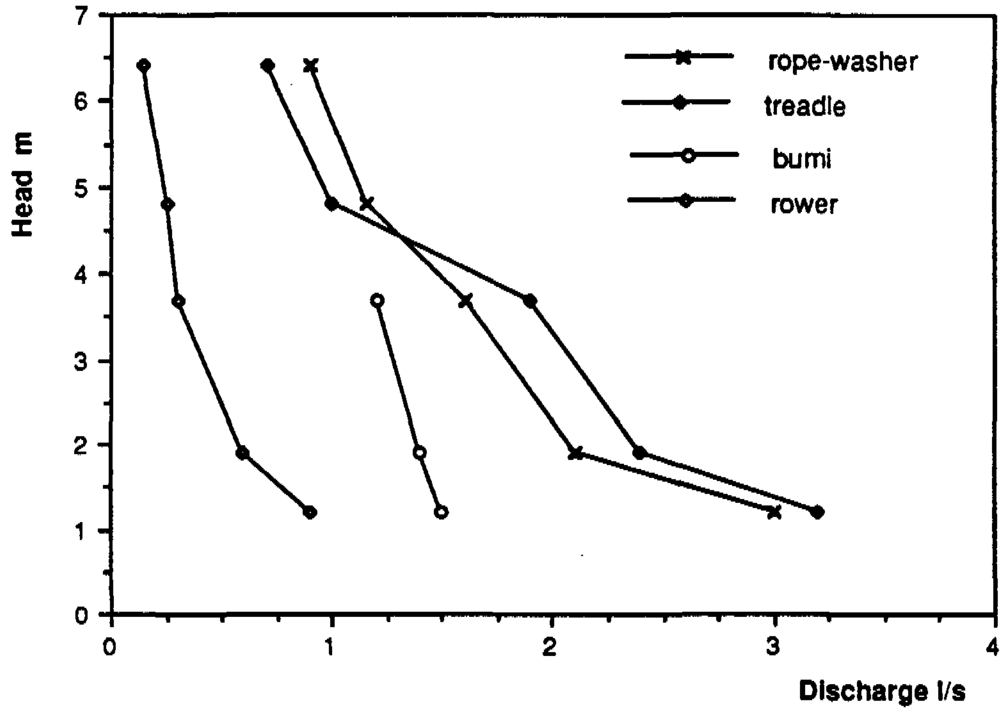


Figure 20
Head vs Discharge for pumps

The diameter of the vertical pipe for the rope-washer pump used in these tests was 50 mm, and the top pulley wheel was approximately 500 mm diameter. The diameter of the cylinders on the treadle pump were 110 mm, and the diameter of the rower pump was 50 mm.

4.2 Field tests

4.2.1 Site selection

A selection of pumps was installed at various locations in Zimbabwe. The principal location was in Chihota communal area, where good contacts had been established by the Dambo Research Unit. Some pumps were installed in Gutu where a German funded group garden project expressed interest in the technology. Shurugwi and Zvishavane were chosen partly because of contacts with local organizations. Table 7 shows the distribution and location of pumps for field testing in the early stages of the project. In the Chihota area monthly visits were made to each farmer with a pump and to a control group of farmers without pumps. This was to monitor the effects of the introduction of the pump on labour and production patterns and to observe any problems that the farmers had with pump operation and maintenance. As the project continued many more pumps were installed privately by pump makers trained in the project and feedback was obtained from a much bigger range of farmers.

Table 7
Field tests: pump type and location in early stages of project

Location / Pump type	Chihota	Gutu	Shurugwi	Zvisha-vane	Total
Rope-washer	10	1	2	1	14
Treadle	2	2	-	-	4
Rower	2	1	1	-	4
Bumi	1	-	-	-	1
Total	15	4	3	1	23

Some of the sites chosen for initial testing were with group gardens, the rest being with individual producers. Where individuals were chosen, the choice was made in conjunction with local village organizations. Selected individuals could use the pump free of charge during the test period and at the end of that period they would have the opportunity of purchasing the pump and pipes. In response to representations from the village organizations no pumps or pipes were given away free as this would have provoked friction between those selected as pump users and those who were not.

4.2.2 Field evaluation

A survey was carried out by a socio-economic consultant, Dan Ticehurst, some months after the pumps were installed to assess the effects of the introduction of the pumps. The survey was conducted in the Chihota area among farmers who cultivated gardens on dambos. Households with and without pumps were surveyed. The survey included a rapid rural appraisal technique using direct matrix ranking and individual interviews with affected households.

Direct matrix ranking. During this exercise, two groups of farmers, one consisting of 7 farmers who had been using the pumps for some time and the other consisting of 6 farmers who had no pumps, ranked crops according to selected criteria. The results of the ranking exercise are given below in Table 8. Except for high price and ease of sale, the criteria and the most popular crops were selected by the farmers. The farmers' criteria have different weightings in their choice of crops. In the table the two most and least important criteria are indicated.

For the farmers with no pumps, irrigation and weeding of crops were regarded as the two most important criteria, which was not the case for those with pumps. High price was regarded as the second least important criterion for those without pumps, while those with pumps regarded it as the most important. For those without pumps the crop with the lowest overall score was rape closely followed by maize. When these farmers were asked to choose only one crop to grow they chose maize. This may be affected by the high score (low preference) for rape in terms of time spent irrigating. For those with pumps maize had the lowest overall score although when asked to choose only one crop they chose carrots. With this group carrots scored a 1 only on high price, their most important criteria, confirming the heavy weighting given to price by this group. For the purposes of this study, the most important outcome of this exercise was the decline in importance of time spent on irrigation as a result of the introduction of the pumps. This seems to have allowed farmers to concentrate on producing high value crops for sale.

Table 8
Ranking of crops according to farmers' criteria

Criteria[1]		Without pumps (n=6)						With pumps (n=7)					
Crop	2	Rape	On.	Tom	Cab	Maize	2	Rape	On.	Tom	Cab	Carrot	Maiz
Low investment		2	3	4	5	1	13	1	4	3	2	5	6
Stable Price		2	4	3	5	1		2	6	4	3	5	1
High price[3]	13	3	5	1	2	4	1	5	2	3	4	1	6
Availablity of seed		3	2	4	5	1	2	1	6	2	5	4	3
Low fertilizer cost		3	1	2	4	5		2	=3	=3	6	=3	1
Less time weeding	2	4	1	2	3	5		=4	3	2	=4	6	1
Less time irrigating	1	4	2	3	5	1		6	4	3	5	2	1
Less pesticide	14	5	1	3	4	2		=4	2	=4	=4	3	1
Stores well		1	2	4	5	3	14	6	2	4	5	3	1
Short duration crop		1	4	3	5	2		1	6	5	4	3	2
Continuous harvest		1	3	2	4	5		1	2	6	4	5	3
Produce travels well		1	4	3	5	2		=5	3	=5	4	2	1
Ease of harvest		3	1	2	4	5		5	2	3	4	6	1
Ease of sale[3]		1	4	3	5	2		6	4	3	5	2	1
Total points		34	37	39	61	39		49	49	50	59	50	29
If grow only one which one?		2	4	3	5	1		6	3	4	5	1	2

1 High score in points indicates a low preference.
2 Weighting of criteria: 1&2 are the most important, 13 & 14 are the least.
3 These criteria suggested by interviewer

Labour time reduction. Through interviews with the study households estimates were made of the amount of time spent on irrigation before and after the introduction of the pumps. Figure 21 illustrates a typical pattern of labour used for irrigation before and after installation. It is clear that there is a considerable saving in labour time through the introduction of the pumps.

Operation and maintenance. In addition to the one-off survey continuous monitoring was carried out in the Chihota area by an enumerator to observe problems that farmers had in operation and maintenance. The pumps were monitored for just under a year and it is likely that problems of repair and maintenance would occur more often as time went on.

One farmer complained that the rope-washer pump felt "heavy" and was difficult to operate. This was because the wooden bearings had been badly carved and no grease was used. This was rectified by the pump-maker. The only other complaint was of a loose rope on one of the pumps which was tightened by the farmer himself. One farmer stopped using his petrol engined pump in favour of the rope-washer pump, stating that petrol was too expensive to purchase. From our survey data it seems that the job of operating the pump is shared between himself, his wife and his son.

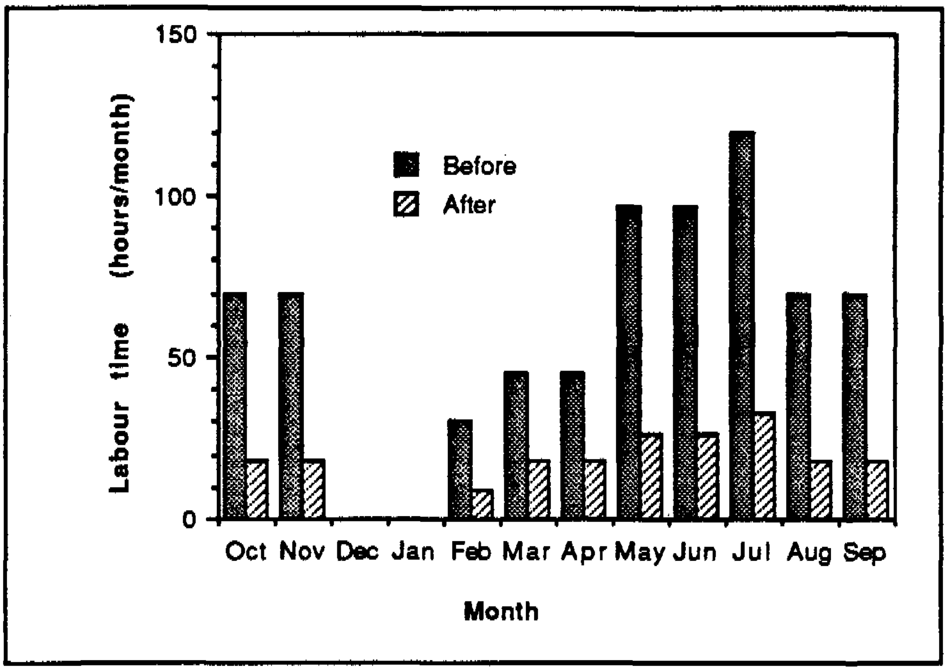


Figure 21
Time spent irrigating before and after pump adoption

Reports from other projects suggest that the diaphragm of the Bumi pump, although very durable, eventually wears out. The diaphragm is specially made by the manufacturer in Harare and spares are not generally available. In one project attempts were made to repair the diaphragm with old car tyre but this was not successful.

The leather cup seals of the treadle pump are also subject to wear, although these are available in hardware stores in the major towns. As the manifold unit of the treadle pump is made from welded mild steel plate it will be subject to corrosion. The manifold has been designed so that repair of any rusted sections is possible with the most basic welding facilities.

The Rower pump had no serious problems although on one pump the plastic fitting which guides the pump rod was badly worn. The pump is made in Harare but spares are not readily available, with the exception of the leather cup seal. However some spares, such as the rubber flap valve may be improvised by a farmer.

General comments. Not all of the installed pumps were used for irrigation. With many of the group gardens the pumps remained unused, and it would seem that the individual plots within a group garden are very small and do not take a lot of time to irrigate. Thus, for each individual the amount of time that can be saved with a pump is quite small. Some concern has been expressed about the willingness of women to operate the treadle pump (or of their husbands giving them permission) as this involves standing on treadles which are quite high off the ground - a position that may be considered undignified. This concern seems to be similar to the concern expressed over women using bicycles. There are strong opinions on both sides and while some women hesitate other women are quite enthusiastic. If the high position of the treadles is a problem, a simple solution is to dig a shallow pit and set the pump in the pit so that the treadles are closer to ground level. This has the added advantage of making it easier to mount and dismount the pump and lessening the danger of a fall. The disadvantage is that the pump is more difficult to move.

However in the Bedzanhomba group garden, which is being monitored by staff at the Chiredzi research station, the group seems to have evolved an effective rota system for the use of the treadle pump. This pump was installed in 1990, towards the end of the field work of this project but recent reports (Lovell, 1991) indicate that the pump is still being used although some women complain that it feels "heavy". Another pump, a rope-washer pump, has been ordered for a neighbouring group garden, where the group has dug a well and the treadle is not suitable.

There was a much higher take-up of the pumps by people with individual gardens although in some cases pumps were rejected or repossessed by the pump maker because of failure to complete payment. The higher success rate with individuals is partly related to the fact that it is easier for an individual to make a decision and abide by it. In areas where there is a fairly large scale production of vegetables and where a pump has obvious financial benefits, most of the gardens are individually farmed. Group gardens are often located in areas where there has not been a history of vegetable production and so there are many new techniques to be learnt, including agronomy, group organization and irrigation technology.

5 PRODUCTION AND DISSEMINATION

5.1 Strategy

It is increasingly being recognised that the diffusion of technical innovation does not proceed only by the centralized diffusion model so long favoured by extension policy makers. Basant (1990) argues that decentralized horizontal diffusion depending on peer networks is an important process, particularly with simple rural technology. In other words, farmers often learn most from each other. Close interaction between the farmer and the fabricator can lead to rapid adaptation of the technology to the farmer's needs.

Although the principal objective of this project was research and development of simple irrigation technology, it was anticipated that there would be some dissemination of the project results. In the event, dissemination started quite early in the project as the introduction of pumps for field testing had the effect of publicising the technology among local farmers. While there was considerable interest in the pumps themselves, the piped distribution system was also very popular. Each farmer who had a pump installed for the test period was given the chance to buy the pump and pipes for a reduced rate at the end of the test period. Many, although not all, of the farmers did so.

The choice of strategy for the production and dissemination of the irrigation technology was dependent on the type of pump used. It was decided quite early on in the project to co-operate with Agritex, the government's agricultural extension service and with local NGOs. Agritex staff are capable of reaching farmers at grassroots level and instructing them in how to use a new technology. However production of the pumps could not be done by Agritex.

5.2 Production

There are a number of possibilities for production of the pumps tested in this project.

- **Factory sector.** Large scale production in the factory sector. This is how most handpumps, including the Bumi pump, are produced. The manufacturer of the Bumi did not have an effective marketing and distribution network. Pumps could be delivered in large numbers to organizations or to individuals who knew of the pump and were prepared to go to the factory to buy it. However, for practical purposes they were not available to individual farmers. The availability of spare parts was a serious problem for the same reason. While the treadle and the Rower could be made in this way, the rope-washer pump is not suited to this form of production, because skilled advice is needed in the its installation.

- **Artisan sector.** Small scale production by rural or urban workshops in the artisan sector. This is how many of the consumer goods used in the rural areas of Zimbabwe are produced. For example over 70% of the cooking grates used in the rural areas are made in this way (Ncube, 1990). There is close interaction between the producer and buyer and adaptations can be custom made by the artisan to the customer's needs. The rope-washer pump can easily be made by such artisans although they would have to travel to the the customer's home to instal the pump. For this reason, artisans based in villages or small urban centres would be in a better position to make and sell the rope-washer pump. When this project was started none of the other pumps were suitable for production in this sector. However, the treadle pump was redesigned for this level of production.

- **Farmer sector.** Production by individual farmers trained by extension workers in the farmer sector. Many agricultural implements or parts for them can be fabricated on the farm. If this is possible then repair and maintenance can be done by the farmer without outside assistance. The only pump that could be made in this way is the rope-washer.

In the initial stages of this study several engineering firms in the factory sector were approached to produce the treadle. One company produced a working prototype model and seemed quite enthusiastic about continuing production. However, they have not as yet produced significant numbers of pumps. The manufacturer of the Bumi pump was also interested but needed an order for a significant number of pumps before beginning production. A third producer started production but due to some very intensive and lucrative alternative contracts decided not to proceed. Production and sale of the treadle has begun in the artisan sector.

It was originally envisaged that the rope-washer pump would be produced by rural artisans who would then sell the pump to farmers in their areas. If necessary maintenance could then be carried out by these artisans. A number of pumpmakers based in rural areas were trained in the manufacture of the pumps. In one case a farmer/artisan in Chihota, Mr Tapera, who had seen one of the pumps installed in his area as part of the pump testing programme made his own pump and started making and selling the pump to farmers in other communal areas. Despite having received no training in pump manufacture, Mr Tapera has made and sold an estimated 20 pumps. However it soon became apparent that farmer/artisans had problems in producing pumps for sale in their own locality. Many of their friends and neighbours are relatives and it can be quite difficult to get them to pay cash for goods or services. It seems easier to sell to non-relatives where there are no pre-existing obligations.

The dissemination of the technology through Agritex has proved quite successful. Despite misgivings about the availability of Agritex staff to find the time to train farmers to make and instal the pumps, in some of areas of the country they have been very successful.

5.3 Dissemination

5.3.1 Training materials: videos, books and toys.

When, early on in the project, it became clear that there would be a demand for the rope-washer pump, it was decided to make a video for training artisans in how to fabricate the pump. A video company based in Harare was engaged to produce the video. Shooting took place in 1988 and the editing was completed in early 1989.

Two videos were produced, one is a 10 minute programme dealing with technology for micro-scale irrigation and aimed at an educated audience on the international conference sector. The second video is a 20 minute programme detailing the steps involved in making a rope-washer pump and aimed at extension agents, artisans and farmers. Because the audience for this video is unlikely to have a good command of English, it was decided to produce the video without a narrative. A booklet was produced to accompany the video. Both videos and the booklet have been published by Intermediate Technology Publications.

The video has been used in several training courses (see below) run during the project. It has also been shown on the national TV network in Zimbabwe and has been used at various agricultural shows. One aspect of using video is that it raises the status of simple technology, technology which may not have the instant appeal of more modern high-tech gadgets. In addition it shows the technology in a real environment whereas other demonstrations at agricultural shows, or in institutions, lack verisimilitude.

In many parts of Africa, children play with ingeniously made wire toys. These toy-making skills have been employed in the dissemination of the rope-washer pump. A number of working models of the pump were produced for training purposes. The maker of these toys has sold several dozen of them at agricultural shows. The toy is an excellent way of demonstrating all the working parts of the pump in a training course.

5.3.2 Training workshops in Zimbabwe

A series of three two-day training workshops were organized for FAO staff involved in horticultural promotion with Agritex. These were run in July - August 1989 in Bulawayo, Mutare and Harare (Lambert, 1989). The original intention of the workshops was to train artisans in the production of the pump. However rather more participants attended the workshops than was anticipated, which was good for publicising the pumps but not so good for the training of the artisans. During one of these workshops, representatives of the Lutheran World Federation (LWF) invited one of the project pump-makers, Mr C Chizengeni, to demonstrate the technology to farmers in their project area. Mr Chizengeni subsequently spent some months working on this with LWF.

In the same year a one week training course was organized in conjunction with Agritex. This course was for staff from the mobile training units stationed in each of the seven provincial areas. These staff are responsible for training farmers in the correct use of technology in crop production and for the dissemination of new technology. During the one week course, the trainees visited sites where farmers were using the pumps. This was followed by a session on the theory behind both the rope-washer and the treadle pumps and the simple irrigation system recommended. The trainees then made their own rope-washer pump and installed it on a well. They each took away with them the pump they had made and one treadle pump for demonstration. The success of this course underlines the importance of having enough time on a training course, in this case one week.

In a follow up visit to some of these staff it was observed that they were making very good progress in extending the technology. In one part of the Midlands Province, Lower Gweru, over 40 farmers had already adopted the technology some months after the Agritex staff had begun extension efforts. In Manicaland it was estimated that 15 farmers had installed pumps. Positive reports were also received from Masvingo and Mashonaland West.

A one week course was held in 1990 in conjunction with the Training Centre for Water Supply and Sanitation based at the University of Zimbabwe. The course was held in Chihota communal area and participants from all over the country attended. This course attracted representatives of NGOs involved in garden projects, a number of artisans and some government staff.

5.3.3 Training workshops outside Zimbabwe.

As a result of articles in development journals such as Oxfam's BAOBAB, (Lambert, 1990) and of a visit to Zimbabwe by representatives of the Kenyan Institute of Organic Farming, invitations were extended to conduct some training courses in Kenya. At the time of writing final plans have been made to conduct two one week courses for NGO and government staff.

Invitations have also been received from other countries, including the Gambia, Botswana, Namibia and Bangladesh. A short training workshop was held for students at WEDC in Loughborough in 1990.

5.4 Credit

It has been noted that for many small farmers access to capital is one of the major constraints to improved production. Providing credit is one of the best ways in which small farmers can be helped (Madeley, 1991). Since Independence in Zimbabwe, great efforts have been made to extend credit to small farmers, principally through the Agricultural Finance Corporation (AFC). These efforts have met with mixed results and there has been quite a lot of defaulting on repayments. Some of the problems include:

- Requirement to grow "controlled" crops. These are crops that may only be sold legally through the State marketing bodies, such as the Grain Marketing Board (GMB). This allows the AFC to put stop-orders on cheques to farmers with loans, ensuring that the loan is repaid. However it means that loans will not be granted for uncontrolled but high value crops, such as vegetables or for other viable rural activities such as artisan production.

• Requirement for collateral. Farmers applying for a loan must have collateral which can be sold if loans are not repaid. This excludes the poorer farmers although it is fairly unworkable in that the AFC is very reluctant to seize property.

• High administrative costs. It is expensive for a conventional credit organization charged with covering its costs, which AFC must do, to administer a large number of small loans to individual farmers. Attempts have been made to reduce costs by giving loans to groups but this has been largely unsuccessful due to the problems of individual liability within groups.

In recent years there have been some notable successes in credit provision to the rural poor, notably the Grameen Bank in Bangladesh (Madeley, 1991). Zimbabwe has its own success story in the Savings Clubs schemes. In these clubs, largely consisting of women, small amounts are saved weekly and each member takes it in turn to use the accumulated savings. While these clubs are very successful, they are not really suited to the larger amounts of credit needed for farming. However it has been shown that the rural poor can be good credit risks provided that a credit system is tailored to their needs and their potentials.

Because of these problems with credit and how they affect the dissemination of new technologies, such as the simple irrigation technology developed in this project, a credit club was set up in one of the project areas, Chihota. After a number of workshops with the local community a written constitution was drawn up and formalized with the help of a lawyer. This credit club is a form of cooperative community capitalism and has the following features:

• Members must be approved by the committee and pay a fee to join the club. These fees purchase shares in the assets of the club and constitute its working capital. Reduced fees may be approved for poorer applicants.

• Loans are made to club members only on the basis of the commercial viability of a proposal put to the committee. Interest on the loans is set by the club and goes towards administrative costs and increasing the value of the clubs assets.

- Shares may be redeemed at any time, given a certain period of notice. As the value of the shares increases with the amount of interest paid, the club also functions as a savings scheme. The fact that at any one time, most members of the club are lenders rather than borrowers means that there is considerable peer pressure on the borrowers to repay their loans.

Recent correspondence indicates that the club is functioning well after almost a year in existence. However, the fees for membership have been increased which may exclude poorer members of the community. The club has created quite a reaction amongst local officials of the AFC, who have responded very positively to this development and are attempting to disseminate the system to other farmers' groups.

5.5 Results of dissemination

There are a number of ways in which the results of the dissemination process can be gauged. The most obvious, measurement of the number of pumps in use, is particularly difficult for technology which is produced and distributed by the informal sector. Unlike production at factory level, where there may be only one producer with good records, production by farmers and artisans in the informal sector requires considerable effort to monitor. If successful horizontal diffusion takes place then this will very likely be unnoticed in official statistics.

Not having done a detailed follow up survey, the number of rope-washer pumps in operation in Zimbabwe has been estimated to be in the order of several hundred units. The number of treadles made and sold is probably in the order of 50 units.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The literature review and analysis, carried out at the start of this project, indicated that there was a large gap between the simplest technology available to small-scale farmers engaged in informal sector or micro-scale irrigation, and "modern" technology such as the petrol or diesel driven pump. The capacity of poor farmers to bridge this gap is severely limited by their access to capital, and by the size of the land-holdings needed to justify such comparatively large investments.

Manually operated systems offer the possibility of bridging this gap, but have long been overlooked by project planners who were influenced partly by over simplified economic and technical arguments, and partly by ethical concern about the promotion of technologies involving hard physical labour, or drudgery. As this analysis shows, even in the case of recurrent costs for fuel, the technical and economic superiority of motorised pumps is not all that clear cut. Availability of spare parts is problematic in most parts of Africa. With the difficulty poor farmers have in obtaining capital or credit, and the high risks involved, the case for manually powered systems becomes much stronger. Alternative energy sources, such as wind and solar energy, although having no fuel costs, are generally much more capital intensive than internal combustion engines, and at present remain well beyond the reach of small farmers. Animal powered systems that have been developed to date have proved difficult to disseminate, probably because the capital cost is still high. Furthermore, poorer farmers may not own or have access to the draught animals required to power such pumps.

Laboratory and field tests show that simple manually operated irrigation systems are feasible for micro-scale irrigation. Two pumps have been developed, the rope-washer which can be made by artisans or farmers, and the treadle, which can be made by the artisans with basic welding equipment. The rope washer pump is very low cost, with material costs in the region of £10 - £20 depending on configuration, and is capable of lifting water from depths in excess of 20 metres and to heights of 4 metres or more. It is particularly suited to wells and ponds but can be used on streambanks as well. The pump can be made and installed in one day by a trained pump maker for a cost of £30 - £60 depending on negotiation. Such training can be given to people with very rudimentary education in one week or less. In some cases, farmers have started making and selling their own pumps even without training. The treadle pump is more expensive, costing about £150. The treadle is suited to areas where a high overhead lift is required and there is water available close to the surface, being capable of sucking water from depths of up to 6 metres and discharging to heights in excess of 20 metres. Such conditions are common in the alluvial water resources found in the drier lowveld areas of Zimbabwe.

Although the main aim of this project was research and development, considerable dissemination of the technology has already taken place in Zimbabwe. This has been done through the informal artisan sector, the government agricultural extension services, and through non governmental organizations (NGOs). Invitations have been received to extend the technology to other countries, including Kenya, Botswana, the Gambia and Bangladesh.

6.2 Recommendations

Given the successful dissemination that has already taken place in Zimbabwe, it is recommended that the technology be extended to other parts of Africa and Asia where it is appropriate. While the training materials produced in the course of this project will to some extent facilitate such dissemination, training courses remain the best way of passing on the technology.

There is a need for continuing research and development of this technology. This can be done both through formal research projects and through informal innovation. Many useful farmer innovations have already been observed in this project. Such innovations need to be documented and disseminated to other farmers. It is recommended that formal research could usefully be carried out on the following topics and technical development of the pumps:

- Monitoring the dissemination of the technology
- Documenting farmer innovation for wider dissemination
- A foot operated rope-washer pump
- Simplified treadle design for manufacture
- Low-cost animal powered pump based on the rope-washer pump.

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APPENDIX

APPENDIX : PUBLIC OUTPUT

Workshops & Training

1991 Two one week practical training workshops in Kenya with local non-government organizations including the Kenyan Institute of Organic Farming and the Kenyan Freedom from Hunger Campaign. (Forthcoming).

1991 Simple irrigation technology: a review of experience in Zimbabwe. Workshop planned for July 1991, Training Centre for Water and Sanitation, University of Zimbabwe. (Forthcoming).

1990 One-week training course for artisans organized in conjunction with the Training Centre for Water and Sanitation, University of Zimbabwe.

1989 Three one-day training workshops organized with FAO in Zimbabwe at Bulawayo, Mutare and Harare

1989 One-week training course for Agricultural Extension Staff (Agritex) in Zimbabwe.

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