AN EVALUATION OF SELECTED APPROPRIATE IRRIGATION TECHNOLOGIES FOR SMALL-SCALE FARMERS

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ABSTRACT

South Africa lacks affordable irrigation technologies suited entirely to the needs of small-scale farmers. This is mainly due to the past emphasis on large, commercial farming technologies and the misunderstanding that emerging farmers can utilise scaled down versions of such technologies. It is now believed that increased irrigation amongst smallholders could largely assist with food security and poverty alleviation in South Africa.

The object of this project was therefore to evaluate selected appropriate irrigation technologies that are currently being used in other developing countries with the intention of introducing them into South Africa. A literature review on all the irrigation technologies currently being used by small-scale farmers in South Africa was performed. The literature review provided information on the factors affecting the adoption of irrigation technologies.

Selected technologies, namely, various low-cost, manual pumps and drip irrigation kits were then imported and evaluated under local conditions. The evaluation process was divided into two sections. Qualitative evaluations were carried out on farms and by farmers themselves and quantitative evaluations were carried out in laboratories and closely monitored field trials. A South African prototype pump was then designed and built following the knowledge gained from testing the imported pumps. The prototype was tested and then refined and rebuilt.

The qualitative test results showed a very positive reaction from farmers towards the pumps. The drip irrigation kits were often not used as a result of a lack of understanding by the farmers. The laboratory test phase highlighted the more critical components of the pumps. A recommended introduction strategy was then developed and is presented. This evaluation process and introduction strategy could in future be used as a guideline when developing other suitable technologies for small-scale farmers.

I wish to certify that the work reported in this dissertation is my own unaided work except where specific acknowledge is made. In addition I wish to declare that this dissertation has not been submitted for a degree in any other university.

Signed: ....

C.J. KEDGE

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LIST OF ABBREVIATIONS

FSR: Farming Systems Research

FSRE: Farming Systems Research and Extension

IDE: International Development Enterprises

IWMI: International Water Management Institute

NGO: Non Government Organisation

PRA: Participatory Rural Appraisal

PWC: Physical Work Capacity

1. INTRODUCTION

South Africa is a country with many contrasts, one of which exists in its agricultural sector. There are two main categories of farmers in South Africa. The first category consists of large-scale commercial farmers, who grow most of the food sold locally and to the export market. These farmers use some of the most highly sophisticated irrigation equipment available in the world. The other category consists of small-scale farmers. These farmers are usually situated in rural areas. They grow most of their produce for subsistence, or family consumption, and sell the surplus to gain a small income. Small-scale farmers do not farm to achieve the highest yields, but rather to meet household needs. There are very few irrigation technologies available to this food-plot farming sector in South Africa. The majority of these farmers are women who fetch water from water sources and carry it by hand or on their heads back to their small plots to irrigate.

Due to the past agricultural development policies, South Africa has used inappropriate methodologies to assist the emerging sector. Government was active in promoting irrigation schemes on which a large number of small-scale farmers were settled and in establishing community gardens where the main contribution was the installation of boreholes for water supply and providing the necessary pumping and infield irrigation equipment. Very few of these government-initiated projects have been successful. There are several reasons for this (de Lange, 1994) but the inadequate provision and management of water has been identified as being a major factor in the failure of many of the schemes. The management of canal systems where the water has to be shared by a large number of individual users is complex and pumping equipment and piping systems are virtually impossible to maintain in the deep rural areas where the necessary technical support is lacking.

The rehabilitation of the failed schemes is being actively pursued by government in an attempt to correct past inequalities. However, it is appreciated that this rehabilitation will be a slow process and that the provision of equitable water distribution to the large number of smallholder farmers is not going to be easy to achieve. The problem is confounded by the policy that farmers themselves must now assume full responsibility for the operation and maintenance of the schemes on a sustainable basis. It is recognised that irrigation can play a significant part in ensuring food security and in alleviating poverty in the remote rural areas. However, small-scale farmers are beset by varying combinations of problems. These consist of limited financial resources, a lack of basic training in farming practices and very few irrigation technologies suited to their requirements.

The disempowering development and management methods used in the past have resulted in a strong dependence on government by small-scale farmers. These methods also resulted in a lack of development of affordable and appropriate equipment suited entirely to the needs of these farmers. Recent agricultural development policy changes have put farmers under pressure to become independent. Government will no longer issue "handouts" in terms of paying for expensive irrigation infrastructure and other expenses such as diesel for pumps. Farmers are to become responsible for their own food security and that of their families.

Other African and developing countries have faced similar problems in the past. Many of these countries went through the same transition years ago. Farmers became aware that they could no longer depend on government for costly technical support because it was no longer forthcoming. This resulted in a change of attitude brought about by the requirement to manage themselves. South Africa can learn from these similar experiences of other countries. While South Africa is behind in the development stage, it is hoped that lessons learnt from other countries will decrease this transition period from dependence on government to independence and food security. Many of these countries still face problems in their small-scale agricultural sectors, however, some have succeeded in developing technologies suited to small-scale farming requirements.

Therefore, the aim of this study, initiated by the International Water Management Institute, IWMI, was to determine whether or not selected affordable irrigation technologies currently being used in other African and Asian countries are suitable for use by small-scale farmers in South Africa. Understanding that new technologies and potential solutions to problems should be evaluated within the systems of production practised by farmers, under their conditions, and with farmer participation is essential (Waugh *et al.*, 1989). Mettrick (1993, p 46) claims that appropriate technology can only be developed if it is based on the full knowledge of the existing farming system. Therefore, to establish the suitability of the technologies for local conditions, two approaches were taken. The first involved understanding the situation of the target market, the small-scale farming sector, and the second was evaluating the new technologies.

The overall objectives for the project were as follows:

1. To review the current situation of small-scale farming in South Africa.
2. To qualitatively evaluate selected appropriate irrigation technologies by placing them amongst farmers and monitoring their use in practical field situations.
3. To quantitatively evaluate selected appropriate irrigation technologies by testing them under laboratory and field conditions.
4. To present a new design for an affordable, manual operated pump suited for use by small-scale farmers based on results obtained from tests on similar imported pumps.

In order to evaluate the technologies a literature review was conducted to determine the factors affecting the adoption of irrigation technologies by small-scale farmers. The review also examined irrigation technologies currently being used by farmers in South Africa and other African countries. The study then proceeded with the importation of selected irrigation technologies. These technologies were installed into operating sites in order to satisfy the first step of the evaluation process. They were also tested under field and laboratory conditions as part of the second step.

The methodologies used and results obtained in the two test stages will be presented in this dissertation. It will then conclude with a discussion of the implications and applicability of the results and the suitability of this methodology of evaluation and introduction of affordable technologies.

2. A REVIEW OF SMALL-SCALE FARMING IN SOUTH AFRICA

The subject of small-scale irrigation is complex and poorly understood. However, there appears to be an underlying, incorrect assumption that small-scale technologies or techniques are simple. Many factors need to be considered before the design of small-scale irrigation technologies can take place. These factors differ from those required for the design of large-scale, commercial farming technologies. There is the set of economic constraints, as well as social factors that may include local farming practices and gender or tribal conflicts. In addition crop water requirements have to be taken into account as well as the sustainability of the technology. The purely technical evaluation of irrigation systems to establish design norms is not adequate. It is essential to look at all components of the farming system in each case.

A number of technologies exist that can irrigate dry lands. Unfortunately, the primary effort of designers and engineers has, in the past, focused on developing products for the most affluent ten percent of the world's population. Very little has been done in terms of designs geared solely towards the small-scale farmer. This is, however, changing with some realisation that irrigation, where properly executed, can transform the production potential of agriculture and represents a main prospect for food security for a large proportion of the inhabitants of many developing countries (Piper, 1986). Irrigation with limited water resources should be efficient and effective. Irrigation equipment should be affordable but also easily maintainable. Projects introducing modern irrigation technologies in the developing world have often failed. There is a clear danger of mis-matching irrigation hardware, developed for one set of physical and socio-economic conditions, with the circumstances in an entirely different environment (Cornish, 1997).

This literature review chapter is divided into three main sections beginning with an exploration of small-scale irrigation in Africa and South Africa. As design factors are important in the correct introduction and acceptance of any new technology to an area, the second section details a selected set of these factors. The third section provides a review of the main irrigation technologies that are available to small-scale growers. The chapter will conclude with a short summary of the elements of the review to set a framework for the case studies found in the following chapter.

2.1 Small-Scale Irrigation

Irrigation is any process, other than natural precipitation, that supplies water to crops, orchards, grass or any other cultivated plant (Stern, 1979, p 13). Underhill (1984) defines small-scale irrigation as those schemes that are under local responsibility, controlled and operated by the local people in response to their felt needs. South Africa is not as advanced in terms of successful small-scale irrigation as other African countries. This could be a result of the past concentration on commercially orientated farmers. A background to small-scale irrigation in both Africa and South Africa follows.

2.1.1 Small-scale irrigation in Africa

Palanisami (1997) states that nearly 65 percent of all land in sub-Saharan Africa is arid or semi-arid, however, less than three percent of the arable land is under irrigation. There are many thousand small farmers practising irrigated agriculture in sub-Saharan Africa. Low-cost technologies are capable of assisting them to increase production, resulting in greater incomes and increased food security (Perry, 1997).

The sub-Saharan regions of Africa have no long tradition in irrigation, hence farmers find it difficult to adjust from extensive rain-land cropping to intensive irrigation (Le Moigne, 1986). The major bottleneck to increased irrigated food production is the lack of low-cost productive technologies (Perry, 1997). Currently most irrigation equipment in the area is imported from other, more developed countries. More often than not it is prohibitively expensive and inappropriate for use by small-scale farmers.

Carter and Kay (1984) stated that Kenya was ahead of other countries in the sub-region in utilising low-cost technologies for small-scale irrigation and it appears that this is still the case today. The practice of traditional irrigated agriculture in some arid regions south of the Sahara; the availability of significant water, land and labour resources in many areas; good and growing domestic and regional export markets for irrigated food crops and the development of appropriate low-cost manual and mechanised irrigation equipment will all contribute to a better future for the subsector (Perry, 1997).

2.1.2 Small-scale irrigation in South Africa

Maritz *et al.* (1998) state that the current population of South Africa is estimated at about 40 million people with an average annual population growth rate of two and a half percent. Approximately six million of South Africa's population live on commercial farms and a further ten million in rural areas where small-scale farming is an important source of subsistence. Similar to the situation in Africa as a whole, research has shown that government-initiated, small-scale farmers' irrigation schemes in South Africa are beset by varying combinations of problems such as limited financial resources, a lack of basic training and few irrigation technologies suited to their requirements (Maritz *et al.,* 1998).

There are, as far as can be ascertained, 202 small-scale schemes in South Africa involving 47 486 hectares. Of the 37 108 participants, only 13 867 can be regarded as commercially oriented. The remaining 23 241 are food plot holders who may sometimes sell a portion of their produce. In addition, there are a number of smaller schemes, less then two hectares in total size, comprising commercial gardens, food plots and household gardens (Maritz and Uys, 1997).

South Africa has a relatively large commercial irrigation sector with well-developed manufacturing, input and service supply industries (de Lange, 1999). However, experience with successful small-scale irrigation is limited and there appears to be a lack of knowledge about gravity water distribution structures. This knowledge gap could be because, for the last three decades, the emphasis has been on modern systems such as sprinkler, micro, drip and centre pivots (Crosby *et al.*, 2000). Given this situation, South Africa could learn from other Southern and Eastern African countries with stronger irrigation traditions (de Lange, 1999).

2.1.3 Climate

Africa's climate is unlike any other in the world. With no mountain range dividing the continent, the climate in this area of the world is very unpredictable. When prolonged drought conditions occur, often for years, it can mean famine conditions in many countries (Reaves, 1995). However, the application of appropriate technology is providing security against the increasingly frequent failures of rainfall (Brabben and Pearce, 1999).

South Africa is a water poor country with only seven percent of the total area receiving more than 800 mm per annum (Schulze, 1997). The high rainfall areas are primarily mountainous with limited possibility for cultivation. Extensive rain fed (dry land) cultivation is practised in relatively cool areas of the central highveld where the average annual rainfall amounts to 600 mm or more. Vast areas of the country have a hot and arid to semi-arid climate with an average rainfall of less than 50 percent of the annual evaporative demand for optional plant growth or production. However, the climate in these areas is highly suitable for the production of a wide variety of crops, and irrigation farming is successfully practised in rural areas where suitable irrigable soils and adequate water supplies for irrigation occur (Maritz *et al.*, 1998).

Due to the high growth rate in water requirements throughout South Africa, the need for efficient water use by irrigation is increasing. With growing competition between farmers who need to irrigate their crops and rapidly expanding cities, water saving forms of irrigation are at a premium (Postel, 1992). Suitable irrigation technologies for small-scale farmers can assist with a more efficient use of water.

2.1.4 Small-scale farmers

The market for small-scale technologies stems from small-scale farmers. These are farmers who either grow their vegetables or crops individually on small plots at home or are involved with community gardens or government-initiated irrigation schemes. Crosby *et al.* (2000) carried out extensive research on small-scale farmers and they estimate that at least 150 000 growers participate on community gardening projects in South Africa and an unknown number grow food in home gardens.

Community gardens are located in areas where communities are living. The size of the gardens can vary from one to ten hectares. They are communal in the sense that a number of people share the infrastructure, and there is generally an overall management committee responsible for the maintenance of infrastructure and the orderly management of the garden (Crosby and de Lange, 1998). The sharing of irrigation equipment, however, is much more difficult to manage satisfactorily and is often a cause of dispute between farmers. Experience suggests that farmers should be as independent as possible in terms of their irrigation equipment (de Lange, 1994).

Participants each work their own allocated area for their own profit. There are sometimes a number of communal plots on which the participants take turns to provide labour and inputs, and the proceeds are used to provide for fuel, repairs and similar common expenses (Crosby *et al.*, 2000).

Normally only a minority of the residents in communities are interested in gardening on any scale. However, there are residents who are enthusiasts. The bulk of the production is for their own use and for friends, but some is for sale, so that each participant in a community garden is essentially a commercially orientated small farmer, and should be regarded as such (Crosby *et al.*, 2000).

Some community gardens are successful, many are not. Crosby and de Lange (1998) suggest that gardens should be developed on the initiative of the community. Where the infrastructure is provided by an external agency and the community is presented with a fenced area, irrigation system and water supply without the communities' financial contribution, the results are often unsatisfactory. However, where a group of farmers, very often women, join together, contribute finance, help with the clearing of an area and the fencing, and then, as a body, go to the authorities for assistance with the development of a water source, often a borehole with pumps, the chances are that the enterprise will flourish.

Water supply constitutes a major problem to community gardens, in terms of water availability, assured supply and water supply technology. Another constraint is the lack of extension support and guidance to small-scale irrigators on community gardens (Crosby *et al.*, 2000).

Large irrigation schemes in the developing world have often failed to fulfil the targets set by the planners and designers (Chancellor and Hide, 1997). Most irrigation schemes in the communal land tenure areas in South Africa were started after 1955. The schemes fell under the management of the Department of Bantu Affairs and were efficient and productive in the beginning but this "top down" approach was not sustainable (Van Averbeke *et al.*, 1998).

Crosby *et al.* (1998) state:

"Before the advent of the homelands the emphasis was on concrete-lined canals and flood irrigation. When capital became freely available and the emphasis became homeland development at any cost an attempt was made to "facilitate" the process by automating the technical and management aspects by introducing centralised pumping facilities and sprinkler and micro irrigation. This approach to bringing about community adaptation to technology failed. One of the reasons is that it is difficult to maintain sophisticated equipment in rural areas where maintenance infrastructure is not readily available.

The development corporations, in an attempt to service the development loans, concentrated on producing "profitable" crops that could be marketed through established channels. To achieve this, they were forced to stifle initiatives including the production of food for own consumption. The farmers were dependent on the managing authority for financing, the supply of inputs, mechanisation support and the maintenance of infrastructure. This resulted inevitably in a culture of dependence and the virtual collapse of schemes"

2.2 Factors Affecting the Adoption of Irrigation Technologies

There are many factors that need to be taken into account when designing appropriate technologies. The following section will review some of these factors.

2.2.1 Farming Systems Research

Farming Systems Research (FSR) has long since demonstrated the inadequacy of technology development alone as a basis for improvement of farming systems in developing countries (Mccown *et al.*, 1993). FSR is a process aimed at increasing the productivity and sustainability of farming systems by analysis of the constraints and opportunities of existing farming systems, implementation of suitable adaptive research programmes, and subsequent development of appropriate technology and complimentary policies (Mettrick, 1993, p 45). An aspect of FSR is the use of scientists from more than one discipline working together as a team in order to understand the farm as an entire system rather than studying isolated components within the system. On-farm research is seen as being at the heart of FSR. Figure 1 shows that there must be a two-way flow of information with research stations and also a relationship with national policy.

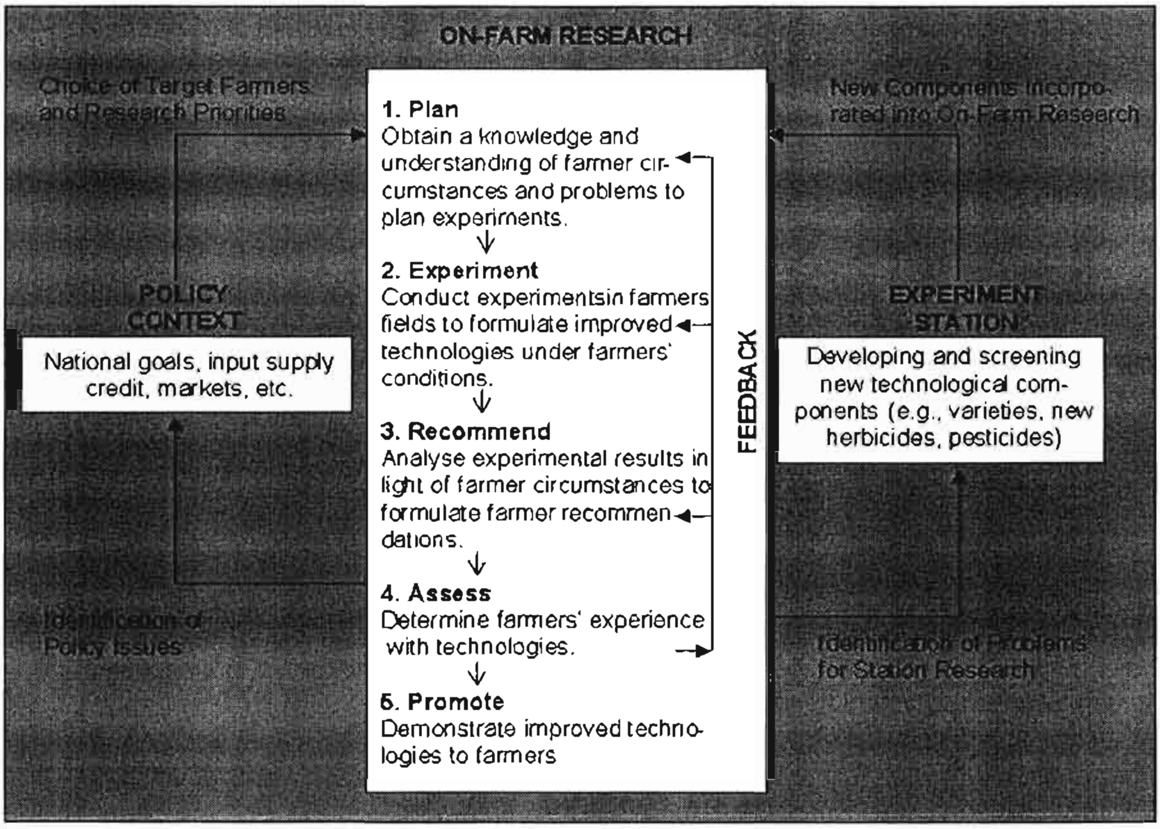


Figure 1. Overview of an integrated research programme (after Mettrick, 1993 p 72).

Criticisms of FSR on methodological grounds have been advanced by Chambers and Jiggens (1986). Some of these include:

- Multi-disciplinary collaboration has proven problematic, FSR being resented by natural scientists as a social science innovation.
- FSR does not focus explicitly on resource-poor farmers.
- FSR is still dominated by a transfer-of-technology approach.
- Scientists are inadequately prepared for face-to face dialogue with farmers. Their approaches, attitudes and reward systems need to be reversed if they are to learn from farmers.

The Farming Systems Research and Extension (FSRE) approach is problem driven and relies on participation of all role-players (Mettrick, 1993, p 53). Basically the FSRE methodology consists of the following stages: (Auerbach, 1995)

1. Diagnostic stage – this is where the main farming systems are identified by a multi-disciplinary team, which includes farmers and other key role-players from the area. This includes identification of problems and possible ways of solving them. Participatory Rural Appraisal is often used during this phase.
2. Applied/adaptive research stage is where new technology is developed on-station and at a basic scientific research level where high technological solutions are developed. The farmers are not usually directly involved, but the research is focussed on solving problems identified during stage one.
3. On-farm adaptive research phase is where the newly developed technology is implemented at a farm level. This often takes the form of testing existing technologies in the farmers' fields under farm and local conditions.
4. Evaluation of the newly tested and introduced technologies needs to include both qualitative and quantitative methods. This is a time when feed back and acceptability by the farming community can be integrated with the quantitative scientific and economic results of the research.
5. Dissemination or adoption stage. Following the on-farm evaluation the technologies can be transferred to a wider group of farmers via study groups, farmers days, co-operatives, local NGO's and extension and health workers. This will then lead to the technology being widely used and in time adopted by the farming community if it truly is appropriate to their needs.

When using the FSR approach in a project it is important to evaluate the needs of the client at grass-roots level to formulate objectives for the project. The method used is called Participatory Rural Appraisal (PRA) and it is of utmost importance that the farmers to be surveyed are participating in the process together with the scientists (Chambers, 1992).

2.2.2 Participatory Rural Appraisal

"Historically, non-adoption of recommendations by small-scale farmers has been attributed first to farmers' ignorance, to be overcome through more and better extension, and then to farm level constraints, with the solution to ease the constraints" (Chambers, 1993, p 67). It has now been found that farmers are in fact far more knowledgeable and better informed than agricultural professionals used to think, and this has resulted in an approach where the farmers are put first. Reasons are now sought as to why farmers do not adopt new technology, not in the ignorance of the farmer but in deficiencies in the technology and the process that generated it (Chambers, 1993, p 69).

PRA is an approach and method for learning about rural life and conditions from, with and by rural people. The concept therefore enables local people to conduct their own analysis, and to plan and take action (Chambers, 1992). It is essential that farmers be involved in the design process of any new technology to ensure that the technology will be suited to their needs. In particular, women should be encouraged to participate in the design process as, while they are responsible for much of the agricultural work done, they traditionally tend to take the submissive role in meetings as men dominate decisions relating to water management (Stimie and Chancellor, 1999).

2.2.3 Crops and their water requirements

The object of irrigation is to reduce or eliminate water stress upon the crop in an attempt to provide the right conditions for optimal growth and so improve economic return (Piper, 1986). The estimation of crop water requirements is essential, firstly when considering the viability of either small-scale or major irrigation projects, and secondly when planning their development. Inappropriately high estimates can have a major impact on decisions whether or not to go ahead with irrigation policy or design (Crosby *et al.*, 2000).

Small-scale farmers generally have to contend with limited water availability, particularly at peak periods. Their water use is generally well below what would be predicted using conventional methods of estimating crop water requirements. Generally the crops are not planted or fertilised to obtain maximum yields, but rather to ensure economic viability even if conditions should become adverse (de Lange, 1994). In places where water is abundant, water saving is not a farmer priority and in cases where over-irrigation has occurred, anxiety over crop failure has been found to be the single most important reason (de Lange, 1999).

2.2.4 Water legislation

Maritz *et al.* (1998) state that irrigation policy is currently under review with all stakeholders having equal opportunity to make inputs into the process. Future policy will be dominated by the need to make the most effective use of available water while at the same time catering to the needs of the previously disadvantaged communities. In the case of small-scale farmers, the emphasis will be on food security (Maritz *et al.*, 1998).

Irrigable land for expansion exists in most areas of South Africa but water is generally a limiting factor. Intensification and improved efficiency of irrigation are evident essentials for water allocation since agriculture has to compete with other consumer sectors for this scarce resource. South Africa has long followed the policy of subsidising the cost of all water. However, subsidising water costs conveys the market signal that water is a cheap, abundant resource and therefore does not stimulate efficiency. Direct State support will only be provided where previously disadvantaged communities are concerned and then only where the prospects of financial and economic sustainability are positive (Maritz *et al.*, 1998).

Farmer-managed, small-farmer schemes are seen as an area for potential irrigation development in South Africa with significant contribution to rural development (de

Lange, 1994). Irrigation development in South Africa envisages concentrating on the rehabilitation, improvement and also construction of farmer-managed schemes (Crosby and de Lange, 1998).

2.2.5 The role of government and non government organisations

The overall government policy in many countries is to promote social and economic development through sustainable irrigated agriculture. This approach must ensure that irrigation development programmes benefit as many households as possible and, in particular, those which belong to the most vulnerable groups of the rural community (Palanisami, 1997). However, government schemes for small-scale irrigation have had numerous problems. There are many reasons for this, but in most cases the management structuring has been fundamentally wrong. Due to the top down management structure, farmers had little decision making power and the schemes were seen to be owned by government rather than owned by the farmers themselves (Crosby and de Lange, 1998).

For example, in many government-run schemes, pump attendants are employed by the government to manage the pumps and the farmers are not involved in anything involving the pumps. Attendance to pump breakdowns is inefficient and unreliable in such schemes (Matshalaga, 1999). Another major constraint for Non Government Organisations (NGOs) and governments is the implicit character of non-profit organisations. This NGO management style leads to a tendency of a top down, subsidy driven approach, which sees the "target population" primarily as beneficiaries rather than customers. There is a tendency for urban bureaucrats or technical experts to make decisions for the farmer. They, the experts, know what is best for the poor, uneducated farmer (Egan, 1997).

The primary responsibility for aiding the development of small-scale irrigation falls on the national governments, who need to create more positive policy environments in which the farmers themselves may take responsibility for their own development. Experience of State-aided, small-scale irrigation in Africa shows that the most common cause of failure is the lack of comprehension in the planning process of what the farmers really feel and want. It is assumed that the farmers will react favourably to economic incentives as seen by the planners (Underhill, 1984).

All role-players including manufacturers, suppliers, designers, scientists, government institutions, NGOs and farming groups in African countries should communicate to ensure that the relevant knowledge of the suitability of small-scale irrigation equipment remains intact and to identify shortcomings (Koegelenberg, 1997).

2.2.6 The role of designers and manufacturers

"Small-scale irrigation is not large-scale irrigation on a smaller scale but is a totally different concept" (Underhill, 1984). This should be taken into consideration when designing small-scale irrigation technologies. The realisation that small-scale irrigation has its own unique requirements and is not merely a scaling down of well-known commercial technology usually comes with exposure to the actual field situation (de Lange, 1999).

A general problem with simple, low-cost technology is that it is not worth consultants' and donors' while to engage in its promotion as it essentially aims to limit expenditure (de Lange, 1999). The role of the private sector in the manufacture, supply and servicing of equipment for small-scale irrigation is essential to make equipment easily accessible to farmers (Chitsiko, 1998).

2.2.7 Gender issues

Researchers estimate that women are responsible for 70 to 80 percent of food grown in rural areas in sub-Saharan Africa. Women perform 90 percent of the work to process food crops and 80 percent of the work to harvest and market. From an engineering perspective, it is important to identify the functions and responsibilities of women in respect of agricultural production, as well as the activities women are involved in, and the technologies applied to perform specific tasks (Maritz and Uys, 1997).

Methods and equipment have in the past seldom been designed with women in mind. An example is the handling of heavy, portable sprinkler irrigation pipes, which can be difficult and unpleasant dirty work. In addition, it is assumed that pipes will be moved in the early morning and late afternoon, just when household chores are at a peak (Crosby and de Lange, 1998). Decision making with regards to farm management, crops, cultivation technology, the acquisition of equipment, and water management in the case of irrigation schemes, appears to be male-dominated in most areas. Women, therefore, appear to have little say in the manner in which their tasks, which take up most of their time, are to be executed (Maritz and Uys, 1997).

Extension services and training are mostly aimed at and attended by men, who are considered to be the real farmers. Women make good extension officers and counsellors, however, most extension officers are males (Maritz and Uys, 1997). This is illustrated by the impact that women extension officers have made in developing successful community gardens. Part of this success is due to their technical knowledge but their people skills are also a significant factor (Crosby and de Lange, 1998).

The reality of women's participation in small-scale agriculture is that the particular needs and limitations of women dictated by physical strength and family obligations have not in the past received attention and this has resulted in inefficiencies and hardships that are not acceptable (Magadlela, 1997). The land tenure arrangements do not favour women if the husband dies and they often lose the right to use the land they are cultivating. Thus married women may be reluctant to invest in irrigation equipment even when it is financially possible (Chancellor and O'Neill, 1999).

2.2.8 The economics of small-scale irrigation

Irrigation is a major economic factor in terms of exports, employment and the potential for rural food security (Magadlela, 1997). However, in the absence of affordable, more productive equipment to increase irrigation capacity, the typical farmer in Africa is handicapped in efforts to boost production through larger irrigated surface areas and greater yields. In South Africa, the cost of irrigation equipment is inhibiting small-farmer development. It should be recognised that even the cost of a single hose pipe is often unattainable for beginner, individual farmers (de Lange, 1999).

Any irrigation technology that does not have a fast payback period is not viable. If the economic returns are only marginal then poor people will not invest the money or the effort to change, nor will they take the risks to adopt the technology. As a general rule, the payback must be less than one year and the durability of the product should be five times the payback period (Egan, 1997).

Saturated markets cause problems for most small-scale irrigators (Chancellor *et al.*, 1999). There is a need to identify crops and irrigation techniques that will give higher returns to water and the overall investment. Different irrigation technologies, input and output prices and break-even yields are important to justify the future of irrigation technology transfer and uptake (Palanisami, 1997).

Economic research in irrigation management has progressed, but there are further areas for improvement. There is a need to improve the farmers' access to information on marketing prices of crops, transport facilities to the marketing centres, credit facilities and new equipment and technologies available on the market (Chitsiko, 1998).

2.3 Small-Scale Irrigation Technologies

Irrigation technology is defined as the physical water supply infrastructure and the in-field irrigation equipment, its design, construction, operation and maintenance (de Lange, 1999). A number of irrigation techniques are currently being used by small-scale farmers in South Africa. The more appropriate and affordable technologies generally require a high labour demand, while the more expensive, highly technical methods are usually not sustainable. This section will review irrigation technologies currently being utilised by smallholders in South Africa.

2.3.1 Hand watering

The simplest piece of overhead irrigation equipment is the watering can, much used for small-scale gardening in temperate regions. Since all the water has to be carried by hand, the watering can method is limited to small plots with an easily accessible source of water. The size of plot that can be irrigated depends largely upon its distance from the source, and the time that it takes to fill the can at the source (Stern, 1979, p 55). Hand watering of vegetable gardens is inefficient. Not only does it take many trips back and forth from the water source, but also hand watering does not get the water down to the rootzone. Rather than go through this tedious irrigation process, many growers usually go without vegetables in their diet during the dry season (Reaves, 1995).

An adaptation of the watering can is cited in a case study performed at Chikava, Zimbabwe. It was found that most of the women used large tins to water their plots, which involved bending down to fill the tins from troughs. The women experienced problems watering seedlings with tins as they found it difficult to control the water flow (Chancellor *et al.*, 1999).

2.3.2 Hose pipes

Wherever there is a piped water distribution system, it is possible to connect a hose pipe to a tap or outlet, and, provided there is sufficient pressure in the system as the water emerges from the hose pipe, this can be used with a nozzle to distribute water over a plot of land. A major disadvantage of this system is the cost of the water supply. An 800 square metre plot might require 160 000 litres in a six month irrigation season. This quantity would be equivalent to six months of domestic water for 15 to 20 people in a rural area (Stern, 1979, p 56).

The following are the conclusions drawn from the Institute for Agricultural Engineering's laboratory tests carried out on the use of hose pipes:

- Watering of vegetable plots with an open-end garden hose is feasible where low-pressure water sources are available, and can be reasonably effective and water efficient.

- The cost of the equipment, which would have to be replaced once in a while, is relatively low.
- Although it is required of the gardener to move the hose regularly from bed to bed, the task is not laborious, and it could be done simultaneously with other gardening tasks.
- This method of watering is technically highly efficient since wastage of water due to distribution losses, evaporation, run-off and the application of water to unproductive areas is virtually eliminated (Uys and Scott, 2000).

2.3.3 Sprinklers

Of the various systems of irrigation the sprinkler method is the nearest to natural rainfall. Water, distributed under pressure through pipes, is discharged as a jet or spray into the air over the land to be irrigated (Stern, 1979, p 56).

Overhead irrigation had scarcely been introduced into developing countries before the rise in energy costs limited its adoption. Despite the introduction of low-pressure equipment to offset energy costs, very little sprinkler equipment is found in the developing world (Le Moigne, 1986). In South Africa, sprinkler irrigation is used on irrigation schemes established by development agencies. As it is not recommended on vegetables, sprinkler irrigation is rarely found in community gardens (Crosby *et al.*, 2000).

Maintenance of sprinkler irrigation systems is often neglected in isolated rural areas. Ignorance of the implications for power consumption and possible yield loss due to poor distribution efficiency, often lead to neglect of this aspect (Crosby *et al.*, 2000). Unless the vulnerability of the sprinkler system can be reduced, its applicability remains impractical to farmers with inadequate access to technical support, training services and equipment dealers (Le Moigne, 1986).

A major advantage of sprinkler systems is that farmers can start with a small section of their land and expand the system as they become more proficient and can afford it. Sprinkle irrigation is attractive to small farmers, but can lead to excessive water use.

This is due to excessive system capacity and little understanding of scheduling practices (Magadlela, 1997).

2.3.4 Drip irrigation

Drip irrigation, the most efficient form of irrigation available, now irrigates a little under two million hectares throughout the world. The main obstacle to drip irrigation's wider adoption is its high capital cost (Postel, 1996). This makes the installation of drip irrigation systems prohibitive for the great majority of farmers in developing countries who cultivate less than five hectares.

Vegetable growers in Malawi and increasingly in South Africa are using a low cost application of drip irrigation. A dripper line is connected to the bottom of a bucket, which is hung in a tree to provide the necessary pressure to irrigate a row of crops. The bucket is filled at intervals during the day and the line moved from row to row. This system saves the farmer the trouble of having to water the crops separately by bucket (Crosby *et al.*, 2000). However, a low cost drip system requires more person-hours per day to move the drip lines and keep the emitter holes clear (Polak *et al.*, 2000).

Low cost drip irrigation offers small-scale farmers a practical method of improving irrigation efficiency. As the applications are localised close to the plant root zone, losses through drainage or by wetting between rows and canopies are minimised (Batchelor, 1984). Drip irrigation systems, like other current irrigation technologies, are difficult to customise to meet the needs of small plots of poor farmers. The emitter spacing and discharge rate depend on factors such as the soil and the crop to be grown (Polak *et al.*, 2000). The success of drip irrigation among small-scale farmers depends largely on the successful manufacture of low-cost plastic drip lines which are resistant to weathering and to insect attack (Le Moigne, 1986).

2.3.5 Surface irrigation

Surface irrigation systems are those that supply water to the land at ground surface level. They are also sometimes known as gravity systems because the water flows under the action of gravity and without the use of pumps (Stern, 1979, p 38). Surface irrigation is the predominant method used in the world (Rangeley and Barnsley, 1986).

De Lange (1999) states that surface irrigation is not suitable for all soil conditions, but has a major advantage over other types of irrigation for small-farmers because the entire system can usually be designed to operate at very low running costs with gravity feed, without pumping or any mechanical equipment. Surface irrigation is regarded as more labour-intensive than mechanised systems. However, it is often more suitable where small-farmers live a considerable distance from their fields, as they can travel to the fields once, complete the irrigation in three to four hours, and then return home (de Lange, 1999).

There are three principal surface irrigation methods, namely, basin, border and furrow irrigation (Stern, 1979, p 38). Furrow irrigation is the most widely used method for irrigating row crops. Water flows along small channels (furrows) between the crop rows. It is important to use the right shape and length of furrow and good water management for the method to work efficiently (Kay, 1986).

Experience in Kenya and Zimbabwe has confirmed that, if correctly designed and applied, furrow irrigation can be more efficient in water use than the more conventional (modern) irrigation methods, and is particularly effective where water is a limiting factor. To gain maximum efficiency from furrow irrigation, the slope in the furrows should be perfectly horizontal (Crosby *et al.*, 2000).

2.3.6 Pumps

People have always found it necessary to raise water from a source to supply their needs, their animals and their crops, and throughout the world much ingenuity has been shown in devising appliances to make the task easier and quicker. Pumps both motorised and manual assist in this regard.

Pumping is an important aspect of the delivery of irrigation water, both for individual farms and for schemes. Pumping is particularly important in the case of small-scale independent farmers because there are few areas in South Africa where direct abstraction from rivers is a viable proposition (Crosby *et al.*, 2000). However, a problem has been a lack of maintenance of pumping equipment. In many instances participants perceive this to be the responsibility of the government (Maritz *et al.*, 1998). In some schemes, farmers do not have any knowledge on how the pump is operated because they rely on pump attendants to start and close the pumps (Matshalaga, 1999).

There are two types of motorised pumps; viz. electric- and diesel- powered pumps. Both pumps perform the same task and can provide the same amount of water at a given period (Matshalaga, 1999). However, the small pumps currently available on the market are not very efficient and are too expensive for small farmers to afford. Investigation into the suitability of electric- and diesel- powered pumps is needed, as electricity is seldom available in the rural areas and diesel is expensive (Crosby *et al.*, 2000).

Nigerian farmers have in the past invested in small diesel or petrol pumps, either to draw water from an adjacent river, or from a shallow tube well in the flood plain. Farmers, as individuals or as small informal groups, pay for the well and for the pump. They can recoup their costs in one year of vegetable growing on an expanded plot (Tiffen, 1984). In South Africa, lands that are close to water sources are not being utilised to their full potential due to the high costs of motorised pumps. If low-cost pumps were made available it would significantly increase local production (Chitsiko, 1998).

Human-powered pumps for small-scale irrigation can be important tools for farmers in developing countries where rainfall is often unpredictable and financial resources are limited. However, in most African countries, water-lifting technologies are currently limited to motorised pumps. These pumps are unaffordable and uneconomical for the majority of farmers who irrigate relatively small plots of land (Perry, 1997).

The treadle pump (Figure 2) is a low-cost, human-powered pump. The treadle pump can lift three to five cubic metres of water per hour from wells and boreholes up to seven metres deep as well as from surface water sources such as lakes and rivers.

This flow rate meets the irrigation requirements of most African farmers. The treadle pump employs the user's body weight and leg muscles in a walking motion. Use of the pump can therefore be sustained for long periods of time without excessive fatigue. The treadle pump is less tiring than other manual pumps that utilise the upper body and weaker arm muscles (Perry and Dotson, 2000).

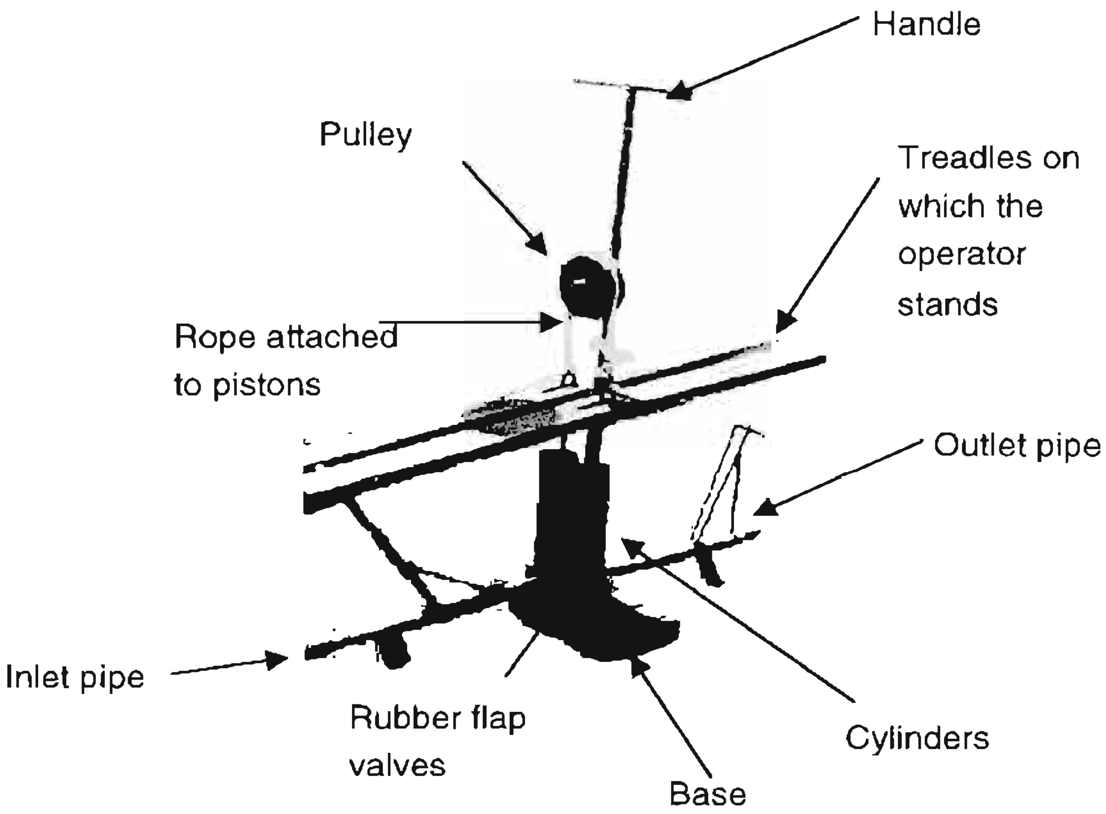


Figure 2. A treadle pump produced in Zambia.

2.4 Discussion

Improved irrigation allows for the increased production of many crops. However, the lack of low-cost irrigation equipment available to small-scale farmers in Africa is hindering their development. The success of emerging farmers is important to the industry, because their growth also represents growth in the irrigation sector.

Small-scale farmers need to be independent in terms of their irrigation equipment as sharing of equipment can lead to disputes. Therefore, technologies need to be at a minimum cost. The technology should offer the farmer sufficient financial return or a reduction in labour demand, to justify the capital investment. Farmers should attempt to sell their produce in order to gain an income. However, the market is often saturated, as many farmers grow similar crops at the same time, resulting in difficulties in selling.

There is an urgent need for water usage to be highly efficient. Irrigators often waste water by applying more than is required or not attending to leaks and other deficiencies in irrigation systems. Technologies therefore need to be produced that will use water efficiently. The bucket drip system is an example of such a technology. Another way to stop water wastage is to force farmers to pay for their water. However, this will lead to another cost for small-scale farmers, many of which are already struggling to earn a profit from farming.

It is vital that the correct crop water requirements for crops grown by small-scale farmers are determined. These differ from commercial crop water requirements, as small farmers do not tend to grow to gain the greatest yields, but often for subsistence. Farmers also require assistance and guidance in terms of the amount of water they should apply and extension workers are necessary for this help.

Extension workers should direct their work towards aiding women as women do most of the farming work in Africa. Their numerous tasks include being mothers and housekeepers, farmers and labourers, and often as entrepreneurs in some form of home industry. Technologies should therefore be geared towards women. If affordable technical innovations in respect of all their tasks are made available and are applied, it could save physical effort and time, which will contribute to the productivity of women.

A vast amount of knowledge and experience on small-scale farming exists in Africa. This knowledge should be shared between countries in order to learn from others' experiences. International technical agencies with world-wide experience of small-scale farming development can be helpful in assisting with the transfer of appropriate knowledge and experience from one country or region to another through workshops, training courses, and the preparation of training materials.
Successful irrigation by small-scale farmers, irrespective of the system or equipment used, can only be achieved using a multi-disciplinary approach, with community participation and the transfer of skills. All sections of the community must actively participate from the planning, design and construction stage, through to the operation, management and maintenance stage of irrigation schemes. Local irrigators could be trained as technicians and facilitators between farmers and suppliers.

Appropriate technologies should have low capital costs. It is important to use local materials where possible as this will decrease costs and increase the accessibility to spare parts. Jobs will be provided if local skills and labour are used to manufacture technologies. The technologies should be user friendly, compatible with local values and preferences and based on traditional methods. It is important that the technologies are easy to operate and maintain at a village or community level. They should ensure minimum dependence on outside help. Technologies should utilise renewable energies such as wind, the sun and animals rather than oil and electricity.

The suitability of an irrigation system is particularly related to the manageability of the system for a specific set of circumstances. The distance from the fields, the priority irrigation farming has in the life of the farmer and the size of the enterprise should all influence the recommendations. In all cases the most suitable choice of equipment should be investigated by the farmers and the irrigation technologist working as a team, with each contributing from their experiences. The final decision on the irrigation technology should be made by the farmers themselves, once enough information exchange has taken place to enable them to make an informed decision.

Successful transfer of technology is dependent on at least three aspects; the availability of the physical technology or equipment; the skills to use the equipment; and the organisational ability and know-how to manage the operation and maintenance.

The introduction of modern technology is sometimes blamed for project failures, but this argument forgets that it is the selection of the most suitable type of technology under the given conditions that is crucial. For example, small-scale irrigation based on pumping may by appropriate where the maintenance, spare parts and fuel can be assured; but in another area where these supporting inputs are not available, the introduction of pumps may result in failure.

The role of the irrigation industry in promoting the development of successful new commercial farmers can be significant, provided designers, manufacturers and suppliers take new farmers seriously and design and supply technology in keeping with their circumstances. However, it is the farmers themselves that ultimately determine whether their farming will be a success or not. Motivated farmers are as essential for irrigation as suitable land, water resources and irrigation technologies.

3. TECHNOLOGY AND SITE DESCRIPTIONS

Mettrick (1993, p 45) states that small-scale technologies should be evaluated, not only in terms of their technical performance in specific environments, but in terms of their conformity with the objectives and capabilities of their ultimate user. A farming systems approach was therefore used in the evaluation of the irrigation technologies selected for this project. The technologies were tested on a field scale as well as a technical level. Mccown *et al.* (1993) state that the testing of potential innovations should be done on farms, with and by farmers. It is essential to recognise that an understanding of the farmers' situation is required when developing technology appropriate to the conditions of limited resource farmers.

Valdes *et al.* (1979) state that the evaluation of new technologies may be attempted in different contexts, depending on certain factors. These factors include who is undertaking the analysis, for what purpose it is being undertaken and whether the technologies are notional, bounded by the imagination of the inventor, or preliminary, the unrefined real products of research. The two contexts of analytic evaluation are the technical side, in the laboratory, and the field side, on the farm. The field side is referred to as the qualitative evaluations throughout the document as it is farmers' opinions that are used in this evaluation process. The technical side is referred to as the quantitative evaluations as technologies are evaluated according to measurable values. It is desirable to avoid confronting the difficulties of the field side analysis until they are unavoidable, and it is for this reason that the technical analysis be carried out to eliminate unsuitable technologies.

However, the problems of the technical analysis stem from the diversity of the target group of small farmers. It has been shown that small-farm systems are characterised by different patterns of resource endowments, production opportunities, skills, beliefs and preferences. Generalised solutions for such systems are almost impossible to achieve, while the number of farms is generally too large to permit analysis of all individual cases. Three main approaches are used to avoid such problems, case studies, representative farms and sample surveys (Valdes *et al.*, 1979). In this project the case study approach was used to evaluate the technologies on the field scale.

This approach will be discussed in more depth in the methodologies chapter (section 4.1).

A description of the technologies selected for evaluation will be given in this chapter. The sites at which these technologies were tested on a field scale will also be described.

3.1 Treadle Pumps

Treadle pumps were originally introduced into Bangladesh in the early eighties by the Rangpur Dinajpur Rural Service as a project of the Lutheran World Service. International Development Enterprises (IDE) a United States based NGO then popularised the technology throughout Bangladesh, Eastern India and Nepal and since then sales have increased to above the million mark (van Koppen, 2000). The unit introduced was suited to lifting water from the shallow wells prevalent in Bangladesh and was simple, cheap and robust. The treadle pump is now gaining acceptance in Africa (Kay and Brabben, 2000). While redesign to allow for local circumstances has taken place, the concept is essentially the same.

3.1.1 A description of the operations and different types of treadle pumps

Treadle pumps can be various shapes and sizes, however, there are essentially two main types, suction pumps and pressure pumps. Suction pumps are designed for lifting large volumes of water from relatively shallow water sources. They are limited to merely raising water from the water source, which is then distributed by means of gravity. Pressure pumps can raise water and then deliver it piped, under pressure to a certain height above the pump. Therefore, pressure pumps can pump water into a header tank or directly into a sprinkler system.

The operation and appearance of both types of pumps is basically the same. Most pumps contain a pair of treadles on which the operator stands. The operator steps up and down in a walking motion. The treadles are joined, either by a rope over a pulley, a chain and rocker system or a centre shaft. This allows one treadle to rise as the operator steps on the other one, lowering it.

Each treadle is attached to a piston, usually made of either rubber or leather cups. The pistons are situated inside two cylinders. The pistons rise and fall inside the cylinders as the operator treadles. The pistons and cylinders have a very close fit so that as the piston is raised a vacuum is created in the cylinder, resulting in a column of water being drawn into it. Non-return valves prevent the water from running back into the inlet pipe. Suction pumps and pressure pumps operate on the same principle. Their main difference is the positioning of the valves.

Suction pumps contain two sets of non-return valves. The first usually consists of a rubber or metal flap, situated at the base of each cylinder. The other set is situated in the pistons. As the piston is raised the cylinder base valve opens and a column of water is drawn into the cylinder, underneath the piston. As the piston is pushed down, the valve in the piston opens and the one at the cylinder base closes. This forces the water through the valve in the piston and into the space above the piston. When the piston is raised again, it lifts this water until it pours out over the rim of the cylinder and into an irrigation channel or tank. At the same time, more water is drawn into the space below the piston. Water is pumped as this process is repeated. Two cylinders allow for the continuous flow of water.

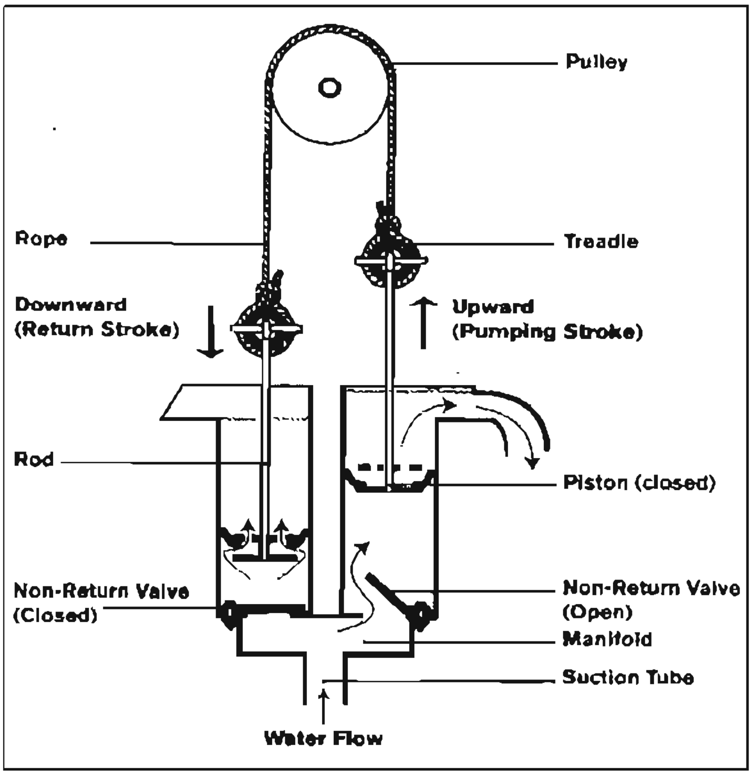


Figure 3. Operating principles of a suction pump (after Kay and Brabben, 2000).

The second set of valves in the pressure pump is also situated at the base of the cylinders, and not in the pistons as with the suction pumps. The area under the cylinder is divided into an inlet and an outlet chamber. The valve attached to the inlet side opens when the piston is raised and closes when the piston is lowered. The valve attached to the outlet side closes when the piston is raised but opens when the piston is lowered. Water therefore enters the pump through an inlet pipe and leaves through an outlet pipe. It is very important that the pistons and cylinders have a very tight fit in the case of pressure pumps. Any air entering the system will reduce the performance of the pump or can stop it from operating altogether. Water is poured onto the top of the pistons so that the pump remains primed while pumping when the seals do not seal effectively.

3.1.2 Materials used and design criteria

Materials used for the cylinders include rolled steel, PVC pipe, concrete and bamboo. The pistons can be made of steel, wood or plastic with leather or rubber cups or o-rings, which form the seal with the cylinder wall. The pump manifold is usually a steel box. The treadles can be made of wood, steel or bamboo. The pulley is usually made of wood.

The sizing of components and careful design is essential to ensure that the pumps work in the most efficient manner. The design involves matching the pump output requirements of discharge and pressure with its mechanical components such as the diameter of the pistons, their stroke length, the weight of the operator and the frequency with which the treadles are pushed up and down. This process of design is made complicated by the wide variations of possible pumping needs of different sites and the wide range and ability of operators who must be comfortable when operating the pump. However, the design also needs to be as simple as possible in terms of its manufacture and maintenance as well as affordable to poorer farmers.

3.1.3 Tested pumps

A selection of pumps was chosen and imported from various countries to carry out the field and laboratory evaluations. This was in order to gather sufficient information on foreign pumps before a South African design was attempted. These imported pumps were also used to establish an initial market survey to see whether or not such a technology would be appropriate for South African circumstances. Table 1 summarises the origin of the pressure pumps and Table 2 the suction pumps. The pumps will be referred to as the name presented in these tables throughout the rest of this document. Appendix A contains the details of the manufacturers and promoters of the evaluated pumps.

Table 1. A summary of the pressure pumps evaluated in the project.

Pump	**Platform Pump**	**Modified Masvingo**	**Super Money-Maker**	**Zambian Pressure**
Country	Swaziland	Swaziland	Kenya	Zambia
Manufacturer	New Dawn Engineering	New Dawn Engineering	Approtec	I DE
Name	Platform	Swazi	Approtec	Zambia P

Table 2. A summary of the suction pumps evaluated in the project.

Pump	**Zambian Suction**	**Swiss Concrete Pump**	**KB Treadle Pump**	**Bamboo Suction Pump**
Country	Zambia	South Africa	India	Nepal
Manufacturer	IDE	BRD Engineering	Shree S.K. Industries	IDE
Name	Zambia S	Swiss	KB	IDE

The Swazi pump (Figure 4) is based on the Masvingo pump design from Zimbabwe but includes a few modifications. The inlet and outlet pipes run perpendicular to the treadles and the base has been adjusted for better stability. The pump has two single-acting cylinders. The pistons consist of leather cups mounted back to back on steel plates. They are joined with a rope, which runs over a steel pulley. The treadles are wooden planks. The Swazi pump has a handle, which is held in place with two lock nuts and can be removed. The valves are mounted internally at the base of the cylinders and can be accessed by undoing wing nuts, which hold the cylinders and base plate together. They consist of steel plates with 12 slotted holes drilled in each of them. This also differs from the Masvingo design, which consists of smaller round holes. The area of the Swazi pump's valves is therefore 20 percent larger than the Masvingo's valves, offering less resistance to the water flow. Each plate has two rectangular rubber flaps attached to it, one on the upper side and one on the underneath side, forming four non-return valves. The pump can either be operated by one operator or two, depending on the mass of the operators. If two operators are pumping, one stands on either side of the handle.

Figure 4. Swazi treadle pump.

Figure 5. Platform pump.

The second of the two Swaziland pumps is the Platform pump (Figure 5). The Platform pump was modified from the original treadle pump design. It consists of a single, double acting cylinder mounted on a base. The cylinder can be placed in three different positions. The settings adjust the mechanical advantage of the pump depending on the weight of the operator and the pumping head. The first setting has a lower mechanical advantage but gives a greater volume at lower heads. The volume decreases as the mechanical advantage increases on settings two and three. A piston consisting of two leather cups mounted back to back on a steel plate moves up and down inside the cylinder as the operator rocks from side to side on a platform, which moves in a similar motion to a see-saw. The top of the cylinder is bolted to the cylinder and contains a sealed hole allowing the piston rod to move up and down.

Four non-return valves are externally mounted. They are made from modified fence post caps and contain a steel plate with holes drilled into it welded inside. A circular rubber flap is bolted onto one side of the plate forming a non-return valve. The valves are joined to the cylinder and the inlet and outlet pipes with small sections of reinforced helix pipe, which has been clamped in position. The platform is a wooden plank with pieces of wood bolted onto each end to prevent the operators' feet from slipping off.

The Zambian pumps are made entirely from steel except for the treadles and pulley, which are wooden. A rope positioned over the pulley attaches the treadles to one another. The cylinders are made of rolled steel, which is welded in place and therefore contain a seam. The cylinder section of the pressure pump (Figure 2, p 23) is bolted to a base plate. The suction pump's cylinder section is welded together. The pressure pumps have a handle, which is held in place with a lock nut. The suction pumps (Figure 6) do not come with a handle. The valves of the pressure pumps consist of rubber flaps positioned on either side of a plate with holes drilled into it. The first set of suction pump valves is positioned at the base of the cylinders. They are plastic and can be removed. The piston cups of both pumps are rubber and are bolted to a circular steel disc in the case of the pressure pump.

Figure 6. Zambian suction pump.

The Approtec pump (Figure 7) from Kenya is made entirely from steel. The cups used for the pistons are made from rubber. The Approtec pump replaces the rope and pulley system of the Swazi and Zambia P pumps with a chain and rocker system. The cylinders are shorter and have a larger diameter than most other pumps. They are joined at the top allowing water to flow between them. The treadles are made of steel and are Z-shaped, placing the operator closer to the ground. The bearings at the different rotation points are made from plastic. The pump also contains a handle, which slides into position and can be removed. The area under the cylinders is completely welded together. The valves are circular rubber discs held in position over a single hole cut in the base of the cylinder. The pump is sold with a foot valve. It is similar to the valves at the base of the cylinders and contains a netting mesh used as a strainer.

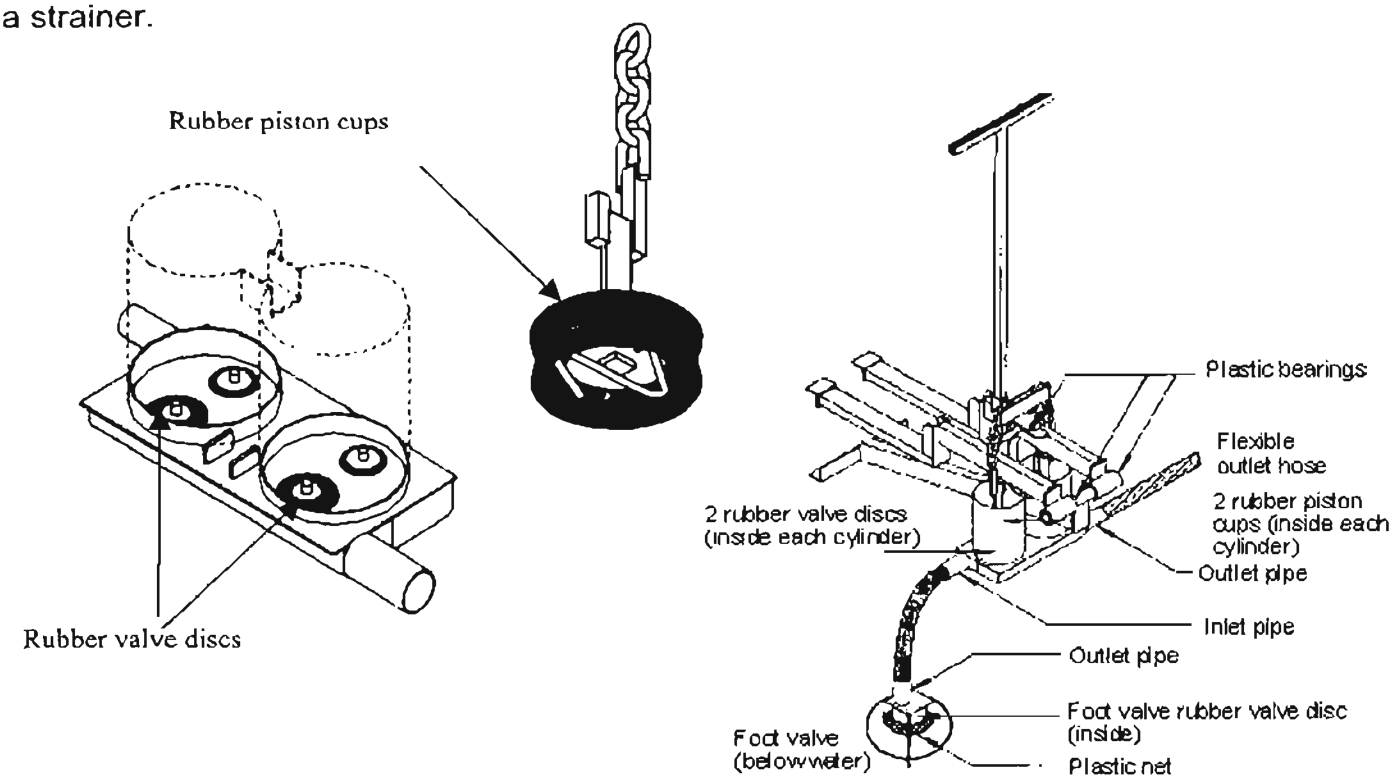


Figure 7. Components of the Approtec pump.

The KB treadle pump's design is based on the original treadle pumps introduced into Bangladesh by IDE but contains a few modifications. The frame is made entirely from steel. The piston cups are made from rubber. A shaft connects the two treadles. The treadles are V-shaped at the end and the operator stands on a steel cross bar. The pump stands on four steel legs. A circular rubber flap bolted to the cylinder acts as a non-return valve at the base of each cylinder. The pump does not come with a handle and the operator should erect a bamboo or wooden frame for support.

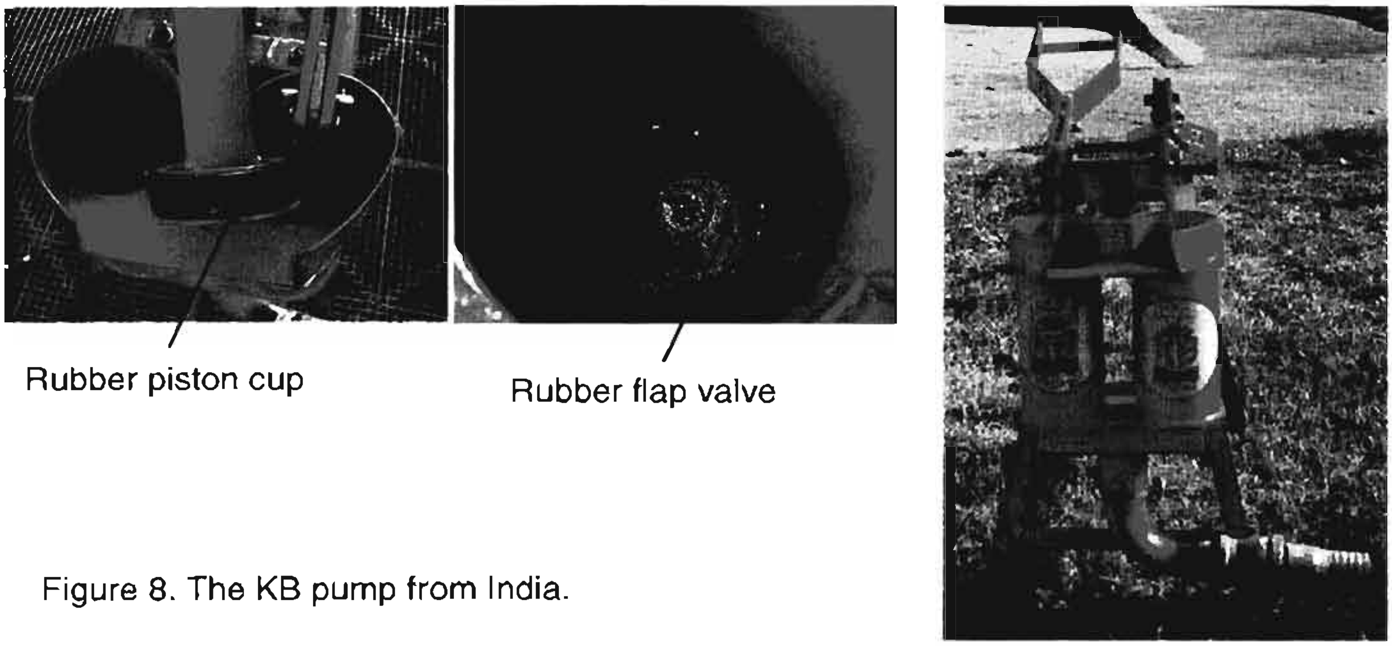


Figure 8. The KB pump from India.

The IDE suction pump (Figure 9) is sold in Nepal as just the cylinder and piston mechanism. The operator then builds the frame out of bamboo. The frame was built out of steel square tube for testing purposes, as bamboo is not readily available in South Africa. The treadles are mounted on a centre pole with a shaft. The long bamboo treadles usually act as a counterweight eliminating the need for a pulley or rocker system. Weights were mounted on the scrap metal treadles as they were shorter and therefore required additional counterweights. The piston cups are rubber. The non-return valves at the base of the cylinders consist of a metal flap placed on a rubber seal. The water spills over through a shaped spout when it reaches the top of the cylinders.

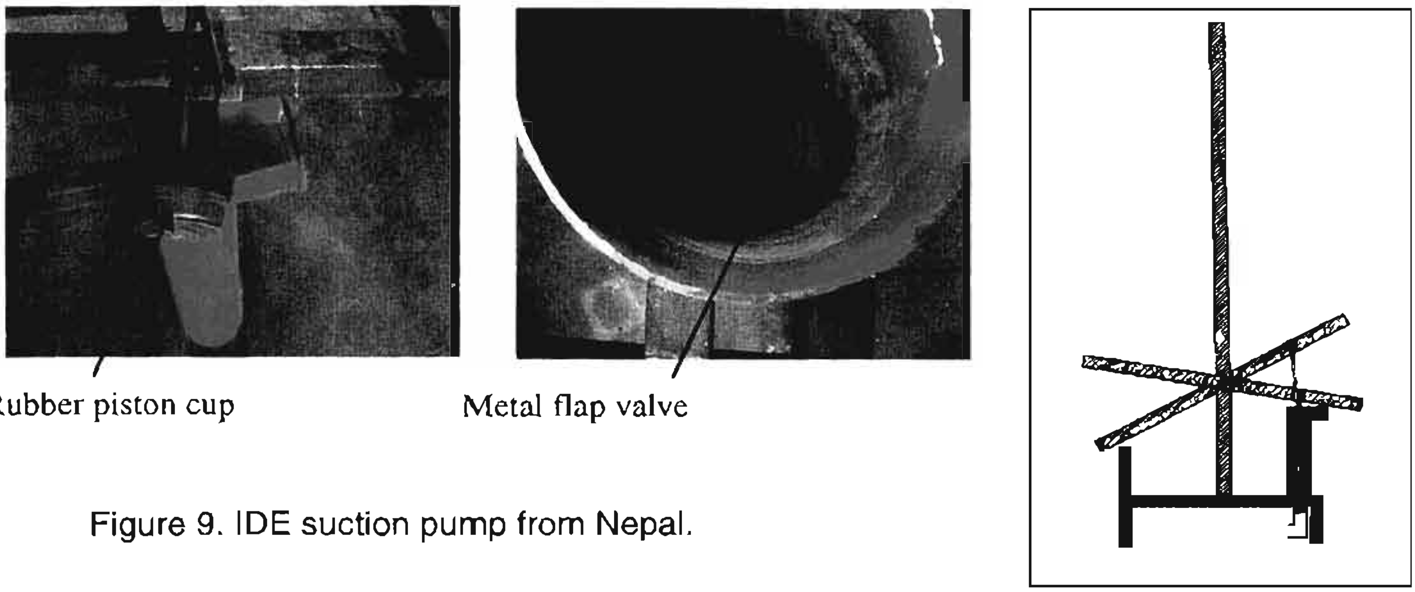


Figure 9. IDE suction pump from Nepal.

The pump evaluated from South Africa is based on the Swiss concrete pump design and is therefore referred to as the Swiss pump (Figure 10). It is a suction pump, and consists of two sets of valves, one positioned in the pistons and the other at the base of the cylinders. The Swiss's cylinders are made of uPVC pipes, encased with concrete to hold them in position. The rest of the pump is held together by a steel frame. The treadles are made from wood. The pistons' seals consist of small pieces of hose pipe held in a circle by short pieces of electrical cable and positioned on circular steel plates. As the piston is raised, water is drawn into the cylinder as the hose pipe seals against the cylinder walls. When the piston is lowered, the water passes between the circular hose pipe and the cylinder wall, positioning itself on the upper side of the piston. On the next rise of the piston, the water at the top is raised and spills over onto the concrete. The valves at the base of the cylinders consist of circular rubber flaps, held in position by two short pieces of steel bicycle spokes. These flaps lift on the up stroke allowing water to pass into the cylinder, but seal on the down stroke, forcing the water to the upper side of the piston, therefore preventing it from flowing back into the inlet pipe. A shaft mechanism on the under side of the treadles joins them together, raising one when the other is lowered.

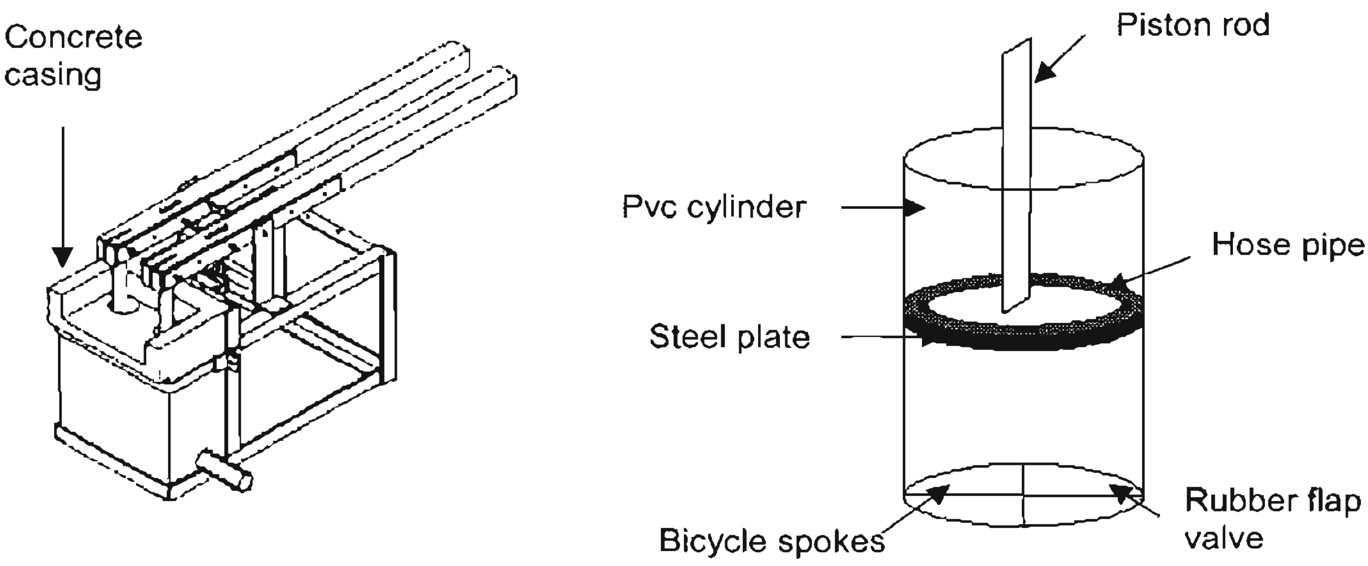


Figure 10. Swiss concrete pump, cylinder and valve mechanism.

3.2 Low Head Drip Irrigation Kits

Low head drip irrigation kits are usually available in two different types. The bucket kit consists of a 20 litre bucket with a hole in the bottom, attached to a filter and two dripper lines. The drum kit consists of a 210 litre drum attached to a filter and several dripper lines. The bucket or drum is mounted about a metre above the ground, the water movement through the drip lines worked through simple gravity. Water flows through the filter and then through the drip lines to the row crops placed at the emitters. The bucket kits are usually filled twice a day and the drum kit once, depending on the crop, climate and soil conditions. The water used should be clean, preferably from a river, dam, well or rain water collected from roofs. If dirty water is used, most kits require extra filtration by pouring the water through a cloth. The drip tape is installed with the emitters facing upwards in order to avoid clogging by dirt.

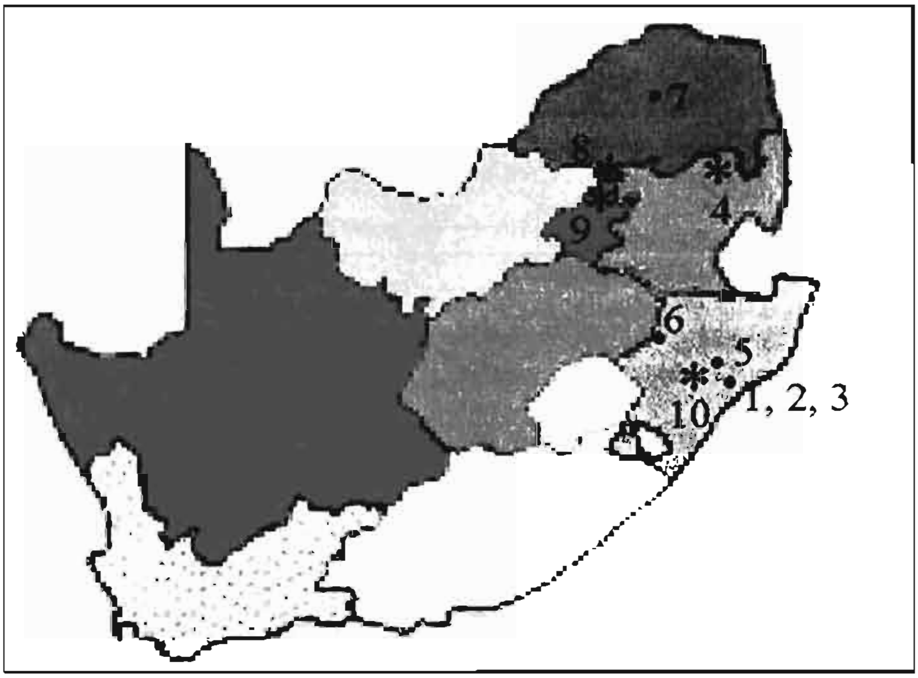
Different promoters use different materials for drippers and filters. Chapin Watermatics uses dripper tape and a mesh filter attached to a rubber stopper. IDE use thin piping for the main line and laterals attached to thin spaghetti tubing used as drippers. Their filter is also a mesh fitted into a plastic holder, which attaches directly into the pipe. ARC's Institute for Viticulture and Oenlology in South Africa promote a low-cost system consisting of 15 mm class 3 polyethylene pipes with holes burnt with a nail at 300 mm intervals. Nylon string is then tied through the holes allowing the user to unblock them. Stones and sand placed in the drum act as the filter for the system, which can handle dirty or soapy water.

Another form of drip tape available in South Africa is known as Wetpipe. It is a porous pipe made out of rubber from old car tires. When filled with water, the pipe leaks slowly due to its porosity. A bucket kit was made up using Wetpipe instead of dripper tape to evaluate its efficiency in practice.

3.3 Site Descriptions

Before new technologies can be introduced on any scale they should be tested at the farm level under local constraints by farmers themselves. However, to implement this, a sample of farmers must be identified to perform these on-farm trials. This process of farmer selection should not be underestimated as it significantly affects the results of the on-farm trials.

Farmers that were already farming, both individually and those farming in community gardens, were selected for the evaluations. The gardens were chosen according to their positioning relative to the water source, their size and the crops that were being grown. The farmers were chosen according to their knowledge of farming practices, their ability to communicate, their willingness to co-operate and their current irrigation techniques. Figure 11 is a map of South Africa showing the sites used for the field evaluations of the irrigation technologies. The sites used for qualitative evaluations and those used for quantitative tests are shown differently.



- Quantitative sites
- Qualitative sites

1. Silwayiphi
2. Siyazama
3. Thuthukani
4. Boschkloof
5. Winter Roses
6. Burford
7. Sepitsi
8. Kwaggafontein
9. Tshepo's homestead
10. Ukulinga

Figure 11. Map showing the sites used for the qualitative and quantitative evaluations of the irrigation technologies.

3.3.1 Qualitative sites

Silwayiphi is a community garden on the bank of Inanda Dam near Hillcrest in KwaZulu-Natal. There are about 25 farmers farming in the garden. They have been farming there for about six years. The garden is approximately three hectares in size. Each farmer has a plot of about four metres width and 15 metres length. A number of different vegetables are grown there. The farmers are not able to sell their produce, as there is no market because most of the people in the area grow vegetables.

Siyazama is an individually owned garden on the bank of Inanda dam. The garden was started at the beginning of the year 2000. Initially, only about half of the half hectare area was being cultivated. After the installation of a treadle pump, the farmer cleared and planted the rest of the area. The farmer grows vegetables, which are mostly used for family consumption and a few are sold to neighbours. The garden is fenced with thorny bushes but the farmer has problems with cattle and goats getting in and eating the vegetables.

Thuthukani is a community garden situated near to Siyazama. There are currently seven farmers farming individual plots in the 1.5 hectare garden. The farmers mentioned, however, that other farmers who had stopped farming would be returning the following season after a Zambian P pump was installed in the garden, making it easier to transport water. The farmers have been farming there for about eight years. The farmers were previously walking to the dam to fetch water and carrying it back to their plots to water by hand. The garden is situated about 40 metres from the water. It is fenced with a wire fence and has a gate, which the farmers lock with a padlock.

Winter Roses is a community garden situated at Table Mountain, on the outskirts of Pietermaritzburg. It is about two hectares in size. The Department of Agriculture in KwaZulu-Natal placed a sprinkler system in the garden, but it was proving too expensive for the farmers to run as the water is primary water and the farmers have to pay for it themselves. The farmers irrigate twice a week, on a Tuesday and a Friday. They used the sprinkler system on Fridays and irrigate by hand on Tuesdays. Two bucket kits, one IDE and one Chapin model, were placed in two of the farmers' plots.

Burford is a community garden situated next to a small perennial stream near Ladysmith in KwaZulu-Natal. A group of ten farmers started working together in 1999. Due to the hard work experienced whilst fetching water from the stream, two members withdrew from the group. Before the garden obtained the Approtec pump from Kenya, they were only producing crops during the rainy season and were only using a small section of the three quarter hectare garden.

Sepitsi is a community garden situated near Lebowagomo in the Northern Province. It is ten hectares in size and there are currently 102 farmers, both men and women, farming on small plots of about 0.1 hectares each. There were initially 134 farmers when the garden began in 1997 but some have left. A variety of vegetables are grown all year round, the most popular being tomatoes. The water source is the Olifants River from which water is pumped with a diesel pump. The farmers pay for the diesel themselves with income from selling some of their produce. They irrigate using furrow irrigation. The University of the North is involved with the training of farmers.

3.3.2 Quantitative sites

Boschkloof is an irrigation scheme situated in the Northern Province. It is currently being assessed for rehabilitation. A canal, fed by the Steelpoort river, runs through the scheme and is the water source for most of the farmers. Most of the farmers on the scheme grow maize, some of which is for family consumption and the surplus is sold. A Zambian S pump was given to the chairman of the scheme. He has a plot of about half a hectare, which he was unable to farm as it is above the canal. A set of trials involving pumping with treadle pumps as a means of delivering water into furrows for furrow irrigation were carried out at his plot.

A community garden near Kwaggafontein in the Northern Province was also used as a case study site for the treadle pumps. The garden is about three hectares in size and there are approximately 50 farmers that are currently growing vegetables on small plots. The farmers sell some of their produce to a nearby market. The garden is about 100 metres from a small perennial stream. The farmers have dammed the stream on the higher side of the garden. They have dug small earth canals to divert the water from the stream. These canals run through the garden. The canals sometimes dry up in the winter season. The farmers are all currently watering by hand. They fetch water in large buckets and containers and then carry this water back to their plots. They then scoop the water out of these containers with smaller containers, usually cans, with holes punched into the bottom. They move these cans over the plants to irrigate them.

A homestead situated near Pretoria was used to evaluate other applications of the treadle pumps. The owner currently grows vegetables in a small kitchen garden situated near her house. She irrigates these vegetables using water that is stored in a tank in the ground. This water is recycled from the kitchen and bathroom and is known as grey water.

The University on Natal's research farm, Ukulinga, was used to set up the drip irrigation kits for monitoring. The kits were compared to other methods of irrigation commonly used by small-scale farmers in South Africa. These methods were hand watering using a watering can and a bottle drip system. This method uses two litre plastic cooldrink bottles with a small hole drilled in the bottom, and placed randomly in a small vegetable garden. The bottles are half buried. They are then filled with water, which leaks out slowly through the small hole and enters into the ground at the root level. Tensiometers were used to monitor the water movement in the ground from the different systems. A description of this set up will be given in section 4.6 in the methodologies chapter.

4. METHODOLOGIES

The irrigation technologies were evaluated on two different levels, qualitatively, by farmers in the field, and quantitatively, in the laboratory. The qualitative evaluations were done initially to establish whether or not the technologies would be accepted by farmers in South Africa. It would have been unnecessary to carry out extensive laboratory tests and design procedures if farmers were not going to use the techniques. It is for this reason that the qualitative methodologies are presented before the quantitative methods in this chapter and throughout the remaining document.

This chapter will begin with a description of the case study approach. This approach together with the FSRE approach was used as a basis for the qualitative evaluations. Due to limited time and manpower the steps could not be followed exactly but were merely used as a guideline. The following sections presenting the methods used to evaluate the treadle pumps and drip kits will be separated according to qualitative and quantitative assessments. The chapter will conclude with a description of two new prototype treadle pumps that were designed and built following the test phase of the imported pumps.

4.1 The Case Study Approach

On-farm trials were used together with the case study approach to meet the original aims of the project to evaluate the technologies on farms and by farmers. Valdes *et al.* (1979) state that in the case study approach a few farms are chosen, not so much for their representitiveness as for their suitability for analysis. The justification for the case study approach is that, from an intensive study of one or a few cases, insights of general or widespread relevance to the population of farms may be gained. Any unusual features of the particular farm studied are accepted and accounted for in interpreting the results. The contextual problems of evaluating technology for small farms are severe. It is accepted, however, that a partial, incomplete and inadequate analysis is better than no analysis at all. The on-farm trials were conducted within the framework of the (FSRE) methodology, which is explained in section 2.2.1.

Initial PRA work was carried out at a few selected sites in order to gain familiarity with the practical situations and the needs of small-scale farmers in South Africa. A questionnaire was used as a guide. A number of organisations both governmental, non-governmental and commercial were also visited in order to establish their roles in assisting farmers. The questionnaire and answers given by farmers as well as a summary of the meetings held are presented in Appendix B.

4.2 Treadle Pump Qualitative Assessments

The initial imported treadle pumps were placed at various selected gardens in KwaZulu-Natal and the Northern Province.

One of the Zambia S pumps was placed at Silwayiphi community garden. Due to the layout of the garden, it was decided that the farmers would continue to water with buckets and the pump would merely assist in transferring the water from the dam to a 210 litre drum placed in the centre of the garden. However, as the pump is a suction pump, it was necessary to raise it above the height of the drum so that the water would spill over into the drum. A platform was built out of wooden gum poles and the pump was attached to a pallet, which was attached to the poles. The platform was about a metre above the ground. The pump was placed about 30 metres from the water's edge and raised the water to a total height of about three and a half metres. This set up can be seen in Figure 12.

After about three months it was found that the farmers were not using the pump as it was too high off the ground and they were scared to climb onto the platform. The pump was taken off the platform and moved further away from the water source. It now drew water a distance of about 50 metres and height of five metres and then gravity fed the water back through a pipe into a drum. Figure 13 shows the second set up of the Zambia S pump.

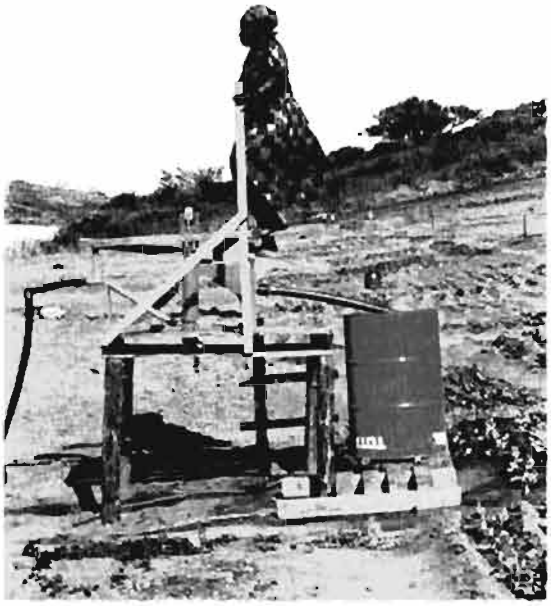


Figure 12. The Zambia S pump on the wooden platform.

Figure 13. The Zambia S pump placed on the ground.

One of the Zambia P pumps was placed at Siyazama. The pump raised the water a distance of ten metres and a height of half a metre. It then delivered the water to a 210 litre drum placed 30 metres away from the pump with a two metre height difference. After a month of using the pump to fill the drum, the farmer made a hose pipe connector out of an old plastic bottle which he had punched holes into the bottom of. He then used this to spray his vegetables while his wife pumped.

The other Zambian P pump was placed at Thuthukani next to the gate on the inside of the fence. It drew water to a height of about six metres. The pump was about 40 metres away from the water source. It then delivers the water into three, 210 litre drums placed ten metres from the pump and one metre higher than the pump. Figure 14 shows a farmer pumping the Zambia P pump.

Figure 14. A Zambia P pump at Thuthukani.

One of the Approtec pumps was placed at the community garden at Burford. The pump was positioned just inside the garden's fence but was still taken home every evening. It raised the water to a total height of about four metres, and then filled a 210 litre drum placed in the centre of the garden. The pump was positioned about 20 metres from the stream, and the drum a further 30 metres from the pump.

4.3 Treadle Pump Quantitative Assessments: Laboratory Tests

A good treadle pump must satisfy many criteria. It must be effective or efficient, durable, portable, adaptable over a range of users and delivery heads, easy to clean and repair, easy to install and start. The amount of water that can be pumped by a treadle pump depends on the pump efficiency, the total head and on the physique of the operator. It is not practical to replace human operators for testing purposes by calibrated motors or engines, so test procedures must accommodate the variability of a person as a power source.

The Consumers Association Testing and Research has set out a "Guideline Test Procedures for Testing and Development of Handpumps" (1983). The standard test procedures include issues such as ergonomics and endurance, however, it doesn't take into account the operator. This is an essential criterion in the testing of human powered pumps.

The methods used to evaluate the treadle pumps under laboratory conditions in this project are based on a combination of methods used by Lambert and Faulkner (1991) and others suggested by Thomas (1993). The tests were carried out in January 2001 at the Institute for Agricultural Engineering's hydraulics laboratory in Pretoria. They aimed to provide the scientific and engineering background for introducing treadle pumps into South Africa by quantifying the performance of selected treadle pumps in terms of efficiencies, both mechanical and ergonomic. Six treadle pumps from various countries were tested. These included three suction pumps and three pressure pumps. Table 3 summarises the dimensions of the pumps that were tested. All the dimensions are given in millimetres unless otherwise stated.

Table 3. Dimensions of the treadle pumps tested in the laboratory test phase.

PUMP	Platform	Swazi	Approtec	Swiss	KB	IDE
Treadle length (mm)	991	1350	790	1000	680	1100
Treadle width (mm)	230	95	60	60	120	50
Treadle height above ground (mm)	600	540	175	400	580	529
Handle height (mm)	-	1443	1200	-	-	-
Cylinder length (mm)	310	295	155	220	185	313
Cylinder diameter (mm)	104	104	121	100	89	89
Inlet pipe diameter (mm)	50	50	32	40	32	38
Outlet pipe Diameter (mm)	50	50	25	-	-	-
Outlet spout width (mm)	-	-	-	240	130	100
Maximum length (mm)	1240	1350	800	1075	730	1100
Maximum width (mm)	780	1000	400	400	355	800
Pump mass (kg)	51	47	21	62	23	5.4*
Selling cost	E 800	E 1000	5490 KS	1500	RS750	NRS 450
Equivalent selling cost in Rands (2001)	800	1000	544	1500	130	48

* Mass of cylinder and piston mechanism without frame.

4.3.1 The operators

Three operators, two females and a male were selected to carry out the tests. They were chosen according to their different weights, ages and fitness levels. Table 4 provides a summary of the different operators used. They will be referred to as operator A, B and C as shown here throughout the rest of the document.

Table 4. The operators used for the treadle pump tests.

	Operator A	Operator B	Operator C
Name	Sophy Moropa	Bennet Moaka	Lettie Maseko
Gender	Female	Male	Female
Age	31 years	39 years	40 years
Mass	94.48 kg	76.00 kg	67.72 kg
Height	1.6 m	1.7 m	1.5 m

4.3.2 Laboratory set up

The laboratory (Figure 15) contains a sump of ten metres depth. Water was pumped from this sump. The water level was monitored and was kept constant by opening a valve to allow water to flow into the sump during pumping. A powered pump was submerged in the sump and was used to drop the water level to different depths. A 50 mm diameter, class 6, high density polyethylene pipe of 15 metres length was used as the inlet pipe for all the pumps. A foot valve was attached to the inlet of this pipe.

A pressure pump was placed on the ground, about four metres from the sump, during testing. The outlet pipe, a 50 mm diameter, class 3, low density polyethylene pipe of 15 metres length, was attached to the outlet side of the pumps. The other end of the outlet pipe was attached to a ventilated goose-neck, which was attached to an eight metre high ladder, placed outside the laboratory. This enabled the delivery heights to be adjusted. The ventilated goose-neck contains an open end, preventing water from siphoning through the pipe. Water flowed from the goose-neck through another pipe into a 210 litre drum placed on the ground.

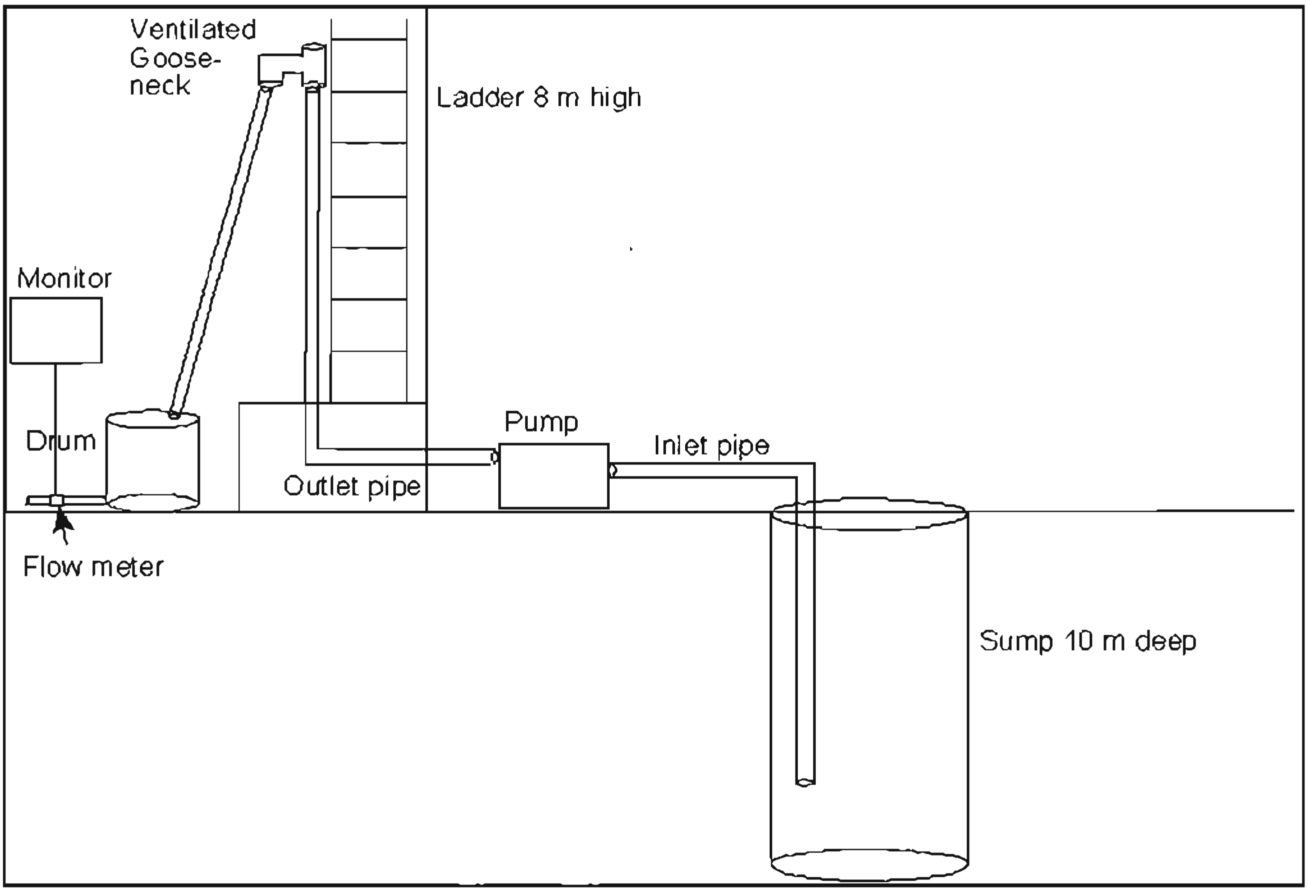


Figure 15. The laboratory set up for the pressure pumps.

The suction pumps were placed on a table of 800 mm height during the duration of their tests. The drum was placed next to the table, underneath the spout of the pumps. The Approtec, Swiss, KB and IDE pumps' pipe connections were adjusted to fit a 50 mm diameter pipe. A flow meter was attached to a pipe connected to the bottom of the drum. The flow meter was also attached to a monitor. Graphs of flow against time were plotted as the operators pumped. The flow meter also recorded the volume of water that was pumped during each session.

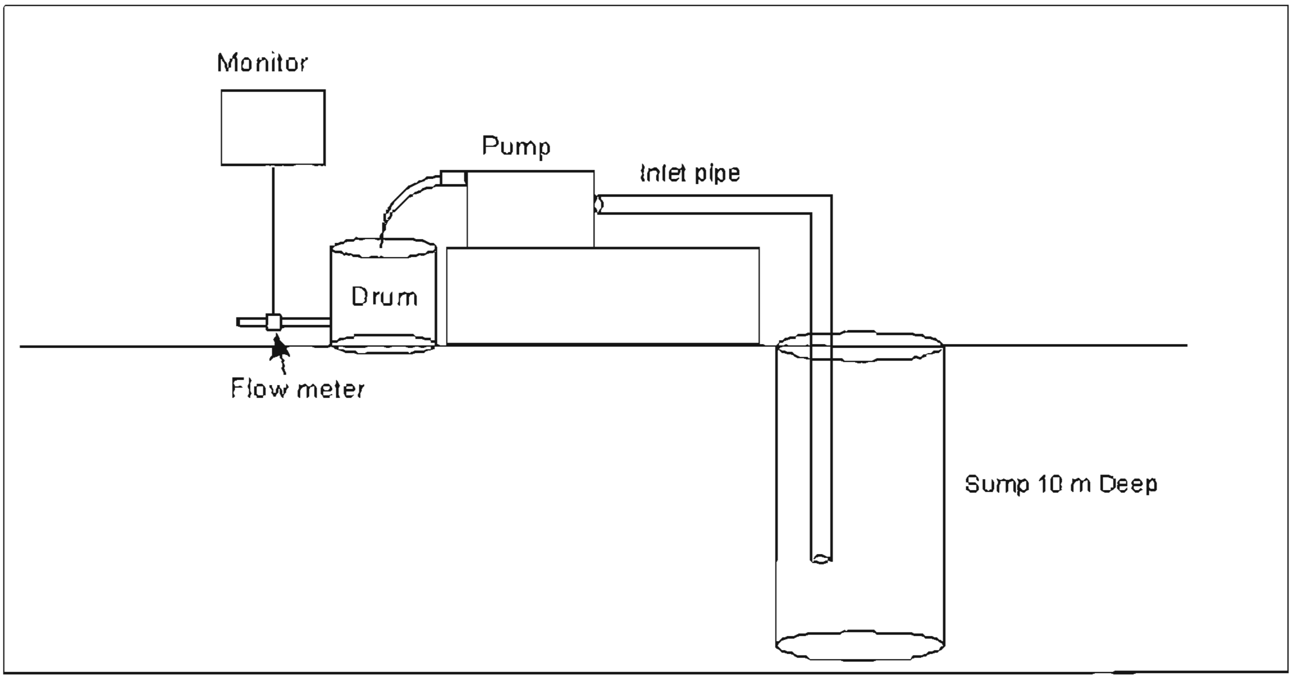


Figure 16. The laboratory set up for the suction pumps.

The tests took place at an altitude of 1350 metres above sea level. The results obtained would differ at lower altitudes as the maximum suction head depends on atmospheric pressure. Atmospheric pressure is approximately ten metres head of water at sea level, the theoretical maximum suction value. A more realistic value is about seven metres due to friction losses in the suction pipe and the effort required to create a vacuum under these conditions. The theoretical value at an altitude of 1350 metres is about eight and a half metres, and this would also decrease due to friction losses.

4.3.3 Visual analysis

A visual analysis was carried out before the testing began. The Platform, Swazi, Swiss and IDE pumps were all new and did not contain any corrosion. The Approtec and KB pump had both begun to rust on the inside of the cylinders. All the bearings of the pumps appeared in order except for the Approtec pump where the right hand treadle bearing was slightly stiffer than the left one A leakage test was performed on all the pumps except the Platform pump. The inlets and outlets of the pumps were blocked and water was poured into the cylinders. No leaks were detected on any of the pumps.

4.3.4 Operators' calibrations

The operators were each calibrated in order to determine their input power. The calibrations took place at the University of Pretoria's Department of Biokinetics. They took place in an air-conditioned room, at a lower temperature than the laboratory where the pump tests took place. Each operator was asked to peddle an exercise bicycle for six minutes. The resistance of the bicycle was initially set at 50 Watts. After three minutes, the operator's heart rate was recorded with a Polar heart monitor. The resistance was then increased to 75 Watts and the operator peddled for another three minutes. The heart rate was again recorded.

The determination of input power for the Swazi pump differed from all the other pumps. This was because the Swazi pump provided a higher resistance for the operator and the cadence values were therefore very low. This meant that the operators' heart rates remained low as they were pumping by merely shifting their weights from side to side instead of using their muscle power on the pumps. It was therefore decided to determine the input power from the weight of the operators rather than their heart rates.

The distances of the operator from the pivot point, L_1, and the pistons from the pivot point, L_2, were used to equate moments. Therefore,

$$mg\,L_1 = F\,L_2 \qquad \text{Equation 1}$$

where m is the mass of the operator, g is the acceleration due to gravity, 9.81 m/s^2, and F is the force acting on the piston. Equation 1 can be used to solve for F. The work done on the pistons, W, is a product of force, F, and displacement. Therefore,

$$W = Fs \qquad \text{Equation 2}$$

where s is the stroke length. Using equation 1 and equation 2,

$$W = \frac{mgL_1s}{L_2} \qquad \text{Equation 3}$$

Power can be calculated by dividing the work done on the pistons by the time taken to complete one stroke, t_s, where,

$$t_s = \frac{60}{\text{average no. of strokes}} \qquad \text{Equation 4}$$

Not all the operators' weight is put on one of the treadles at once and a factor of 0.8 was therefore introduced as it was assumed that approximately 80 percent of the weight was utilised. The input power for the Swazi pump was then calculated using the following equation:

$$P = \frac{0{,}8.m.g.L_1.s.\text{no of strokes}}{L_2.60} \qquad \text{Equation 5}$$

4.3.5 Friction loss

A pressure gauge was attached to the inlet pipe of each pump. The outlet pipe was not attached to the pressure pumps. Water was then pumped with a motorised pump through the inlet pipe of the treadle pump. The treadles were held level as the water passed through the pumps. The pressure at various known flow rates was recorded. A valve was opened to increase the flow rate. The first pressure reading was recorded just as the water started flowing out of the treadle pump. From these values, a friction loss curve was plotted for each pump.

4.3.6 Maximum flow rate

The maximum flow rate was measured at a suction depth of one and a half metres for each pump. The outlet pipes were not attached to the pressure pumps. Each operator was asked to pump for 40 seconds to obtain the maximum flow rate. This was not necessarily as fast as they could treadle as this caused the water to spill over the top of the cylinders of the suction pumps. The number of strokes was counted and the volume of water pumped recorded. The test was repeated and an average of the values was taken. A maximum flow rate for each operator for each pump was then calculated by dividing the volume obtained by 40 seconds.

4.3.7 Mechanical efficiency

The mechanical efficiency of a treadle pump can be approximated as:

$$\eta_{mech} = \frac{W_{in} - W_f}{W_{in}} \qquad \text{Equation 6}$$

where W_{in} is the input power and W_f, the power required to overcome friction. Power is measured as the product of force and speed. Since the speed is the same for both useful forces and for friction forces,

$$\eta_{mech} = \frac{F_{in} - F_f}{F_{in}} \qquad \text{Equation 7}$$

provided both input force, F_{in}, and friction force, F_f, are measured at the same place (Thomas, 1993).

The input force was measured at the end of each treadle where the operator stands. The pump was connected to a four metre head and the weight to move the treadles was recorded. The friction force was then measured at the same point on the treadle with the pump head reduced to zero.

The positioning of an operator relative to the pistons of a treadle pump is based on the lever principle. When an operator is standing on the treadles immediately above the pistons, the pushing force is directly transferred to the pistons. An operator's downward force of say 300 Newtons (30 kilograms) thus transfers directly a force of 300 Newtons to the piston. If the operator moves away from this position and increases the distance from the pivot point of the treadles, a greater force can be applied to the pistons. The converse is also true. If the operator moves to reduce the distance from the pivot to 0.8 metres, the downward force on the piston reduces to 240 Newtons. This ratio of the distance of the operator and the piston from the pivot point is known as the mechanical advantage (Kay and Brabben, 2000).

4.3.8 Sustainable flow and heads

The operators were each asked to treadle for ten minutes at various combinations of suction heads and delivery heads for the pressure pumps and various suction heads for the suction pumps. The heights were determined according to the different pumps as not all the pumps could pump the same heads. The height of the table, 0.8 metres, was included in the suction heads for the suction pumps. The number of strokes were counted and recorded after each minute of pumping. The operators' heart rates were also recorded every minute. Table 5 shows a summary of the various heads that were used.

Table 5. Suction and delivery head combinations, in metres, used for tests.

PUMP	Suction	1		2		3		4		5		6	
PLATFORM	Delivery	2	6	2	4	2	4						
	Total	3	7	4	6	5	8						
SWAZI	Delivery	2	6	2	4	2	5	1	2				
	Total	3	7	4	6	5	8	5	6				
APPROTEC	Delivery			1	4			1	3			4	7
	Total			3	6			5	7			10	13
SWISS	Suction			2.8		3.8				5.8			
KB	Suction			2.8		3.8		4.8					
IDE	suction			2.8		3.8				5.8			

4.3.9 Pump efficiency

The efficiency of a treadle pump can be defined as the ratio of the output power and the input power. This was calculated using the following equation:

$$\eta_{pump} = \frac{\rho.g.Q.H}{\text{operator power}} \qquad \text{Equation 8}$$

where, ρ is the density of water, 1000 kg/m^3, g is the acceleration due to gravity, 9.81 m/s^2, Q is the average flow obtained during the ten minutes of pumping, m^3/s, and H is the total head that was pumped, m. The operator input power was determined using equation 5 for the Swazi pump and the calibration curves obtained from the heart rates for all the other pumps.

4.3.10 Adjustments during pumping

The Platform pump required adjustment before it would operate. The reinforced helix pipe on the suction side was changed to 50 mm, class 3 polyethylene pipe and reclamped with wire clamps. This was because the pump was continuously drawing in air at the joints, decreasing its performance. The valves were not exactly 50 mm in diameter and insulating tape was wound around them to increase their diameter before the pipe was reconnected. The connections were still not completely airtight after the adjustment and this had an impact at high heads. Air was also being drawn through the o'ring seal at the top of the cylinder. Silicon was placed around the piston rod hole to attempt to stop this. The pump was set on the middle setting for all three operators. A frame was built out of scrap metal to use as a handle for the Platform, Swiss, KB and IDE pumps. The height of the frame could be adjusted according to the operator's height and the different heights of the pumps.

The leather cups on the pistons of the Swazi pump were slightly small and the water would therefore not stay on the top of the pistons during pumping. The water had to be constantly monitored and topped up. The cups were greased in an attempt to seal the gaps between the pistons and cylinders. The problem appeared to improve as the pump was used more, because the leather started absorbing the water and therefore swelled. A steel bar was placed through the handle to decrease the maximum stroke length as the pistons would sometimes rise too far, spilling the water over the tops of the cylinders and sometimes popping out of the cylinders. The pump was difficult to prime at higher suction heads.

The Approtec pump always started easily once a little water had been poured into the top of the cylinders. It could not hold it's prime at a suction head of one metre and delivery head of two metres. Water had to be poured into the cylinders about once a minute. This problem only exists at lower heads and is mentioned by the manufacturers in the user manual. Water is able to flow between the cylinders and this helped with priming. The Approtec pump was tested twice, once with the foot valve that came with the pump and once with a brass foot valve, used for all the other pumps. The results presented are those obtained with the brass valve, except for the section where a comparison is made.

The Swiss pump was also tested twice. After the first day of testing it was found that the bicycle spokes holding the rubber flap valves had not been replaced in the correct positions and were no longer holding the valves in place. The 12 mm diameter shaft holding the treadles in place bent after the first days testing, and was replaced for the second tests with a 16 mm diameter shaft.

10 kilogram weights were used for the IDE pump for operators B and C. Two 20 kilogram weights were used for operator A.

4.4 Treadle Pump Quantitative Assessments: Field Tests

A few of the imported treadle pumps that were tested in the laboratories were taken out into the field and tested using different irrigation techniques. The pumps tested and irrigation methods can be seen in Table 6.

Table 6. The pumps and the irrigation techniques used for the field tests.

Zambian Suction Pump	Furrow irrigation
Approtec Pressure Pump	Furrow, hose pipe and sprinkler
Swiss Suction Pump	Demonstration purposes
Swazi Pressure Pump	Hose pipe
KB Suction Pump	Furrow irrigation

The field tests took place in March 2001. They aimed to highlight design characteristics of the pumps that were not apparent from the laboratory testing phase. Pumps were tested under practical field situations for which they are likely to be used in the future. The pumps were not compared with one another but rather the applications of treadle pumps were tested in the field.

4.4.1 Boschkloof

The farmers' plot at Boschkloof irrigation scheme was surveyed using a dumpy level and tape measure. Figure 17 shows the layout of the plot. The heights in metres are shown in italics. The abstraction point at the canal is the reference height zero. Distances are also shown.

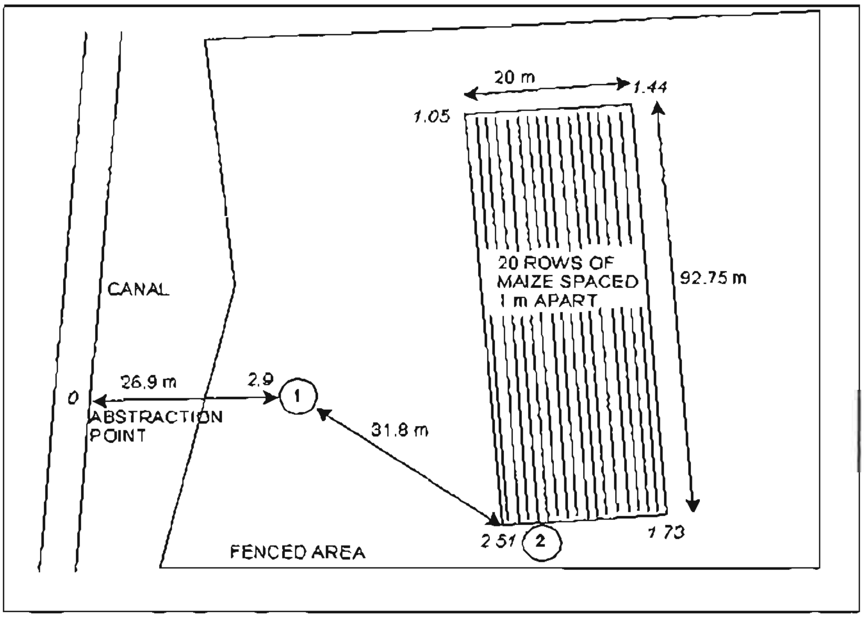


Figure 17. The layout of the plot used for field testing at Boschkloof irrigation scheme.

The farmer had initially placed his Zambia S pump at position 1 marked in Figure 17. An outlet pipe was attached to the pump and the water was flowing through this pipe to the furrows. This was used as the set up for the first trial. The Zambia S pump was then moved to the position marked 2 in Figure 17. The water then spilled directly from the pump into a furrow. A similar set up as position 2 was then used for the last two trials, using the KB suction pump from India and the Approtec pressure pump from Kenya, without an outlet pipe. A class 6, 50 mm diameter pipe was used as the inlet pipe. The pipe was primed by filling it with water, before it was attached to the pump. A non-return foot valve was placed on the end of the inlet pipe to prevent the water from leaking out when pumping stopped.

The farmer was asked to treadle in each set of tests. A stopwatch was used to record the time it took to fill a 25 litre bucket and the flow rate was then calculated. The water was then allowed to spill into the furrow being used. A tape measure was spread out along the length of the furrow. The distance that the waterfront had reached after each minute was recorded.

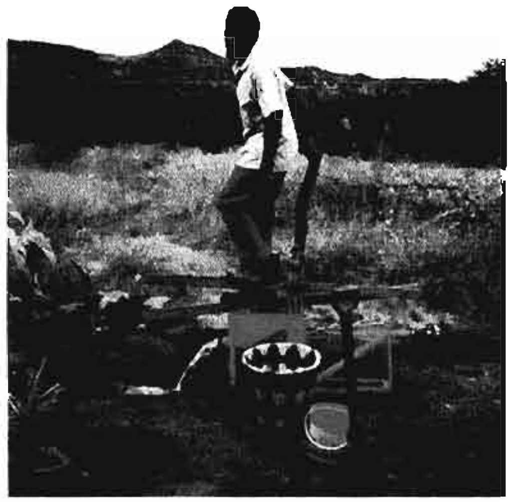


Figure 18. The farmer pumping the Zambia S pump.

4.4.2 Kwaggafontein

A farmer's plot nearby one of the earth canals at Kwaggafontein was chosen to carry out a set of field tests. The application of treadle pumps pumping directly into a hose pipe system was tested. The Swazi and Approtec pumps were used. Figure 19 shows the layout of the farmer's plot.

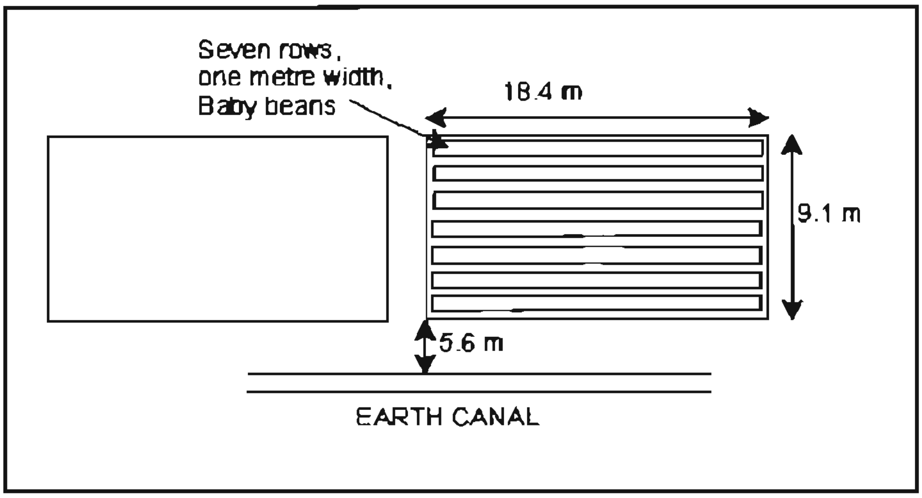


Figure 19. The layout of the plot used for testing the treadle pumps and hose pipe application.

The pumps were connected in turn to a 40 mm diameter, class 3 inlet pipe, placed in the canal. A 25 mm diameter dragline hose pipe of 50 metres length was used. The stopwatch and bucket were again used to measure the flow rates. The pumps were then used to test the hose pipe application. One farmer pumped while another held the other end of the hose pipe and irrigated the beans. The farmer who owned the plot irrigated as he normally would with the bucket and can. The methods were both timed.

Figure 20. Timing the bucket and can and treadle pump and hose pipe methods.

4.4.3 Tshepo's homestead

Three different applications were tested at Tshepo's homestead. The first application analysed potential problems when pumping out of a grey water tank holding recycled water from the kitchen. The Approtec pump was used to pump directly into a bucket system and into two different sprinkler systems, an impact sprinkler and a conical sprinkler. The conical sprinkler will be referred to as a Gardena sprinkler throughout the remaining document. The pump was placed about 50 metres from the grey water tank. The bucket kit was situated a further nine metres from the pump. The sprinklers were placed 25 metres from the pump. The inlet pipe was a class 6, 50 mm diameter pipe and the outlet pipe was a 25 mm dragline hose.

The bucket and stopwatch were again used to measure the flow rate of the water. Catch cans were spread out in the garden to determine the distribution uniformity of the sprinklers. Figure 21 shows the catch can set up for the two different sprinkler systems. The distances in brackets show the set up for the Gardena sprinkler.

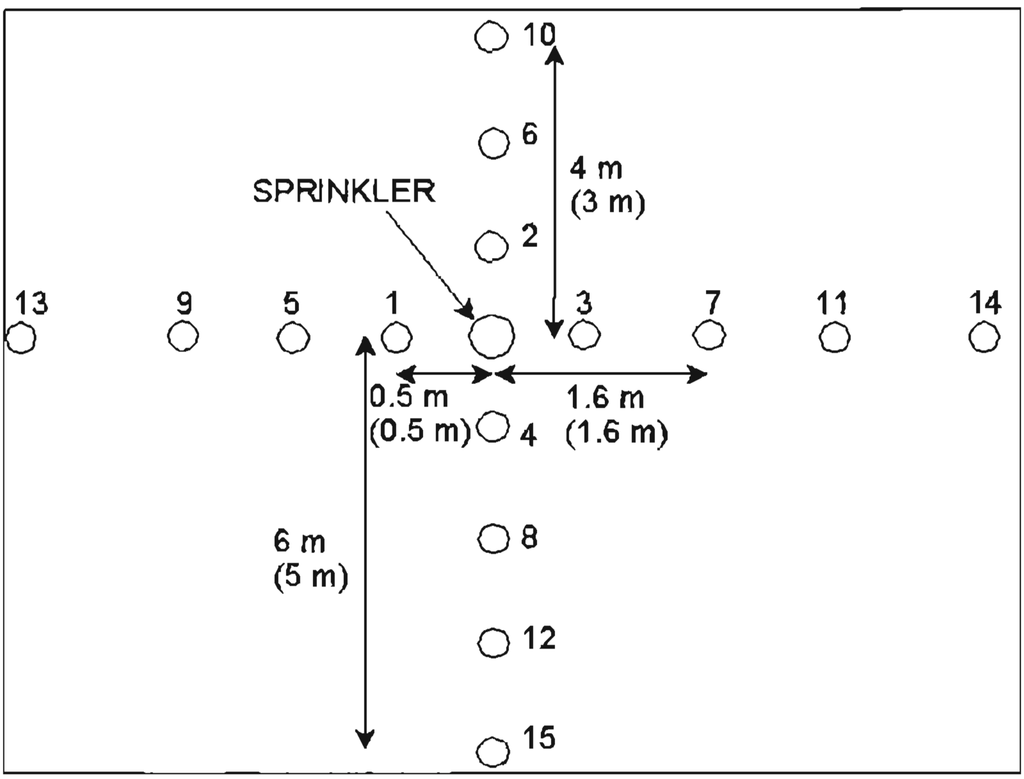


Figure 21. The catch can set up for the impact and Gardena sprinklers in the kitchen garden.

4.5 Drip Kit Qualitative Assessments

The drip irrigation kits were evaluated on a smaller scale than the treadle pumps. This was because other research has already taken place into the effectiveness of drip irrigation kits for small farmers (Reaves, 1995, Ngigi *et al.*, 2000, Uys and Scott, 2000, Walker, 2000a, Walker, 2000b). Kits were again issued out to farmers for on-farm trials.

The farmers at Winter Roses were issued with two bucket, drip irrigation kits. The first was an IDE kit and the second, a Chapin Watermatics model. It was thought that the farmers would welcome the kits due to the fact that they were using primary water for irrigation and that method was becoming very expensive.

Two drum kits were made up from irrigation fittings purchased at local stores and placed at Sepitsi. The farmers assisted with making the second kit after seeing how to make the first. The kits consisted of two bushes attached on either side of a small hole made in the drum. An inline filter was then attached using 15 mm polyethylene piping. That was attached to a T-piece. Six lines of T-tape laterals were then attached to the 15 mm pipe mainline using T-pieces and elbows. The T-tape was closed at the ends using crocodile clamps purchased from a local stationary store. The cost of the entire set up was about R100, including the drum and T-tape. Figure 22 shows a diagram of one of the constructed drum kits.

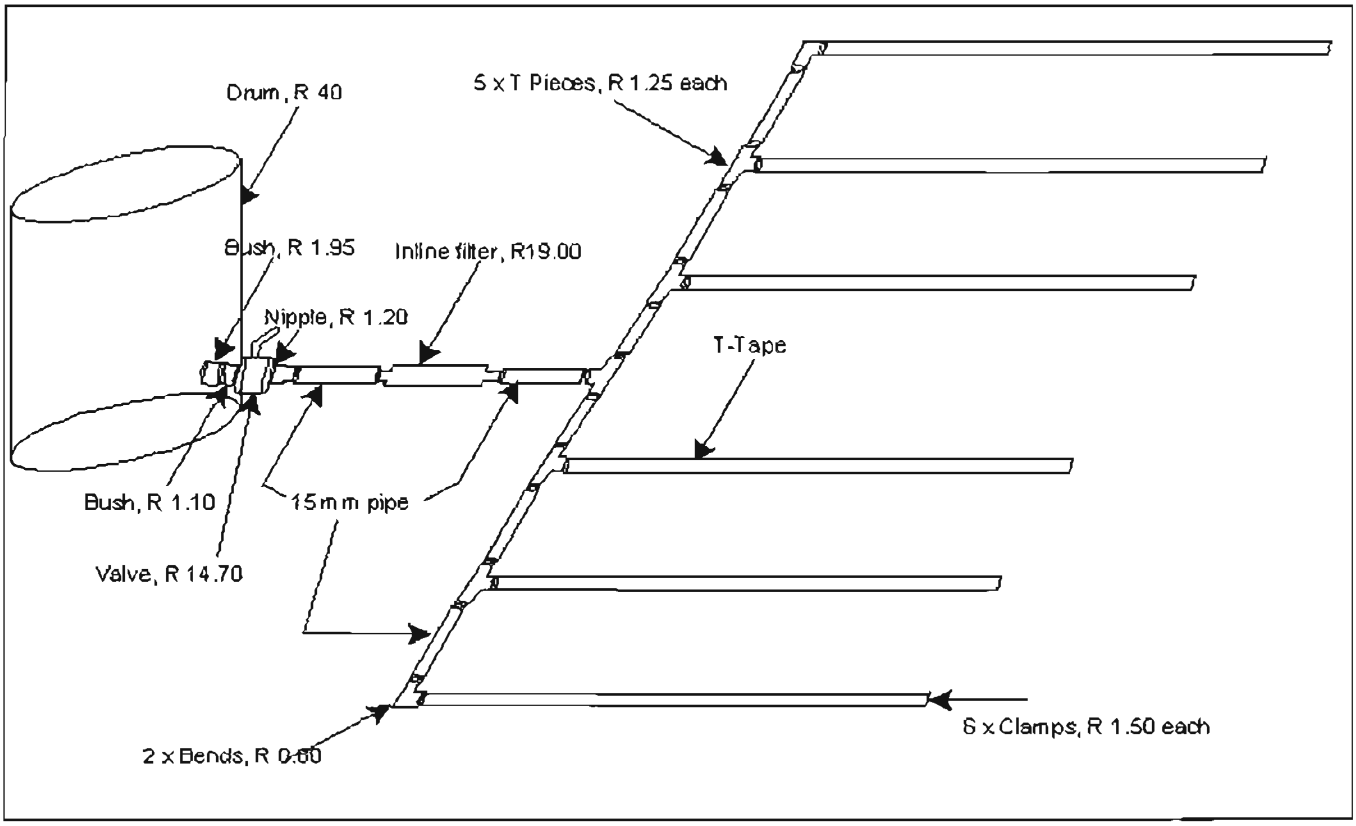


Figure 22. A drum kit placed at Sepitsi community garden.

4.6 Drip Kit Quantitative Assessments

In an attempt to evaluate the effectiveness of bucket drip irrigation kits and to compare this method to other irrigation techniques, a small plot was set up at Ukulinga Research Farm. The site was monitored for two seasons. The first crops were planted on 1 September, 2000, and the second season began on 9 May 2001.

The garden was divided into six plots in the first season. Spinach plants, cabbages and onions were grown. Four different irrigation methods were tested. These consisted of a watering can system, a plastic cooldrink bottle system, an IDE low-head bucket drip system and a modified Chapin Watermatics low-head bucket drip system using porous pipe.

The crops were spaced according to recommended spacing (Uys, 1997). The spinach plants were spaced at 200 mm intervals with 400 mm between rows. They were planted in small hollows so that the water would not run away when irrigation took place using a watering can. The cabbage plants were spaced 400 mm apart within the rows, and the rows were spaced 500 mm apart. Both beds were therefore two metres long and 1.4 metres wide. They each contained six, two litre plastic bottles, buried at a depth of about 100 mm. The onions were spaced at about 100 mm intervals, with a 150 mm spacing between rows. Four rows of onions were planted and a length of leaky pipe placed next to each row. The cabbages using the IDE drip kit as the irrigation method were spaced as above and each plant had a dripper outlet next to its base.

The plants were irrigated according to an irrigation schedule produced by Walker, 1999. He calculated the number of litres of water that one plant of six different crops requires per week and the water required per square metre of four other crops. Water requirements were calculated for planting dates spaced two weeks apart throughout the year. The computer programme Cropwat (Smith, 2001) was used for the calculations. The plastic bottle and watering can systems were divided into two plots. Both plots received the same amount of water, but on a different time basis. Table 7 presents a summary of the crops and the irrigation technique and schedule used in the first season.

Table 7. Plot information for season one.

Technique	**Crop**	**Schedule**				
		Mon	**Tues**	**Wed**	**Thurs**	**Fri**
Watering can	Spinach	5 litres	5 litres		5 litres	4.5 litres
Watering can	Spinach	10 litres			9.5 litres	
Plastic bottle	Cabbage	2 litres	2 litres	2 litres	2 litres	3.25 litres
Plastic bottle	Cabbage	4 litres		4 litres		3.25 litres
IDE drip	Cabbage	25 litres	25 litres	25 litres	25 litres	16 litres
Porous drip	onion	13 litres	13 litres		13 litres	13 litres

Due to an abnormally high rainy season, very little irrigation was required during the summer. Few results were therefore obtained and it was decided to attempt another experiment beginning the following winter. In these winter trials four plots were used and only spinach was grown. The same methods of irrigation were used, however, only one bed using the watering can method and coke bottle method was used. Table 8 provides a summary of the techniques used for the second season.

Table 8. Plot information for season two.

Technique	Crop	Schedule				
		Mon	Tues	Wed	Thurs	Fri
Watering can	Spinach	6 litres		6 litres		6 litres
Plastic bottle	Spinach	1 litre		1 litre		1 litre
IDE drip	Spinach	19 litres		19 litres		19 litres
Porous drip	Spinach	13 litres		13 litres		13 litres

4.6.1 Tensiometers

A tensiometer measures soil water suction, which is similar to the process a plant root uses to obtain water from the soil. A tensiometer consists of a sealed, water filled tube inside a PVC conduit. A pressure transducer attached to the tube links the tensiometer to a data logger. The lower end of the PVC conduit is attached to a ceramic tip. A diagram of the set up can be seen in Figure 23. The tensiometers were inserted into holes made with a 25 mm diameter soil auger. As the soil around the tensiometer dries out, water is drawn from the tube through the ceramic tip. This creates a vacuum in the tube, which can be read on the data logger. When the soil water is increased, either through rainfall or irrigation, water enters the tube through the ceramic tip, lowering the reading on the data logger. The tensiometer therefore gives a measure of soil water tension, or the force with which the water is being held by the soil, which is related to soil water content (Black and Rodgers, 1989).

Before installation, a slurry of silty material was applied to the ceramic tip to ensure a good contact was made with the soil. Ley and Thomas (1994) state that the ceramic tip of the tensiometer must be put in complete contact with the soil. The loggers were launched before installation. They were set to take a reading every 12 minutes.

At selected intervals of the growing season, approximately once a month the data was downloaded onto the HOBO Shuttle (Onset, 2000). The voltage of the batteries was checked and the tensiometers replenished with de-aired water. The date of the download and replenishment was noted as this affects the readings of the tensiometers for a few hours.

Seven nests of tensiometers were installed at Ukulinga farm during the first season and two were removed leaving five remaining for the second season. Each nest consisted of three tensiometers at depths of 298 mm, 662 mm and 1000 mm. Three transducers linking the tensiometers to the data logger were also installed at each nest. A six-volt battery powered the data logger. The nest name, irrigation method and lengths and depths of tensiometers for each season are shown in Table 9 and Table 10.

Table 9. Tensiometer information for season one.

Nest	Irrigation	Crop	Lengths (mm)			Depths (mm)		
1	Watering can	spinach	298	712	1069	298	662	1000
2	Plastic bottle	spinach	298	719	1069	298	662	1000
3	Plastic bottle	spinach	298	662	1069	298	662	1000
4	IDE drip	cabbage	298	721	1120	298	662	1000
5	Watering can	spinach	300	829	1069	298	662	1000
6	Reference		304	704	1218	298	662	1000
7	Porous drip	onion	298	712	1069	298	662	1000

Table 10. Tensiometer information for season two.

Nest	Irrigation	Crop	Lengths (mm)			Depths (mm)		
1	Watering can	spinach	298	712	1069	298	662	1000
2	Plastic bottle	spinach	298	719	1069	298	662	1000
3	IDE drip	spinach	298	721	1120	298	662	1000
4	Porous drip	spinach	298	712	1069	298	662	1000
5	Reference		304	704	1218	298	662	1000

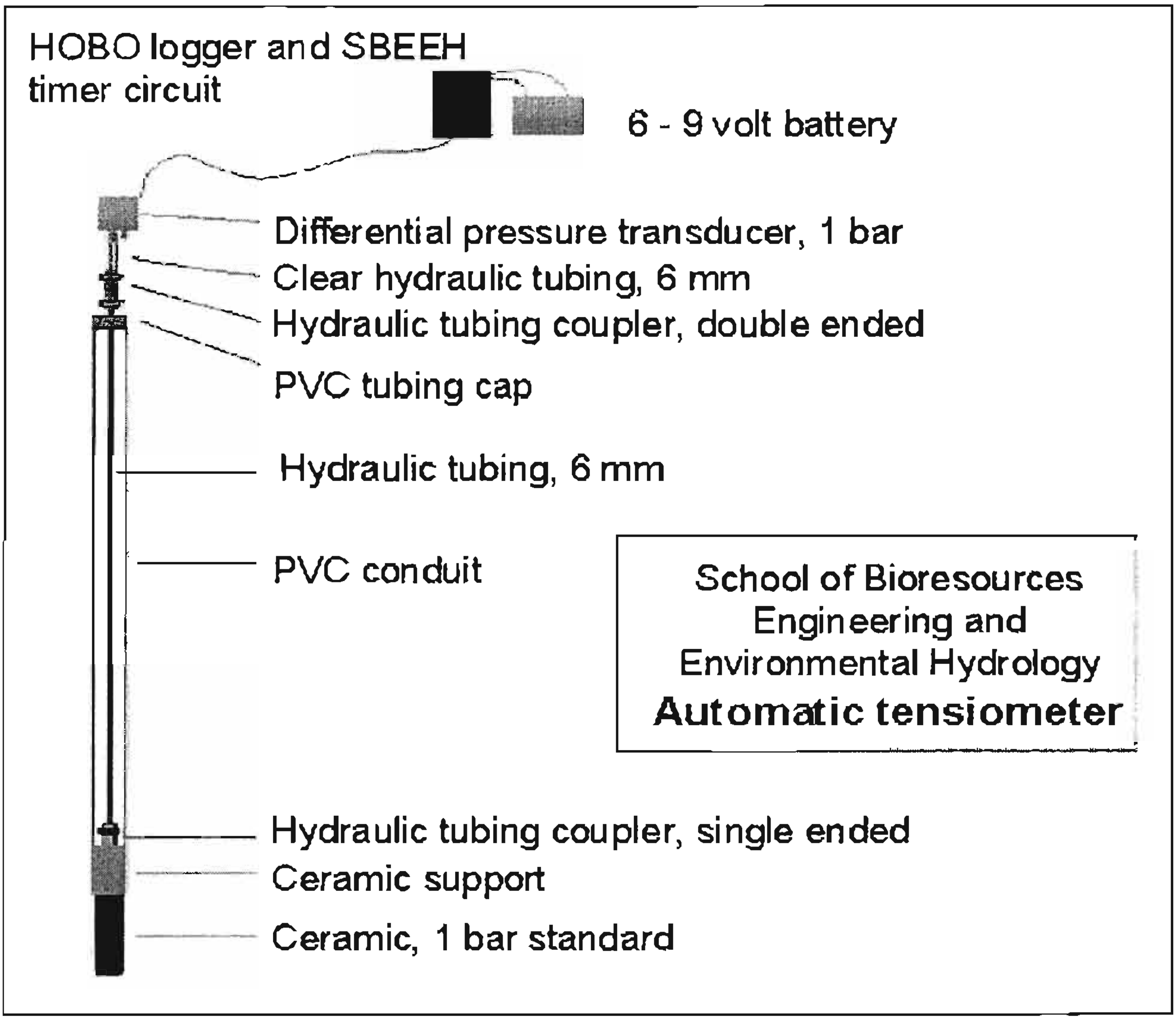


Figure 23. Automatic tensiometer components (after Thornton-Dibb and Lorentz, 2000).

4.6.2 Wetting front detector

Two wetting front detectors were installed into one of the spinach plots during the first season. A wetting front detector (Figure 24) is a funnel-shaped object that is buried open end up in the soil (Stirzaker *et al.*, 2000). During irrigation a wetting front is produced that moves through the soil. As the front moves into the wide opening of the funnel the unsaturated flow lines are converged, which increases the water content at the base of the funnel. The dimensions of the funnel are such that the soil at the base becomes completely saturated. The water flows through a filter and fills the bottom section of a narrow PVC tube. A lightweight foam rod floats on the water within the tube, rising out of the tube. Figure 24 shows a simple version of a wetting front detector designed for the use by small-scale irrigators. The detectors were placed at depths of 150 mm and 300 mm respectively.

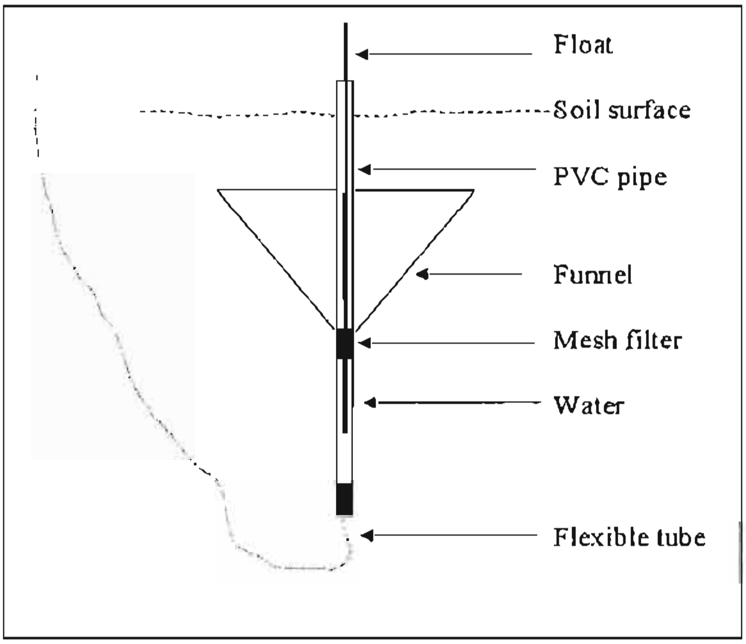


Figure 24. A wetting front detector (after Stirzaker *et al.*, 2000).

4.7 Prototype Treadle Pump Design and Development

From the results of the research on treadle pumps it was found that a new pump should be developed for South African conditions. This was because:

1. South Africa has a deeper water table than the other countries where introduction has been successful;
2. South Africa has access to more resources than most other African countries;
3. labour costs in South Africa are high comparatively, therefore increasing the cost of a steel unit requiring welding by an engineering manufacturer;
4. South African farmers are generally larger and heavier than those from Asia and therefore pumps would require a sturdier frame; and
5. results from the laboratory tests showed that many improvements could be made on the imported pumps.

It was decided to design and build a pressure pump using materials that were readily available at most local shops. The intention was to keep the design as simple as possible so that it could be produced by local manufacturers in most rural areas. Two pumps were designed and built. The first was an experiment to test new ideas that had not been used before. Brass check valves were mounted externally instead of the normal rubber flap valves, mounted at the base of the cylinders. This pump can be seen in Figure 25. The second pump (Figure 26) was a refinement of the first and followed the same idea, but used different, less expensive materials. Appendix C contains tables of the materials used to build the pumps and includes pump design drawings and additional photographs.

Figure 25. The prototype one pump.

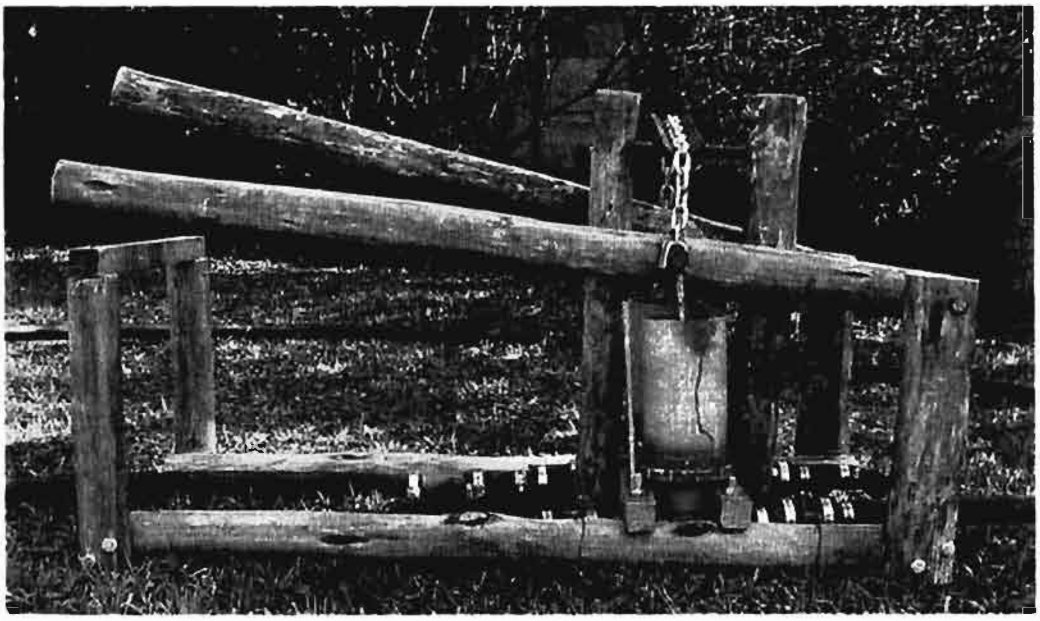


Figure 26. The prototype two pump.

The prototype pumps were again tested at the Institute for Agricultural Engineering's hydraulics laboratory. Only one operator was used as the tests merely aimed to determine maximum head and sustainable flow values for the pumps. The laboratory was set up as before (section 4.3.2), except that a stopwatch was used to measure the time of pumping and a scale was used to measure the volume pumped.

5. RESULTS

The evaluations of the treadle pumps and drip irrigation kits were separated into two different sections. The first section describes the qualitative evaluations, which took place on farms and were largely carried out by farmers themselves. The quantitative evaluations were the second phase of the project. In this phase, treadle pumps were tested under laboratory conditions and then underwent field-testing which took place at selected gardens. The drip kits were evaluated on a small plot at Ukulinga farm, which was monitored throughout two seasons. Other irrigation techniques such as hand watering with a watering can were also tested at the plot under similar conditions.

This chapter presents the results obtained from the evaluations of the different technologies and techniques, using the different phases of assessment. Again, the treadle pump qualitative assessments will be presented first followed by the treadle pump quantitative assessments. The drip kit qualitative and quantitative results will then be presented. The chapter will conclude with results obtained from the laboratory testing of the two new prototype treadle pumps, which were designed and built following the test phases of the imported pumps.

5.1 Treadle Pump Qualitative Assessments

The qualitative, on-farm trials showed how farmers reacted to the pumps after using them in actual field situations. Initial adjustments had to be made to some of the Zambian pumps as they were not of a very high quality. This section will begin with a description of these adjustments and will follow with a summary of the results obtained from the various gardens.

5.1.1 Initial adjustments made to the pumps

There were many adjustments that had to be made to the Zambian pressure pumps before they operated correctly. The pulleys' centre slots were filed as they were too small, preventing the pulleys from rotating on the shafts. The threads on the inlet and outlet pipes were bent and buckled and sockets could therefore not be screwed on. The slits in the treadles where the piston rod shifts horizontally as it moves up and down had to be filed as they were too small and the rods were unable to move. This resulted in the pistons rising off centre, breaking the seal between the cylinders and pistons. The treadles had been attached at the wrong end of the pump, decreasing the mechanical advantage.

The rubber flaps at the bottom of the cylinders did not seal causing water to overflow out of the cylinders when pumping stopped. This was because the holes had been drilled too close to the edges of the cylinder base. The most significant problem was that the rubber cups on one of the pumps were not the correct size, allowing air to enter the system and breaking the vacuum. This was rectified by placing two cups, one inside the other, in each cylinder on the suction side. A leather cup, purchased locally, was used in one of the cylinders as it had a tighter fit than the rubber cups. There were leaks at the base plate seal. The brass foot valves obtained with the pumps did not seal correctly causing water to leak out of the inlet pipe.

5.1.2 Results from qualitative sites

On the first visit to Silwayiphi it was found that the rope had broken and that the farmers had attempted to replace it. They had, however, made the new rope too long and the pistons were therefore not reaching the required height for water to spill over into the trough. After a few visits it was found that the ladies were not using the pump as it was too high off the ground. The children enjoyed pumping but they were not always there as they were attending school. The pump was then lowered. One of the rubber cups had to be replaced after three months. The foot valve did not close properly and this meant that the pump often had to be primed. The inlet pipe sucked closed as it was a class 3 pipe. This did not stop the water flow all together but did affect it.

While the ladies were very keen to use the pump in the first two months, it appeared that they lost interest after a while. Priming was difficult and gravity feeding into the drum took time as a vacuum had to be created in the pipe before the water could flow. They returned to their original method of walking to the water. The pump was removed from Silwayiphi during the summer season as it was apparent that the farmers were not using it.

Siyazama was one of the most successful gardens that acquired a pump. The farmer was enterprising and keen to try new things. He buried the inlet pipe to prevent it from getting damaged. The pressure pump worked well throughout the entire season. There were no technical problems, except for the foot valve. It was replaced with a locally purchased valve. The farmer checked that the valve was fully closed if the inlet pipe was empty. The farmer's wife was prepared to pump even though she was fairly old. They did not find treadling difficult. The farmer often moved the outlet of the pipe to suit the garden. He expanded his garden during the season as a result of the pump. He used an old plastic bottle with holes punched in the bottom to spray the water as his wife pumped. This can be seen in Figure 27. They maintained that using the pump was much quicker than their previous method of walking to fetch the water and hand watering.

Figure 27. The farmer and his wife from Siyazama.

Thuthukani was another successful garden. The farmers were happy with the pump as they had to walk 40 metres down a steep bank to fetch water. One of the ladies said that they previously took about 18 trips back and forth to the water to fill their drums. Using the pump made it much easier and quicker to irrigate, taking about eight minutes to fill a drum by treadling. The ladies did not find treadling difficult. One was seen treadling with a baby on her back. The rope broke after a while and was replaced with a chain. The site was visited on one occasion after a few weeks of rain. The pump had not been used as the farmers had not been irrigating. It had rusted on the inside of the cylinders and other areas where the paint had chipped off.

As a result of the adequate watering due to the introduction of the Approtec pump, the farmers at Burford began noticing better quality crops as it was "much easier to water using the treadle pump." They expanded the small area of the garden that they were originally using and began to use all the available plots. They also said that they were planting different varieties of crops since obtaining the pump, as they had only been planting potatoes before. Another improvement was that they found it was easier to get their children to assist with irrigation. Before the introduction of the pump, the children did not enjoy the laborious task of fetching and carrying water. The farmers said that other people from the community had approached the members wanting to join the garden, as they were seeing the better quality crops and had realised the pump was decreasing their irrigation time and effort.

5.2 Treadle Pump Quantitative Assessments: Laboratory Test Results

The laboratory tests highlighted the important components that should be taken into consideration for future designs of treadle pumps. Human operators were used for the tests and the results are therefore accurate according to practical situations. The operators also gave their opinions of the pumps and mentioned particular muscles that hurt during pumping. The following section presents the results obtained in the laboratory tests.

5.2.1 Operators' calibrations

Table 11 shows the heart rates in beats per minute at the different power inputs for each operator obtained from the calibrations carried out at the University of Pretoria.

Table 11. Heart rates, in beats per minute, at different power inputs.

	OPERATOR A	OPERATOR B	OPERATOR C
REST	98	105	97
50 W	130	136	145
75 W	144	151	162

From these results, a regression line was fitted enabling the determination of power input for all heart rates. Table 12 shows the y-intercept, slope, and R-squared values of the plots of heart rate against power. These plots can be seen in Appendix D. The physical work capacity, PWC, of each operator determined at a heart rate of 170 beats per minute can also be seen in Table 12. The relative PWC is determined by dividing the PWC of each operator by that operator's mass. The normal relative PWC value for females is two Watts per kilogram and for males, two and a half Watts per kilogram. These results show that all three operators are slightly unfit when compared to the normal values.

Table 12. Data required to determine power input at all heart rates.

	OPERATOR A	OPERATOR B	OPERATOR C
y-intercept	98.29	105.0714	98
Slope	0.617	0.614	0.88
R-squared	0.998972	0.999935	0.99384
PWC	116.2 W	105.7 W	81.8 W
Relative PWC	1.2 W/kg	1.4 W/kg	1.2 W/kg

5.2.2 Friction loss

Table 13 shows the pressure and flow values obtained for each pump from the friction loss test. The friction loss curves for the pumps can be seen in Appendix D.

Table 13. Pressures recorded at various flow rates.

PLATFORM		SWAZI		APPROTEC		SWISS		KB		IDE	
flow m^3/h	Pres kPa	flow m^3/h	Pres kPa	flow m^3/h	Pres kPa	Flow m^3/h	Pres kPa	flow m^3/h	Pres kPa	flow m^3/h	Pres kPa
5	4	5	3.8	5	38.7	4.4	1	2.8	2.7	3.23	1.1
6	5.4	6	4.8	6	45.7	5.15	2.5	3.81	3.8	5.12	2.1
7	7.2	7	5.8	7	57.6	6.46	4.7	5.01	5.2	6.1	3.1
8	8.7	8	6.8	8	62	7.75	6	6.6	7.3	7.88	4.6
9	10.3	9	7.7	9	85	8.9	8.2	7.35	9	8.93	5.8
10	14.3	10	8.8	10	95	9.77	9.8	8.3	10.7	10.3	7.7
						10.7	11.3	9.7	12.9		

These results show that the friction loss through the Approtec pump is about ten times greater than that though the other five pumps. This is probably due to the smaller valves of the Approtec pump, which decrease the flow of water and increase the internal friction. The Swazi pump provided the least friction out of the three pressure pumps, followed by the Platform and then the Approtec. The Swazi manufacturers had purposely enlarged the holes through which the water passes and made them oval in shape in order to decrease friction. The IDE provided the least friction of the suction pumps, followed by the Swiss and then the KB. The IDE and Swiss gave lower friction values at certain flow rates than the Swazi pump.

5.2.3 Maximum flow rate

Tables 14 and 15 show the average values obtained from the maximum flow rate tests.

Table 14. Maximum flow rates and maximum cadence for pressure pumps.

PUMP	PLATFORM			SWAZI			APPROTEC		
OPERATOR	A	B	C	A	B	C	A	B	C
TIME (s)	40	40	40	40	40	40	40	40	40
STROKES	74	92	83	55	88	88	67	91	94
CADENCE (str/min)	111	138	125	83	132	132	101	137	141
VOLUME (l)	78	67	56	82	101	77	55	57	46
FLOW (l/s)	1.95	1.67	1.4	2.05	2.53	1.93	1.38	1.43	1.15
AV FLOW (l/s)	1.67			2.17			1.32		

Table 15. Maximum flow rates and maximum cadence for suction pumps.

PUMP	SWISS			KB			IDE		
OPERATOR	A	B	C	A	B	C	A	B	C
TIME (s)	40	40	40	40	40	40	40	40	40
STROKES	118	146	122	109	115	117	38	45	47
CADENCE (str/min)	177	219	183	164	173	176	57	68	71
VOLUME (l)	79	74	66	36	36	32	18	24	25
FLOW (l/s)	1.98	1.85	1.65	0.9	0.9	0.8	0.45	0.60	0.62
AV FLOW (l/s)	1.82			0.91			0.56		

The results show that the Swazi and Platform pressure pumps have a much greater maximum flow rate than the Approtec pressure pump. The Swiss flow rate greatly exceeds that of the other two suction pumps. The Swiss pump also obtained the greatest cadence values, followed by the KB pump. The short stroke of the Approtec pump resulted in high cadence values as did the rocking action of the Platform pump. The lower cadence and flow rate values of the IDE pump could be a result of the different pumping action caused by the weights, which the operators struggled to get used to. Operator C produced the least flow for all the pumps except for the IDE pump. Operator A always produced the least number of strokes, opting for a longer stroke. This, however, resulted in the highest flow rates of the Swiss, Platform and KB pumps, and a flow rate of above two litres per second for the Swazi pump and therefore shows that a faster cadence does not necessarily mean a higher flow rate.

5.2.4 Mechanical efficiency

Table 16 shows the mass required to move the treadles at a head of zero metres and then four metres with the pumps attached to an inlet pipe and with no pipes attached. The masses given are in kilograms. It also presents the mechanical advantage of each pump. A mechanical efficiency has been calculated for each pump using equation 7.

Table 16. Mechanical efficiencies and advantages.

	PLATFORM	SWAZI	APPROTEC	SWISS	KB	IDE
No pipes	8.76	2.5	4.65	2.1	1.42	2.47
0 m	10.46	10.9	7.28	3.24	4.56	5.44
4 m	27.92	17.21	25.98	17.2	5.0	24.01
η_{mech} **(%)**	63	37	72	81	8,8	77
Distance: foot to pivot (mm)	452	934	778	823	462	545
Distance: piston to pivot (mm)	355	1026	243	172	136	240
Mechanical Advantage	1.3	0.91	3.2	4.8	3.4	2.3

All the mechanical efficiencies are below the norms of 95 percent for a new pump and 90 percent for a worn pump (Thomas, 1993). The Swiss pump has the highest mechanical efficiency and mechanical advantage. The KB pump has a high mechanical advantage but very low mechanical efficiency. This is because there was very little difference in the forces required to move the treadles at zero head and at four metres head. The Platform pump requires a comparatively high mass to move the platform. All the mechanical advantages are greater than one, except for the Swazi pump where the operator stands between the pivot point and the pistons. This is a result of the adjusted base from the Masvingo pump. The pump tips over when the operator stands on the other side of the treadles. This is not the case, however, when two operators are operating the pump as their masses would then balance out. Only one operator was used for testing purposes.

5.2.5 Sustainable flow, input power and pump efficiency

The raw data and graphs of average flow rates, input power and pump efficiencies for the various total heads and operators can be seen in Appendix D. The main trends and more significant graphs will be shown here in the results section.

Figure 28 shows plots of flow rate against total head for each pump and operator. The Swazi pump delivers the highest flow rate averaged over all the tested heads and operators. While the results show that the Platform pump gave a very low flow rate, it should be remembered that the Platform pump was constantly drawing in air which decreased its performance. The three suction pumps all gave average flow rates between 0.3 and 0.45 litres per second, 1,08 and 1,62 cubic metres per hour. The Swazi pressure pump had a higher flow rate value than the three suction pumps, even though suction pumps are designed for greater volumes. The three pressure pumps had the expected curve shapes of decreasing flow with increasing head. The slight drop in the Approtec curve at five metres total head is because it was drawing four metres and delivering one metre, whereas the total head of six metres was only drawing two metres and then pushing four metres. This shows that pressure pumps should rather draw a lower height and push more. The suction height of the three suction pumps did not appear to have any effect on the average flow values. The Swiss and IDE pumps produced the greatest flow rates at four metres suction height, and the KB pump's flow rate actually increased with suction height.

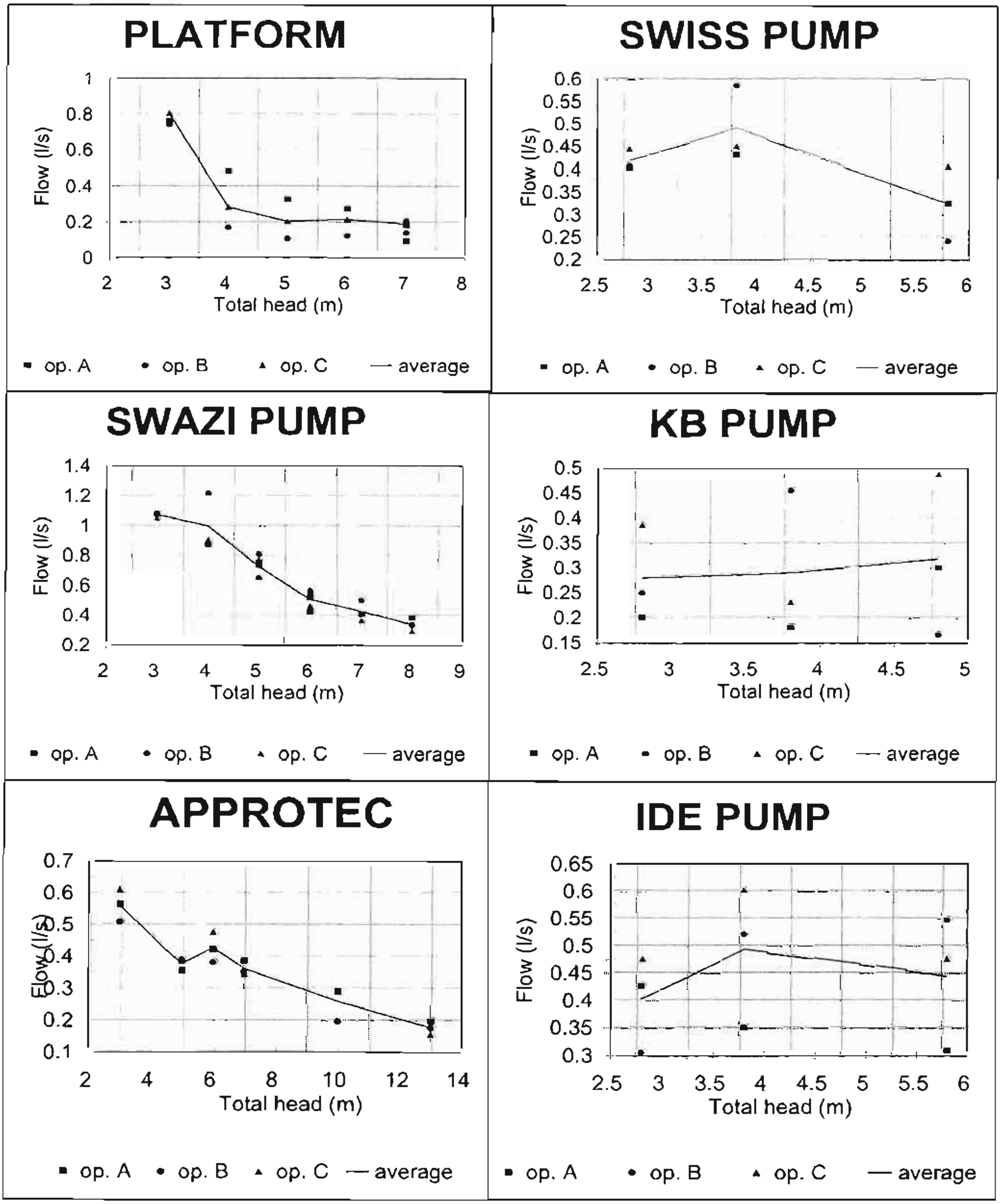


Figure 28. Graphs of flow plotted against total head for each pump and operator.

Table 17 shows the pumps in descending order of average flow, cadence, input power and efficiency. The Swazi and IDE pumps gave the highest flow rates, yet they both had comparatively low cadence values. The Swiss pump produced the highest average cadence, followed by the Platform pump. The three pressure pumps show a general decrease in cadence with an increase in total head (Appendix D). This is due to the increased resistance as the delivery head increases. The increase in suction heads of the suction pumps does not appear to have any affect on their cadence values. The three pressure pumps gave an overall average of 50 strokes per minute, while the three suction pumps averaged 63 strokes per minute. This could be a result of the higher total heads that the pressure pumps were tested at. The suction pumps were also generally easier and less stiff to pump than the pressure pumps.

Table 17. Pumps in descending order of average flow, cadence, power and efficiency.

Flow	Cadence	Power	Efficiency
Swazi	Swiss	IDE	Swazi
IDE	Platform	KB	Approtec
Swiss	KB	Swazi	Swiss
Approtec	IDE	Swiss	Platform
Platform	Approtec	Platform	IDE
KB	Swazi	Approtec	KB

The input power averaged 49.07 Watts for all the pumps. This is lower than the assumption that a reasonably fit, well fed human being between 20 and 40 years old can produce a steady power output of around 75 Watts for long periods (Kay and Brabben, 2000). They do, however, continue to state that this may not be the case in developing countries, where a more realistic value of 30 to 40 Watts should be expected. The operators were well fed, but were less fit than the average human being, hence their average power input lying at about 50 Watts. The operators put the most power, 58.82 Watts average, into the IDE pump. This was probably because the IDE pump, with the different treadling action, required the most effort, therefore causing the operators' heart rates to rise. The least power was used on the Approtec pump, 40.49 Watts average. This was probably the result of the easier action of the Approtec pump allowing the operators to relax more while pumping, and therefore having lower heart rates.

The trend of pump efficiencies follows that of the average flow with the Swazi and Approtec pumps having the highest efficiencies. Thomas (1993) states that a worst case efficiency of 50 percent is acceptable and that pump efficiency will generally be lowest at low heads. Only the Swazi pump with 74.05 percent and the Approtec with 57.72 percent were greater than 50 percent. All the pumps had lower efficiencies at low heads except for the Platform pump, where the efficiency decreases as the total head increases. Again the air leaks would come into effect here as they appeared to have more influence at higher suction heads. The KB pump had a very low average pump efficiency of 20.65 percent.

Operator A produced the least average flow rate for all the pumps. Operators B and C produced similar shaped curves of average flow plotted against the pumps (Appendix D). Operator A's curve was slightly different, with the KB pump having the lowest average flow rate instead of the Platform pump as with operators B and C. Operator C always produced the highest number of strokes (Figure 29) except for the Swazi pump where operator A produced the highest number. Otherwise operator A always produced the least number of strokes. Operator A also put the least power into most of the pumps (Figure 30), and produced a lower average pump efficiency (Figure 31). Her pump efficiency was, however, highest on the Swiss and Platform pumps. Operator B averaged 50.19 Watts input power, slightly higher than the overall average of 48.11 Watts. Operator B's input power on the Approtec pump was very low, only 30.94 Watts. His heart rate seldom went above 125 beats per minute.

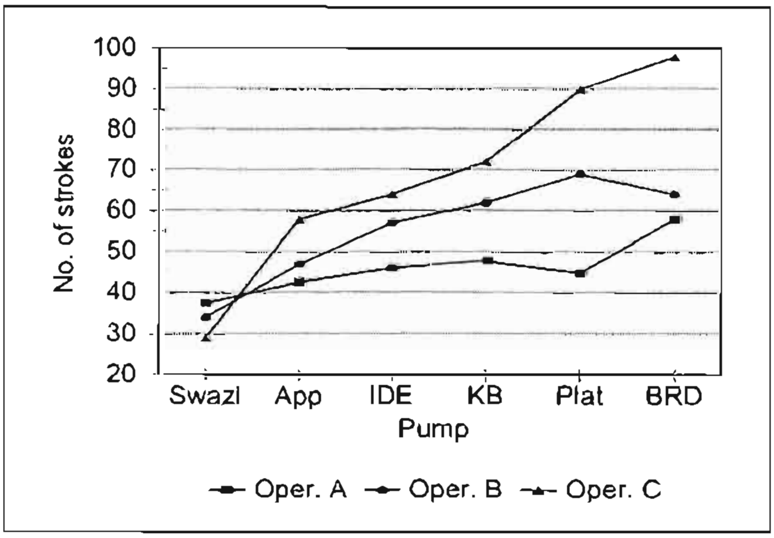


Figure 29. Graph showing the average number of strokes per minute for each pump and operator.

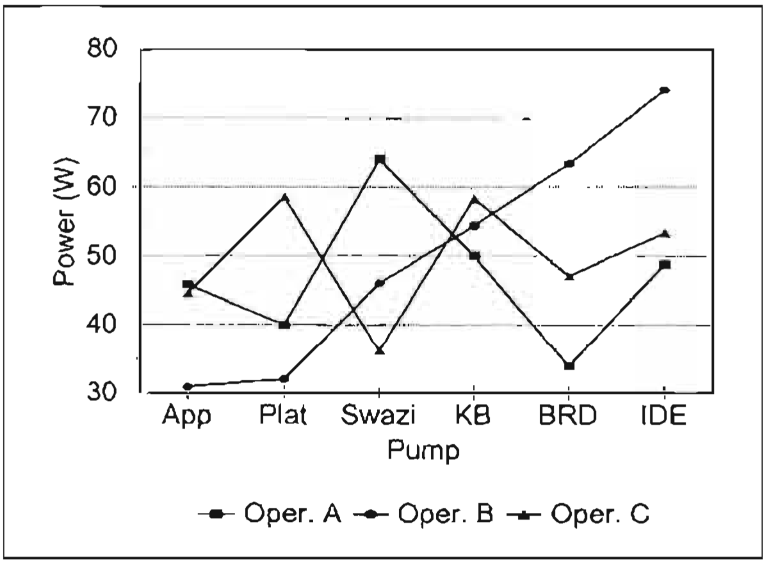


Figure 30. Graph showing the average input power for each pump and operator.

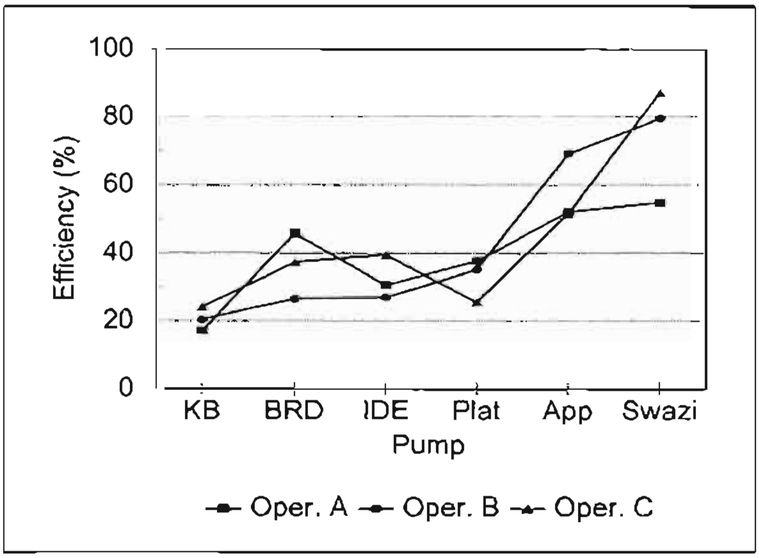


Figure 31. Graph showing the average efficiency for each pump and operator.

5.2.6 Approtec pump without Approtec foot valve

The Approtec pump was tested twice, once with the foot valve that was purchased with the pump and once with a brass foot valve that was used for the other pumps. It was observed that the pump was very stiff to pump with the Approtec foot valve. Table 18 shows the average flow rates and cadence values with and without the Approtec valve.

Table 18. Comparison of flow rates and cadence with and without the Approtec foot valve.

	Average flow rates (l/s)			Average cadence (strokes per minute)		
Total Head (m)	6	7	10	6	7	10
With Approtec valve	0.29	0.27	0.15	26	22	18
With brass valve	0.43	0.36	0.26	49	48	37
Difference	0.14	0.09	0.11	23	26	19
Average difference	0.113 l/s			23 strokes / min		

The results show that there is an average difference of 0.113 litres per second when pumping with and without the Approtec foot valve. The cadence values were also less when pumping with the Approtec foot valve. The foot valve increases the internal pump friction, which is already high when compared to the other pumps. This could be a combination of the small holes in the netting used as a strainer and the rubber flap covering a relatively small hole inside the foot valve.

5.2.7 Operators' opinions

On completion of the two weeks of testing, the operators were questioned about the use of the pumps. After each session of testing they were questioned as to which muscles hurt while pumping and which were sore afterwards. The results of these questions can be seen in Table 19.

The Approtec was by far the favourite out of all the pumps in terms of ease of use. The Swiss was the favourite suction pump. The operators preferred the pumps with handles, the Swazi and Approtec, and felt that all pumps should have a built in handle. The operators felt that the KB pump gave the best flow rate when compared to the effort that they were putting in. However, they felt the least stable on the KB pump. They thought the Approtec pump was the safest to stand on, being closer to the ground. They also felt very stable on the Platform pump.

The operators felt that the IDE pump was the worst to use. This was probably because they struggled to get used to the weights on the treadles. This would have been different had the pump's frame been built with bamboo to the exact dimensions that IDE suggest. This would have eliminated the need for the extra counterweights as the bamboo treadles would have served as counterweights. The operators could only carry the Approtec and the KB pumps on their own. The others were all too heavy and awkward to carry without assistance.

Operator A battled with the KB pump, stopping after about six minutes. She was pumping without shoes and her feet were sore. The footrests became very slippery when they were wet. The treadles are too close together for larger people to be comfortable. The pump is designed for Indians who are generally smaller than South Africans. The four legs were not the same length and a piece of wood had to be used as a wedge to make the pump more stable. This would have been different had the sharp edges of the frame been embedded in soil, as would be the case in a field situation.

It was noted that Operator C, the oldest of the three operators, struggled to climb onto all the pumps except for the Approtec pump. All three operators found the Approtec pump very straining on the front of the thighs at low heads. Operator A gave up after six minutes as the pain was unbearable. At higher heads they were able to use their weight instead of their muscles and pumping was therefore easier. The operators appeared to prefer to lean on the handle of the Approtec pump while pumping rather than to stand at the end of the treadles, therefore decreasing the mechanical advantage.

The operators preferred to stand half way along the treadles of the Swiss pump. The stroke length was too long and their feet dropped too far below the pivot point, causing pain in the front of their ankles, when they stood at the end on the treadles. The mechanical advantage was therefore decreased.

None of the operators stood with their feet against the wooden stops on the Platform pump as the stops were too far apart. This meant that their feet slipped outwards when the platform became wet. Operator A at one stage turned to face forwards and rocked backwards and forwards instead of from side to side. It was difficult for the operators to get into a rhythm with the Platform pump as it was constantly drawing in air and was therefore not pumping water on every stroke.

The Swazi pump became stiff to pump at higher heads. The operators used the handle to pull against in addition to their weight.

Table 19. Muscles that hurt during and after pumping.

	OPERATOR A	OPERATOR B	OPERATOR C
PLATFORM	Ankles	Ankles	Front of thighs
SWAZI	Back of thighs	Knees	Back of thighs
APPROTEC	Front of thighs	Front of thighs	Front of thighs
SWISS	Knees	Front ankles when facing forwards	Back of knees
KB	Back of calves and back of knees	Knees	Nothing
IDE	Back of ankles and thighs	Front of ankles	Thighs

5.2.8 Qualitative assessment

Table 20 shows a comparison between results obtained during the two weeks of testing and those quoted by the manufacturers of the pumps.

Table 20. A comparison of test results and manufacturer's results.

Pump	Maximum Flow (m^3 / h)		Sustainable Flow (m^3 / h)	Maximum suction height (m)		Maximum total height (m)	
	Manuf.	Tests	Tests	Manuf.	Tests	Manuf.	Tests
Platform	5	6	1.12	5	3	9	8
Swazi	7.2	7.8	2.4	4	4	10	8
Approtec	5.4	4.75	1.62	6	6	13	13
SWISS	6	6.55	1.4	8	6	8	6
KB	4	3.3	1.15	7	4	7	4
IDE	3.6	2.02	1.44	5	6	5	6

Most manufacturers quoted higher suction heads for the suction pumps then were possible in the laboratory. The pressure pumps obtained their maximum head values, except for the Platform pump due to the air entering the system. Most of the maximum flow rates were in the region of the flow rates quoted by the manufacturers, however, the sustainable flow rates were always much lower. This is important as one can not guarantee that the flow rates that the manufacturers quote will be sustainable over any length of time.

A qualitative assessment was carried out on the pumps in terms of maintenance and operation in field conditions. The Platform pump would require a set of spanners or wrenches to replace the rubber flap valves, to open the cylinder and to shift the cylinder position. Most of the connections are easily available and recognisable at most shops. Operators could replace the reinforced helix pipe and clamps if they wore out. The hole at the top of the cylinder for the piston rod could wear with frequent use.

The rope on the Swazi pump broke in the laboratory after one day's testing. While this is not difficult to replace, a chain over the pulley might be a better option. The owner of a Swazi pump would also require a set of spanners or wrenches to replace the valves at the bottom of the cylinders and to replace the leather piston cups. Leather cups are easily available in most farming stores. The wooden treadles are strong and should not break very easily.

The Approtec pump can be maintained without spanners. There are no threaded connections on the Approtec pump. The rubber flap valves can be reached from the top of the cylinders. The piston cups stretch over a plate, which holds them in place, eliminating the need for spanners. The rubber cups would require replacement after a while and would need to be specially stocked at local stores.

The Swiss pump is also fairly maintenance free. The wooden treadles are strong and should not break. The hose pipe piston seals and bicycle spokes holding the rubber flap valves in place can easily be replaced. Tyre tubing can be used as flap valves. The PVC piping is well protected by the concrete. The shaft that bent during the first day of pumping will in future be replaced with a stronger 20 mm diameter shaft by the manufacturers, BRD Engineering.

The KB and IDE pumps also contain rubber cups that would require replacement after a certain period of use. There are no threaded connections on either pump, eliminating the need for spanners. The rubber flap valve of the KB pump could be replaced with tyre tube. The metal flap valve of the IDE pump could break with excessive use and would be difficult to replace. The steel legs of the KB pump could bend and break if not looked after carefully. The spouts of both pumps could bend and break off if mishandled during transport.

5.3 Treadle Pump Quantitative Assessments: Field Test Results

The aim of the field test section of the treadle pump quantitative assessment phase was to evaluate the imported pumps while using them in actual field situations. It is not correct to only evaluate a new technology in the laboratory as important aspects might not be considered due to the unnatural conditions. The following section presents the results obtained in the field-testing phase of the treadle pumps.

5.3.1 Boschkloof

Table 21 shows the recorded flow rates for the different pumps used in the furrow irrigation trial at Boschkloof irrigation scheme.

Table 21. A summary of the pump positions and recorded flow rates.

PUMP	POSITION	TIME (s)	FLOW RATE (l/s)	CADENCE (str/min)
ZAMBIAN S	1	92	0.27	71
ZAMBIAN S	2	48	0.52	99
KB	2	27	0.93	101
APPROTEC	2	30	0.83	58

Comparing the flow rates it can be seen that the KB pump produced the highest flow rate followed by the Approtec pump. The Zambian pump in its first position produced the lowest flow rate. This was because the farmer would pump for a few strokes, and then have to wait for the water to flow down the outlet pipe, otherwise it would spill over the reservoir in the pump. The farmer preferred the KB pump as it gave the highest flow rate, even though he admitted that it was the least comfortable to operate. He opted to pump with his hands rather than his legs.

Figure 32. The farmer pumping the KB suction pump.

The resulting graphs of time plotted against distance for each pump can be seen in Appendix E. The first trial, with the Zambian pump in position 1, was carried out until almost the entire furrow was wet. The land sloped slightly uphill towards the end of the furrows and the water therefore did not reach the end. The farmer was then asked to pump for a set time for the other three trials. The full furrow was therefore not completed.

The graphs can not be compared directly as each furrow had a unique shape and slope. When comparing the distance that the water had travelled after 25 minutes, it can be seen that the Zambian pump in position two had gone the furthest at 55 metres. This is followed by the Zambian pump in position one and the Approtec pump which had both reached just over 40 metres. The KB pump had reached about 37 metres after 25 minutes of pumping. Again these values can not strictly be compared as each furrow differed. The KB pump had the highest flow rate yet the water was fairly slow in that particular furrow.

These tests show that it would probably take approximately 45 minutes to irrigate a furrow of 100 metres length if the flow rate is about 0.7 litres per second. The farmer admitted that his furrows were too wide. They were approximately 0.6 metres wide. It can also be seen from the graphs that the water tends to stop every now and then. This is a result of the uneven slopes of the furrows.

5.3.2 Kwaggafontein

The Approtec pump produced a flow rate of 0.6 litres per second. The Swazi pump's flow rate was less at 0.3 litres per second. Both pumps required water to be poured into the top of the cylinders constantly. In the case of the Approtec pump, it was because the pump was not lifting the water to the minimum head of one metre that is required. The problem with the Swazi pump was that the piston cups were not sealing against the cylinder walls, allowing water to leak between these gaps.

The hose pipe method took three minutes, 55 seconds to completely irrigate two rows of the plot. The farmer using the bucket and can method took six minutes, 26 seconds to irrigate just one row. This involved three trips back and forth to fetch water from the canal. The treadle pump and hose pipe method was therefore over a third of the time quicker to irrigate a row. This method did, however, require two people to carry out the irrigation, one to pump and one to handle the hose pipe, and taking this into consideration was therefore only about one and a half times quicker. In the second set of tests the Swazi pump and hose pipe system took four minutes 56 seconds to complete four rows of a second plot. A female farmer using the bucket and container system took two and a half minutes to irrigate one row. In this case, the Swazi pump and hose pipe took half the time that it would normally take to irrigate using the bucket method.

5.3.3 Tshepo's homestead

Table 22, shows the volume of water caught in each can during the trials held at Tshepo's homestead. The flow of water produced by the Approtec pump was 0.52 litres per second. It therefore took about 40 seconds to fill the ten litre bucket attached to the dripper lines. No problems were experienced with the pump as a result of using the grey water. The water was filtered through a cloth before it went into the bucket so as not to block up the holes of the dripper lines.

Table 22. The volumes caught in the catch cans.

CAN	Impact Volume (ml)	Gardena Volume (ml)
1	4.2	20
2	7.2	8.5
3	12	12.8
4	10	20
5	5	21
6	3.6	13.8
7	2.5	20
8	4.2	24
9	1.5	7
10	2	15
11	5.6	10
12	4.2	12.8
13	0	0
14	0.5	0
15	0.25	0

The graphs showing the profiles of the two different sprinkler systems used can be seen in Appendix E. The graphs show that the Gardena sprinkler has a better distribution uniformity and gives a greater volume than the impact sprinkler when connected to a treadle pump. The main reason for this is probably due to the pulsating action of treadle pumps. The pressure drops as the piston reaches the end of each stroke, resulting in the impact sprinkler returning to a set position and therefore irrigating the same segment again. The wind was blowing during the experiment and played a role in the low distribution uniformities.

The operators each treadled for fifteen minutes. This appeared to deliver a sufficient volume of water of about 15 ml average (in the case of the Gardena sprinkler) onto the plot area of approximately 40 square metres. The pump was, however, fairly stiff to pump due to the resistance of the sprinkler. The operator managed 20 strokes per minute with the impact sprinkler and 36 strokes per minute with the Gardena sprinkler.

5.4 Drip Kit Qualitative Results

The farmers at Winter Roses used the bucket kits for about a month. They agreed that the drippers used the water more efficiently. They did, however, take the buckets home after each irrigation session, as they were worried that they might get stolen. They were also worried to leave the drip tape in the garden. After the first month of using the kits, the Department of Agriculture placed a borehole in the garden, allowing the farmers to use the sprinklers at a lower cost than before. They then stopped using the buckets, as the sprinklers required less effort.

The response was very positive when the drip kits were installed at Sepitsi. Many of the farmers were keen to purchase the fittings and put some kits together themselves. A few of the farmers were sceptical as the spacing of the drippers was different to the usual spacing of tomatoes and they were worried the plants might not receive enough water. They were also wary as the wetted area looked too small to be giving the older plants' roots enough water.

After a visit it was found that the farmer that had received the drum kit had not yet planted in that plot as he was not convinced that it would provide sufficient water to irrigate his tomatoes. He was again informed that it would work more efficiently as the roots would get the water and it was suggested that he try it for a season on a small plot. The farmer agreed to use the kit during the following season and thus the results were delayed for this test site.

5.5 Drip Kit Quantitative Results

The following section will present the graphs resulting from the quantitative evaluations of the drip irrigation kits, the watering can method and the cooldrink bottle method. The main trends will be discussed.

5.5.1 Drip Kits

The plots obtained from the results of the tensiometers set up to measure the soil matric pressure at site four show that the water table is about 80 mm below the soil surface level at this site. This is seen by the line resulting from the 298 mm tensiometer staying at around – 220 mm soil matric pressure, and is confirmed by the 662 mm tensiometer line at around – 580 mm, shown in Figure 33. There are very few significant changes resulting from irrigation events. One can see, however, that the drying up of the soil profile, which occurs after 19 September, is kept down as a result of the irrigation events. An event on the 19 September affects the 298 mm tensiometer immediately and has a delayed effect on the 662 mm tensiometer. No effect is seen on the 1000 mm tensiometer. This is probably a rainfall event as no irrigation is recorded on that day.

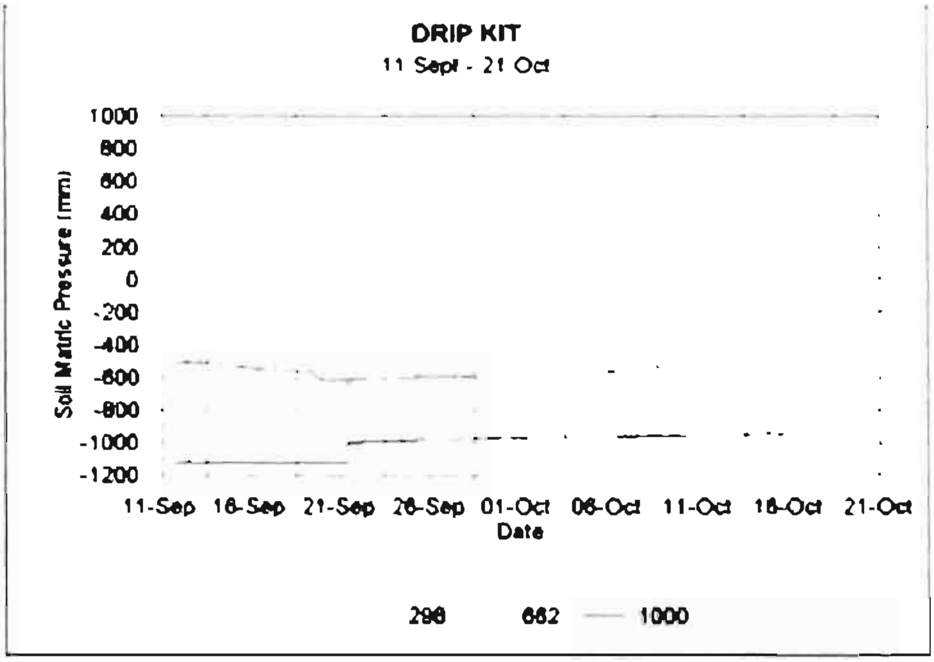


Figure 33. Tensiometer data for drip kit, summer season.

There is a progressive drying out of the near surface tensiometer throughout the time series, which ends in large diurnal fluctuations due to non-replenishment just before the beginning of October. If one draws a straight line through these fluctuations it can be seen that the soil is still drying out, but at an increased rate, with irrigation events on successive days of the 2, 3 and 4 October slowing the rate down.

The 1000 mm tensiometer shows that nothing significant is happening at that depth as a result of irrigation events, but also shows a slow, progressive drying out. Again it confirms the wet soil profile at this particular site.

The data obtained in the winter season (Figure 34) follows a similar pattern with the water table at about 70 mm below the soil surface. Irrigation events that took place on the 14, 16, 17 and 18 May all have an effect on the 298 mm and 662 mm tensiometers and the slight drops can clearly be seen. The drip irrigation appears to hold the soil matric pressure constant at all three depths.

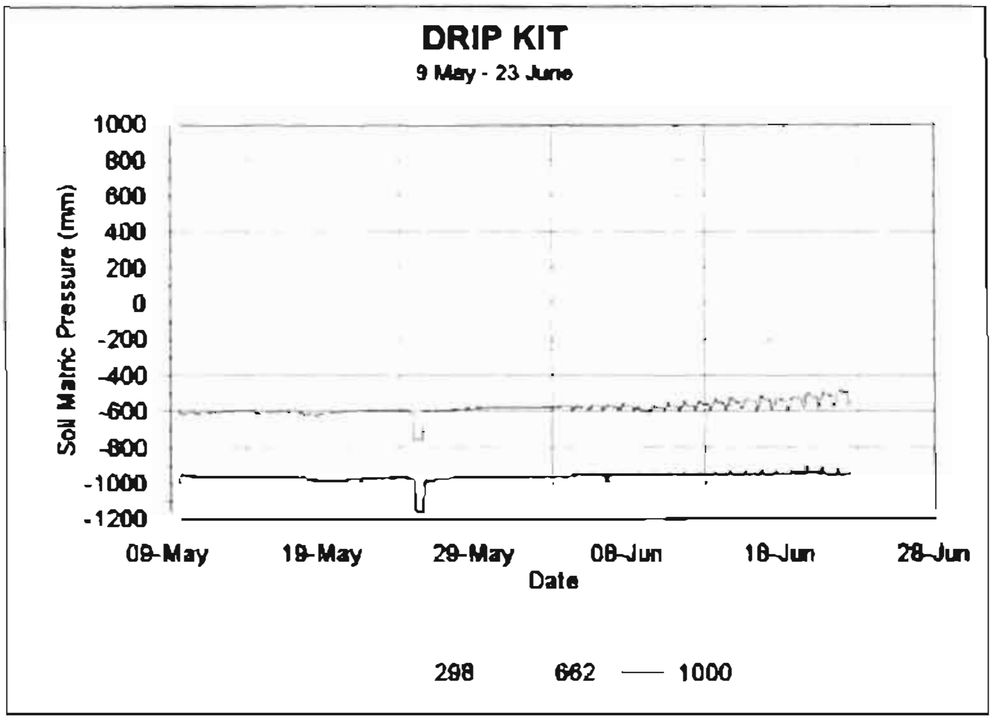


Figure 34. Tensiometer data for drip kit, winter season part one.

The drop offs in the 662 mm and 1000 mm tensiometers on the 25 May are a result of replenishment, however, one can see that the tensiometers soon return to their previous state of equilibrium at about – 600 mm and – 970 mm respectively. The irrigation events on the 4, 6, 8, 11 and 14 June have an effect on the 298 mm tensiometer, raising the water table by about 10 to 15 mm. Air had by this stage entered the 662 mm tensiometer and the diurnal fluctuations make it difficult to recognise the irrigation events. The 1000 mm tensiometer shows a slight drying up of the soil profile from about the 25 May.

Figure 35 shows the plot of data from the 22 June to 12 July. It shows drying up at the 662 mm and 1000 mm levels. Air appears to be inside the 662 mm tensiometer for the entire time series and could be a result of the water that was used having air bubbles in it. However, the general trend shows that the 662 mm tensiometer is drying out at a higher rate than in the previous summer season. Irrigation occurred in this plot on the 27 and 29 June and the 5 and 16 July. The first two events significantly affect the 298 mm tensiometer, which appears to be drying out rapidly before each event occurs. The irrigation event on the 5 July again delays this drying up and returns the water table to approximately 100 mm below the soil surface level.

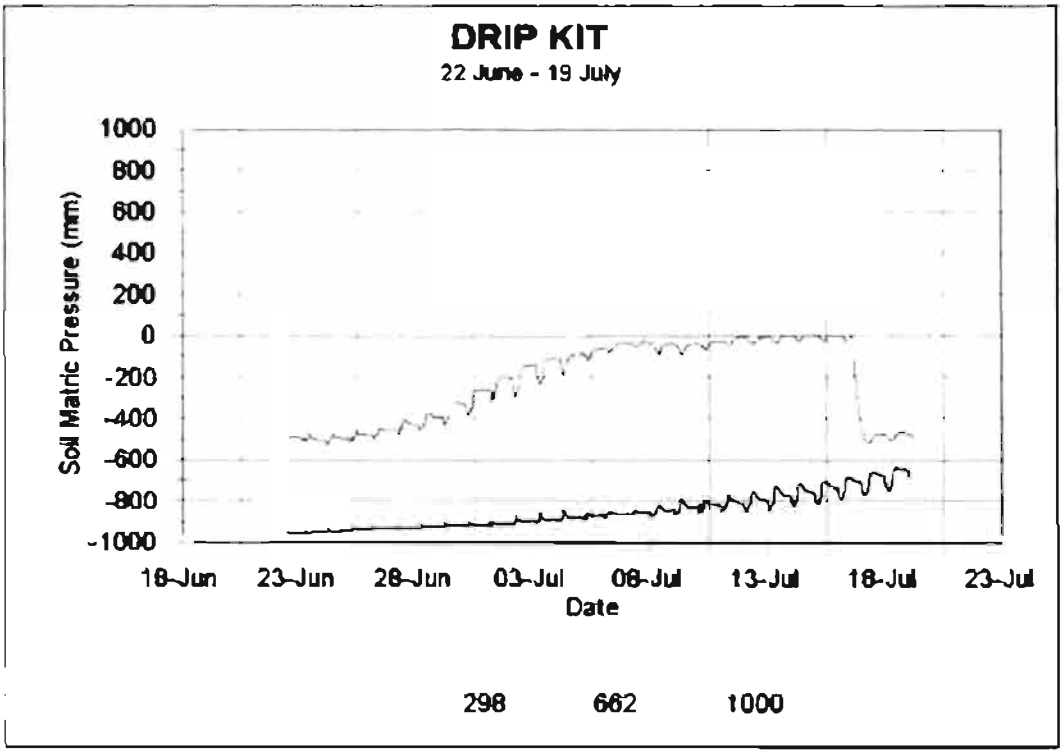


Figure 35. Tensiometer data for drip kit, winter season part two.

The filter on the drip kit required cleaning before every irrigation event. The drippers seldom blocked up. When blocking did occur, the drippers were cleared by blowing through the spaghetti tubing. However, the plant growth was not very uniform throughout the bed, with the spinach plants closest to the bucket growing larger.

5.5.2 Cooldrink bottles

The results obtained from the tensiometers placed at site two show a much dryer soil profile compared to site four. The 298 mm tensiometer does not appear to be operating for the first part of the season (Figure 36), with results only being recorded after the first replenishment on 21 September. The 662 mm and 1000 mm tensiometers' signals show a uniformly dry profile at a fairly constant level of between 250 mm and 1000 mm for the first part of the time series and 200 mm and 700 mm for the second part. It can therefore be concluded that the irrigation must hold the tensions at this level and that the water table at this site is at a level of about 1,4 metres depth below the soil surface.

After the first replenishment when the 298 mm tensiometer appears to begin operating, one can see that it steadily dries out. The irrigation event that took place on the 26 September temporarily slows this drying out, as does the event on the 4 October. The 662 mm tensiometer appears to stay fairly constant, except for diurnal fluctuations, and the 1000 mm tensiometer also slowly dries out during the time series.

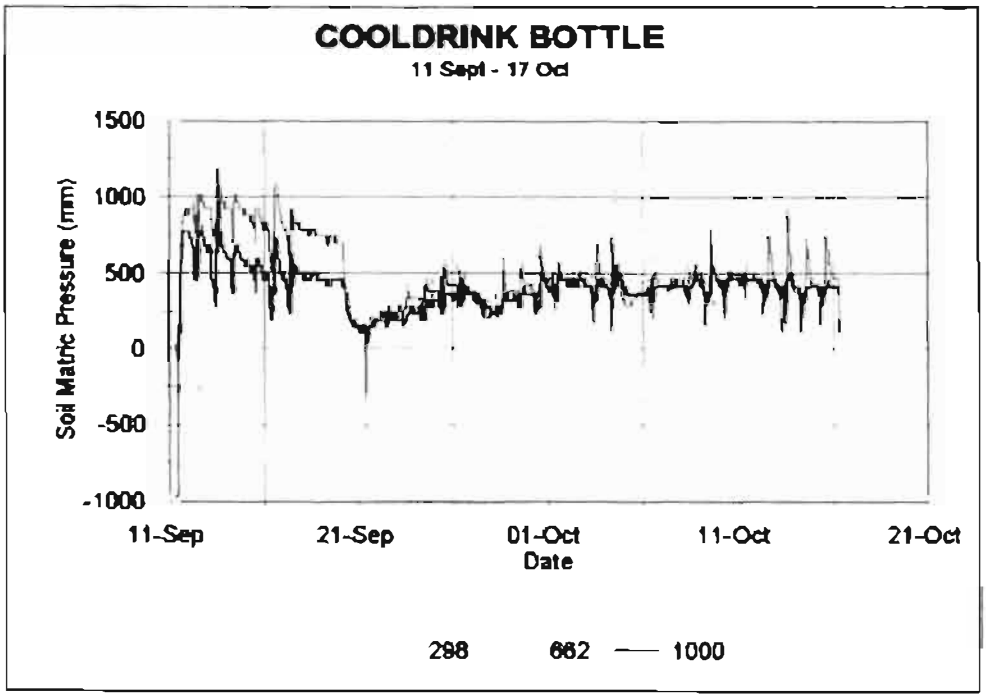


Figure 36. Tensiometer data for cooldrink bottle, summer season, site two.

The data obtained from site three for the summer season can be seen in Figure 37. A malfunction again occurred in the 298 mm tensiometer between the 11 and 21 September before the first replenishment and the results from this time are not included in the graph. All three tensiometers then begin to dry out very steadily with irrigation events slowing this rate down. Irrigation events on the 27 September, 2, 4 and 12 October result in slight drops of all three lines.

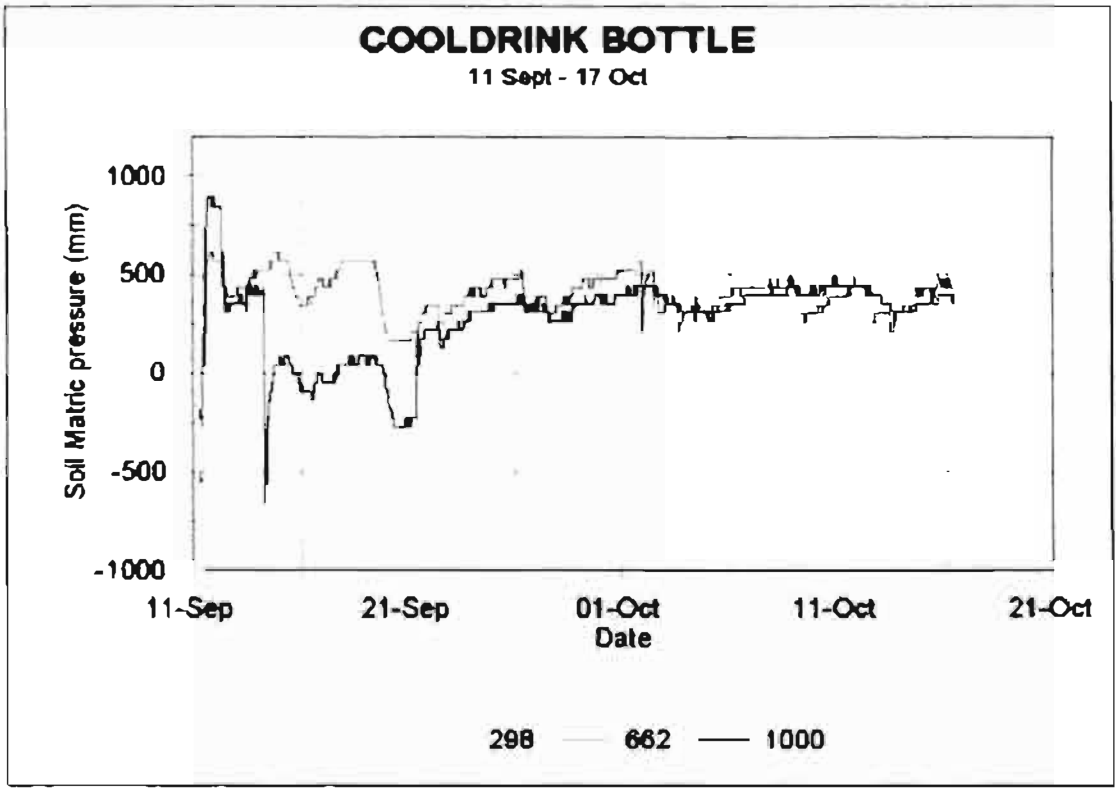


Figure 37. Tensiometer data for cooldrink bottle, summer season, site three.

The results from the first part of the winter season at site three show that the 298 mm tensiometer and the 662 mm tensiometer are steadily drying out, again with irrigation events postponing the drying out at certain intervals (Figure 38). All three tensiometers respond to the irrigation event on the 14 May, with the response being slightly delayed for the 1000 mm tensiometer. The 298 mm tensiometer responds to irrigation events that took place on the 16, 17 and 18 May. Both the higher two tensiometers respond to the event on the 24 May, with the 662 mm response slightly delayed. A sudden drop off occurs in the 1000 mm tensiometer due to replenishment that took place on the 25 May. It then stays below the other two lines, and it is assumed that there was a malfunction prior to 25 May. Diurnal fluctuations occur towards the end of the time series, having a greater effect on the 298 mm tensiometer, however, one can still see a gradual drying out.

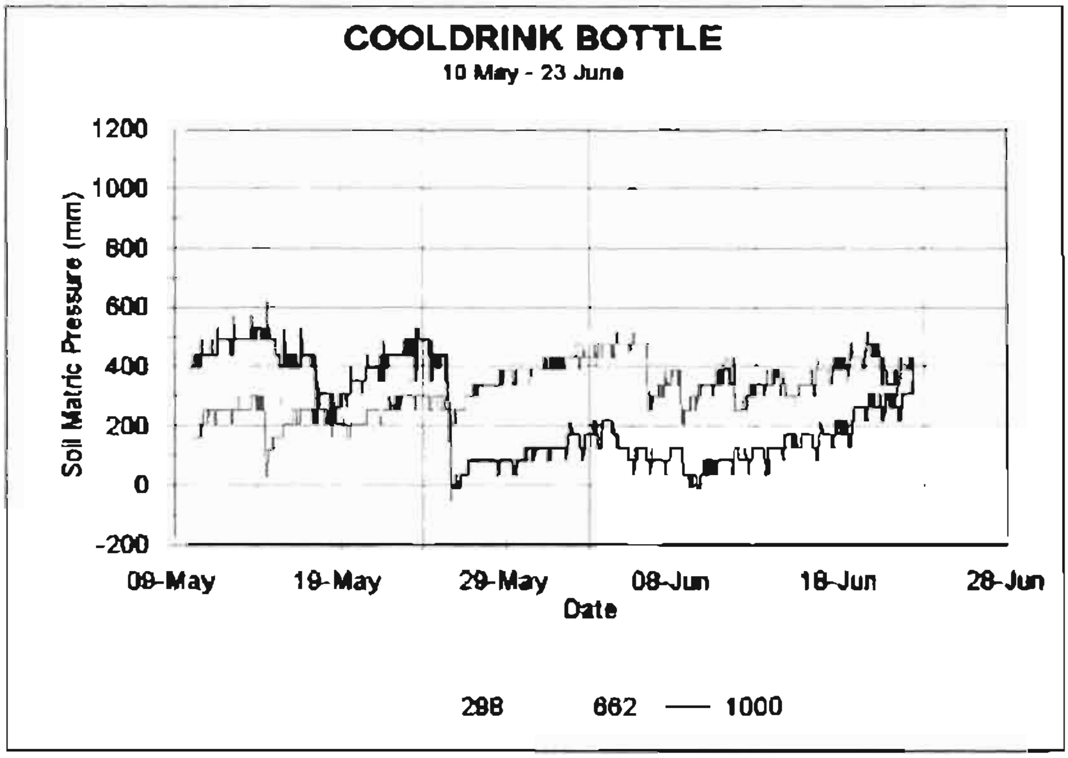


Figure 38. Tensiometer data for cooldrink bottle, winter season, site three.

The holes at the base of the cooldrink bottles required cleaning once a week as algae grew inside the bottles and they sometimes clogged up with mud. This bottle method required comparatively more effort than the other three irrigation techniques, as it took time to fill the bottles using a watering can and funnel.

5.5.3 Watering can

The data obtained from site one, one of the watering can sites, again shows a dryer soil profile compared to the drip irrigation site. Figure 39 shows that the 1000 mm tensiometer starts at a very high soil matric pressure of about 7000 mm, which it can not hold, and therefore breaks the hydraulic connectivity on about the 15 September. After replenishment on the 21 September, the soil matric pressure returns to about 6000 mm, confirming that this high value is probably correct. The 662 mm tensiometer also drops off from a value of about 200 mm on the 16 September, and returns to this level after replenishment.

The 298 mm and 662 mm tensiometers show significant drying out compared to the rates of other sites during the same period. The irrigation event affects the 298 mm on the 26 September. An event, probably rainfall, slows the drying rate on the 8 October but only in the upper 300 mm of the soil profile. Diurnal fluctuations can again be seen, having the greatest effect on the 298 mm tensiometer. One can, however, conclude that the irrigation from the watering can is not keeping the soil at a constant tension as the drip does, and that the soil at this site is much dryer.

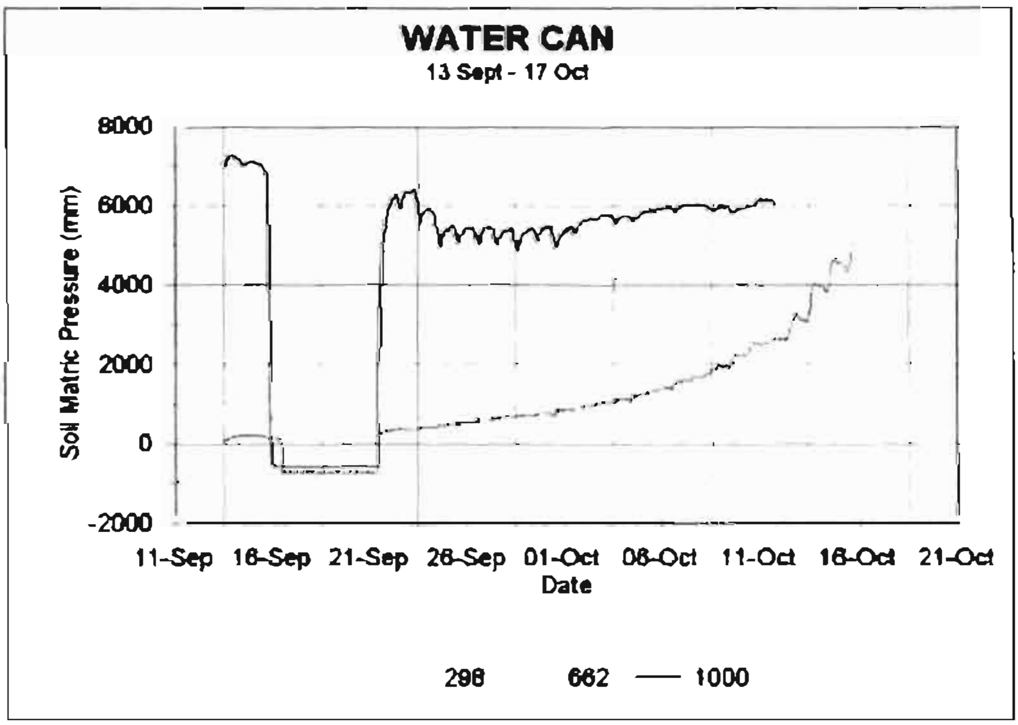


Figure 39. Tensiometer data for watering can, summer season, site one.

The first part of the season at site five shows all three tensiometers drying out slowly, and then loosing contact, hence the sudden decreases in the lines (Figure 40). The 298 mm tensiometer looses contact first on the 19 September, followed by the 662 mm and then the 1000 mm tensiometers which are delayed. However, before this the 1000 mm tensiometer is sitting at about 6000 mm soil matric pressure, with the 298 mm and 662 mm tensiometers climbing to about 4000 mm and 5000 mm respectively. This again shows a much dryer soil profile than the previous two sites. An irrigation event on the 12 September affects all three tensiometers, slowing down the drying out rate, as does an event on the 16 September.

After replenishment on 21 September, the 1000 mm tensiometer drops the soil matric pressure right down, and then again shows a slow drying out of the soil profile. This throws some doubt on the pre 21 September highs. Irrigation events on the 2, 3 and 4 October appear to affect the 298 mm tensiometer and an event on the 12 October affects the 298 mm and 1000 mm tensiometers. However, it is difficult to see exactly how they were affected as diurnal fluctuations resulting from air also play a role. One can see a steady drying out of all three tensiometers.

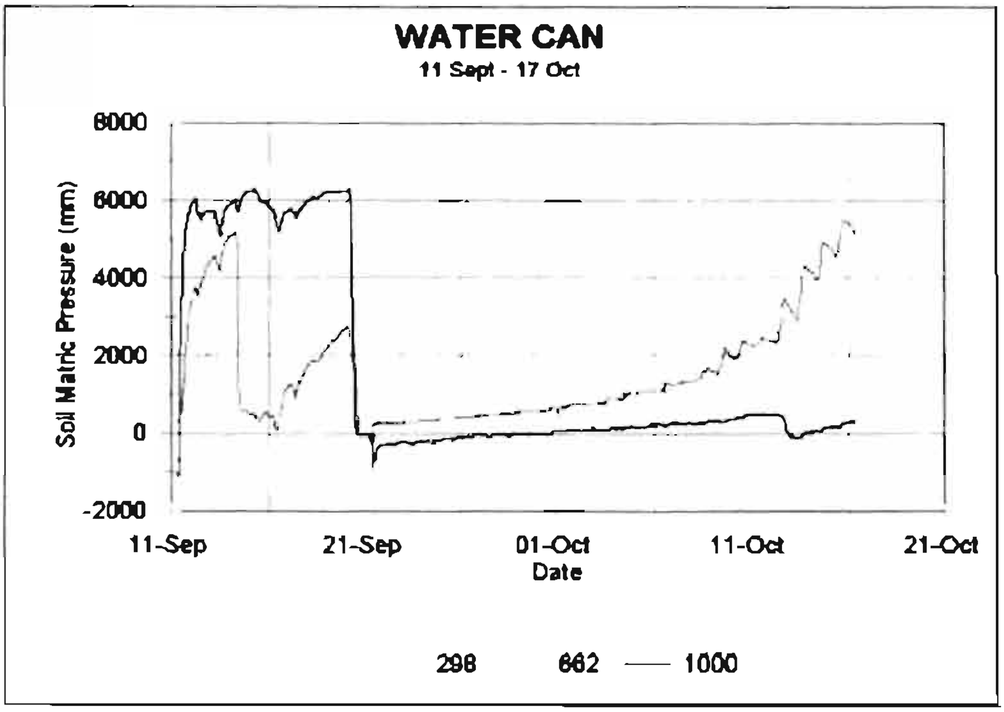


Figure 40. Tensiometer data for watering can, summer season, site five.

The data from site 5 for the winter season can be seen in Figure 41. It again shows a drying out at the 662 mm and 1000 mm levels. The 298 mm tensiometer shows diurnal fluctuations during the beginning stage. Irrigation events that took place on the 17 and 18 May appear to have an effect on the two deeper tensiometers. The large drops on the 25 May are a result of replenishment, as are the abnormal signals on 22 June. The 298 mm tensiometer appears to only operate up to the 8 June and shows a gradual drying out. The 662 mm and 1000 mm tensiometers are drying out at a much faster rate, and could be a result of the water not reaching those depths.

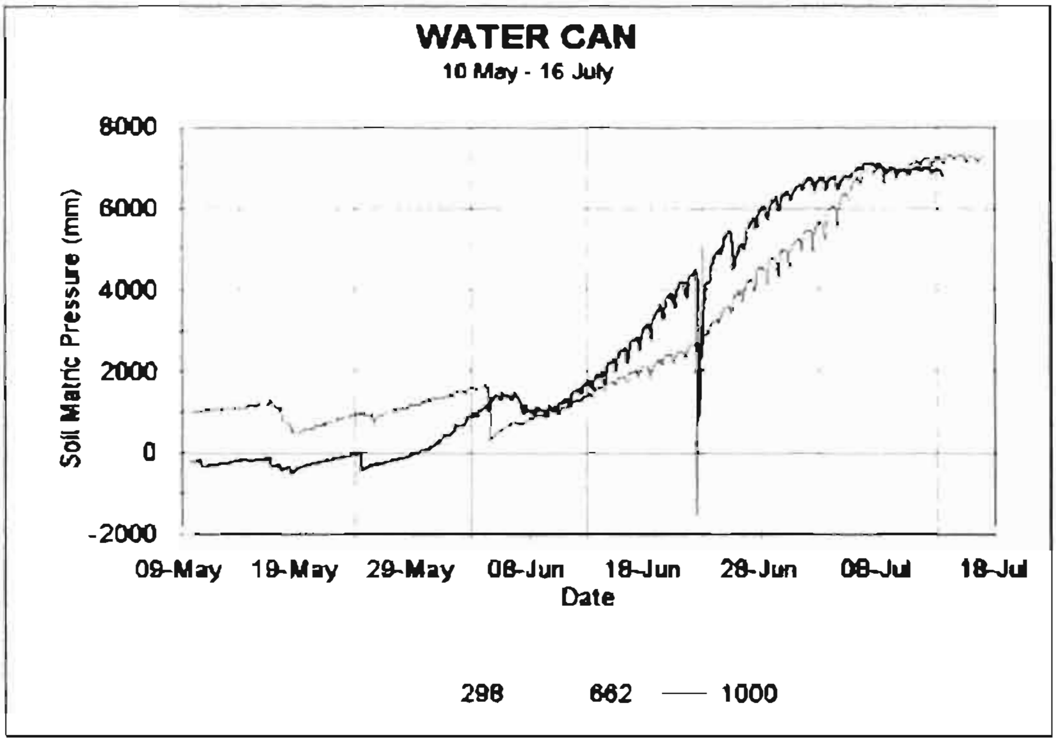


Figure 41. Tensiometer data for watering can, winter season.

The watering can method appeared to be the least efficient in terms of supplying water to the plants' roots. Plants were covered with mud when they were seedlings as a result of the water splashing when being applied. The wetting front detectors often popped up when irrigation events occurred, showing that the water front was reaching the shallower depths.

5.5.4 Wetpipe

The data obtained from site seven shows a wetter soil profile than the watering can and coke bottle sites for the summer season, however, it is still not as wet as the drip kit site. This can be seen in Figure 42. The soil is slowly drying out at all three depths, with irrigation events keeping the rate down. The irrigation that took place on the 27 September can be seen in all three plots. No other irrigation events appear to show up on any of the lines, however, the consistency of the signal indicates the irrigation ability to hold the entire profile at a steady moisture content. Diurnal fluctuations can be seen towards the end of the time series as a result of air. The soil matric pressure stays below 750 mm for the two lower depth tensiometers, and climbs to above 1000 mm for the 298 mm tensiometer.

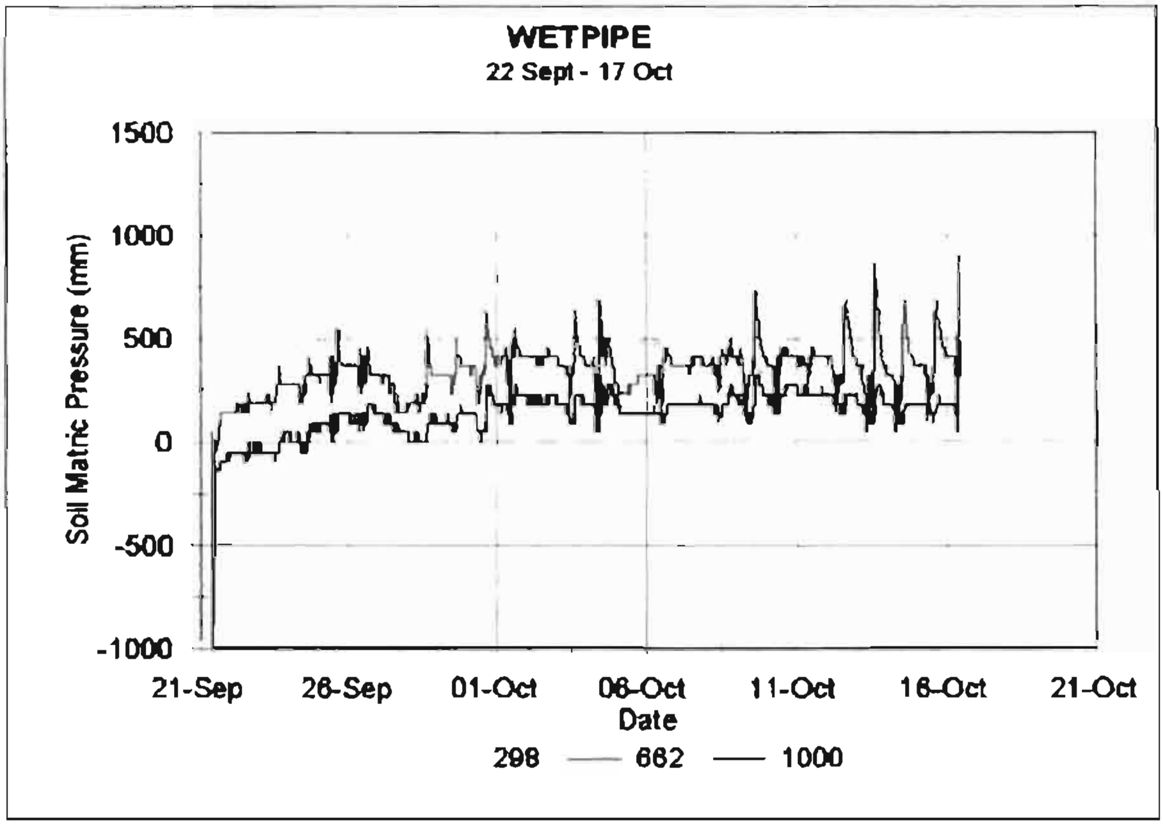


Figure 42. Tensiometer data for wetpipe, summer season.

Figure 43 shows the data for the wetpipe winter season. The 298 mm tensiometer was not connected during the first part of the winter season. It appears to operate correctly after replenishment on 25 May, and then looses contact again on about 1 June after reaching a tension of almost 8000 mm. The other two tensiometers show a dryer soil profile than the previous summer season and show a steady drying out over the season. The large decreases on the 25 May result from replenishment. The 1000 mm tensiometer appears to steady out on about the 5 June and remains oscillating around about 6000 mm soil matric pressure. The 662 mm tensiometer dries out at a faster rate. Diurnal fluctuations can be seen throughout the entire time series.

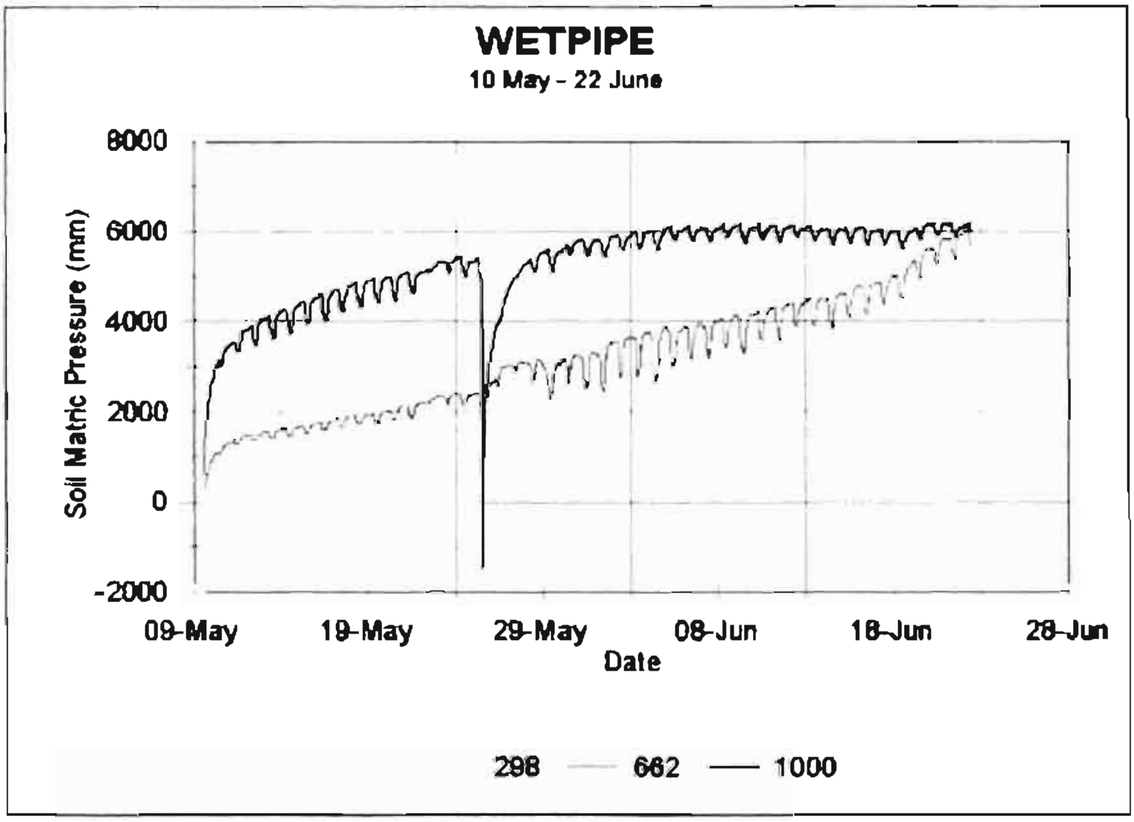


Figure 43. Tensiometer data for wetpipe, winter season.

The wetpipe required filtration after the summer season. This was carried out by flushing water through the pipe from the other direction using a hose pipe. The holes again started blocking up with mud towards the end of the winter season. The plants did not compare unfavourably with those using the other methods, however, it could be seen that the plants closer to the bucket grew larger than those further away.

5.5.5 Reference nest

The data from the reference nest for the two seasons can be seen in Figures 44 and 45. Figure 44 shows the fairly wet conditions that occurred during the summer season, with the tensiometers seldom rising to higher than 500 mm soil matric pressure. Figure 45 shows much dryer conditions in the winter season with the tensiometers loosing contact at various intervals and showing faulty signals for parts of the season.

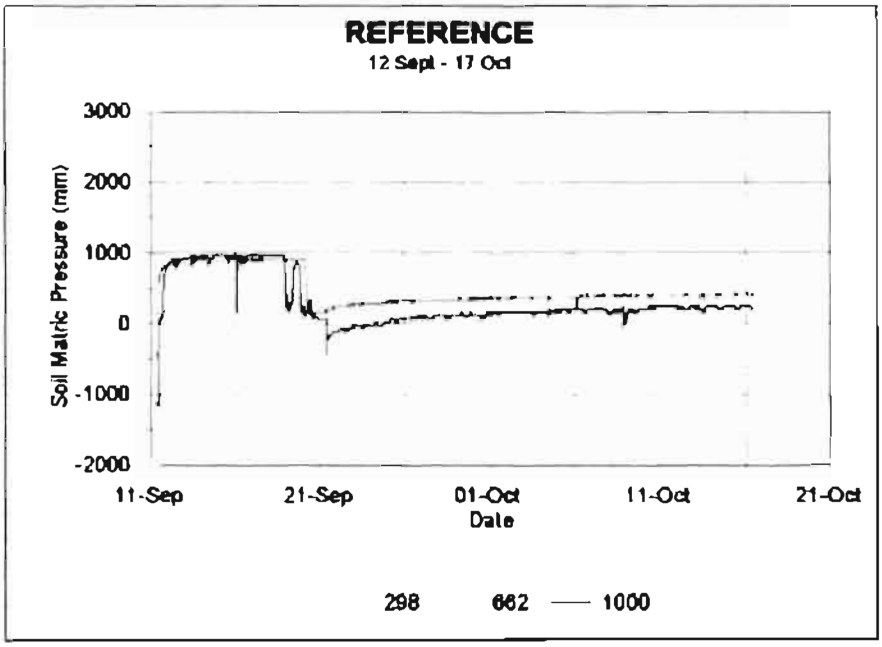


Figure 44. Tensiometer data for reference site, summer season

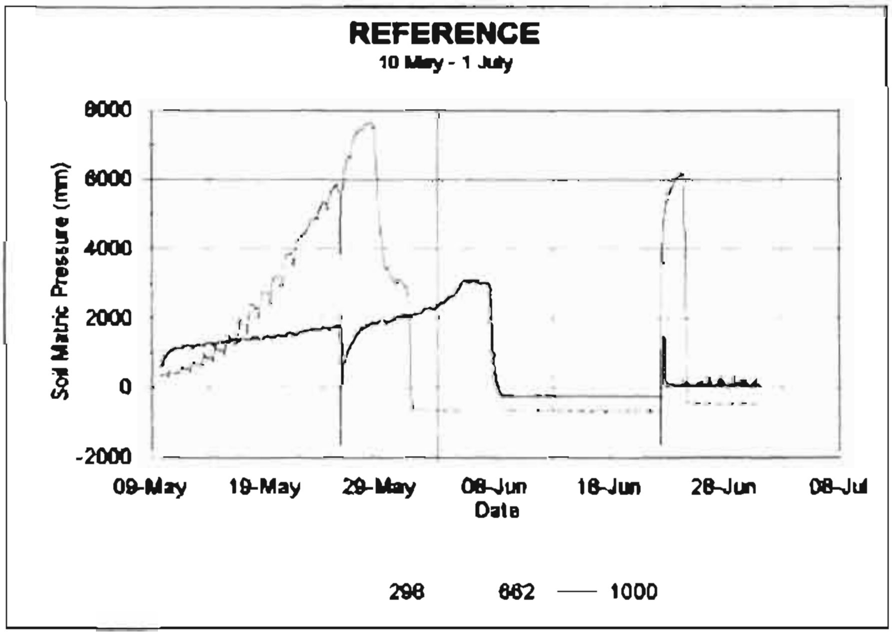


Figure 45. Tensiometer data for reference site, winter season.

5.6 Laboratory Test Results of Prototype Pumps

The two prototype pressure pumps built at the engineering workshop of the University of Natal were taken to Pretoria to be tested in the hydrology laboratory of the ARC's Institute for Agricultural Engineering in May and June, 2001. The object of these tests was to see what the pumps were capable of in terms of flow rates and heads. It was also necessary to see any problems that might arise when pumping for long periods of time as the pumps had not yet been used for any length of time. The pumps were first tested at fairly low heads, which were gradually increased as the test procedure continued.

5.6.1 Prototype one

This section presents the results of the testing phase of the first prototype pump. Table 23 shows the head and flow rates.

Table 23. Head and flow rates for prototype pump one with spring check valves.

SUCTION (m)	DELIVERY (m)	TOTAL (m)	TIME (s)	FLOW (l / s)
1	2	3	282	0.42
1	6	7	342	0.36
2	2	4	227	0.52
2	6	8	248 *1	0.48
4	2	6	Did *2	Not Pump

*1 The right hand leather cup had not formed correctly in the cylinder and while the pump still drew water without any problems, water was spraying out of this cylinder on the downward stroke. The hole for the bolt holding the piston rod to the treadle was also slightly out of place and the piston was therefore not rising in a vertical position. The hole was redrilled in the correct position so that the piston would rise vertically.

*2 It appeared that the valves were not allowing sufficient water through during the time of one stroke. Brass flap valves were then purchased and the 32 mm spring check valves were replaced with these flap valves.

It was also decided to attempt to use four leather cups instead of two on each piston rod. It was thought that this would increase the suction ability of the pump. However, the increase in leather cups did not work and the pump ceased to operate. The extra leather cups were removed and testing continued. Table 24 shows the results of the tests using the new valves.

Table 24. Head and flow rates for prototype pump one with brass flap valves.

SUCTION (m)	DELIVERY (m)	TOTAL (m)	TIME (s)	FLOW (l / s)
2	2	4	137	0.86
2	6	8	166	0.71
3	6	9	176	0.67
3.5	6	9.5	177	0.67
4	6	10	219	0.54

It can be seen that the flow rates obtained with the brass flap valves are higher than those with the spring check valves. These flow rates also compare well with the results obtained using the three imported pressure pumps (Platform: 0.2 litres per second at seven metres total head, Swazi: 0.32 litres per second at eight metres total head, and Approtec: 0.2 litres per second at ten metres total head). It was, however, necessary to increase the stroke length of the pump to allow the valves sufficient time to open during a stroke. The increased stroke length is less comfortable for the operator. Another problem noticed during the testing was that the cylinders moved around during pumping. This movement is likely to cause fatigue after long periods of use. The weld holding the treadle pivot rod to the frame broke during the tests as a result of the twisting action and the join was re-welded.

The following are the suggested modifications for a refined pump that resulted from these tests.

- The valves need to be redesigned. While the 32 mm flap valves work well, they are too expensive, costing 65 Rands each.
- The design of the frame needs to be improved. A block shaped frame would be better due to the twisting movement during pumping.

- The treadles need to be strong as bending results in too short a stroke of the pistons to draw any water into the cylinders.
- The cylinders need to be held in place to prevent lateral movement.

Redesign and rebuilding then took place. The vital components, the valves, cylinders and pistons were carefully analysed before the second prototype was built.

5.6.2 Prototype two

Table 25 shows the head and flow rates of the second prototype obtained in the laboratory tests.

Table 25. Head and flow rates for prototype pump two.

SUCTION (m)	DELIVERY (m)	TOTAL (m)	TIME (s)	FLOW (l / s)
1	6	7	71	0.65
2	6	8	73	0.56
3	6	9	72	0.48
4	6	10	74	0.45
5	6	11	Did	Not Pump

The operator stated that the pump was easy to pump and did not require much effort as it did not provide much resistance. This was probably due to the light ball valves that opened and closed quickly on each stroke. The wooden frame was light and therefore moved around on each stroke. This could be rectified by placing the poles holding the pivot rod into the ground, therefore preventing them from moving laterally and vertically. This would, however, limit the pump to a certain position in a garden, unless more than one frame was built.

The results were again favourable when compared to the imported pressure pumps. The major advantage of this pump is that it is less expensive than any of the others, including the prototype one pump. It can also be manufactured very easily with few tools.

6. DISCUSSION AND CONCLUSIONS

This discussion chapter is again divided into the different sections, the qualitative and quantitative evaluations of the two different technologies, treadle pumps and drip irrigation kits. Two other sections are also added, namely, potential areas of application where treadle pumps could be utilised in South Africa and an introduction strategy that will assist with successful introduction and adoption of treadle pumps. The final section is a conclusions and recommendations section where the work will be summarised and recommendations for future research presented.

6.1 Treadle Pump Qualitative Assessments

The first aspect that resulted from the field trials was the importance of quality control on a technology of this nature. It was a struggle to get the initial imported pumps to operate as they should. Vital components had not been assembled correctly, or were incorrectly sized. A farmer who spent hard-earned money on a pump might not be as forgiving as researchers and this could damage the reputation of future pumps. It is also easier to fix non-functioning components in a workshop full of tools than it would be in the field. Working products only should in future be demonstrated or sold to farmers. Research products should be tested on farms and by farmers but it should be stressed that it is merely a test procedure and pumps will be modified before sale takes place.

An important lesson that resulted from the fieldwork is the necessity to select the correct farmers for future on-farm trials. The women farmers from Silwayiphi were unable to adjust to using a treadle pump as a method of transporting water from the dam. One can, however, not conclude that it was the fact that the farmers were females that deterred them from using the pump. The farmers at Thuthukani and the farmer's wife from Siyazama were very willing to pump.

Silwayiphi itself was also not the correct set up for the type of pump that was placed there. There might have been a very different response had a pressure pump been introduced to fill up the drums. It is therefore necessary in future to match the correct type of pump to the garden and type of irrigation method. Farmers using furrow irrigation would probably prefer a pump that could deliver a higher flow rate and a suction pump would suit this category. However, if farmers want to fill up drums inside a garden from which they can fetch water to irrigate by hand, pressure pumps would be more suitable. Farmers could use suction pumps for this application if they lowered the drums into the ground, allowing the water to spill from the pump into the drum. It is therefore necessary that both types of pumps are introduced and that farmers are made aware of the pumps' abilities and are then given the option of which pump they would like. Pressure pumps are usually more expensive than suction pumps due to the extra set of valves, and some farmers might prefer to pay less for the pump and then bury the drums.

It is necessary to see that the cost of a treadle pump is not the only cost incurred when purchasing a pump. Piping and foot valves are expensive and should be added to the overall cost when quoting the price of installing a pump. High quality pipe, class 6 or high-density polyethylene, is required for higher suction heads to prevent collapse under suction. The inlet pipes at three out of the four qualitative sites had been purposely cut. Pipes should be buried to protect them from vandals as well as softening up in the sun.

It was disappointing to see that some of the farmers did not look after their pumps as they should have. The pumps were left outside during the rainy season, even though they were not being used, resulting in rust. This is probably because the farmers were given the pumps, and therefore did not maintain them as they would have if they had purchased them themselves. Another reason is probably due to the weight of the pumps. A pump that could detach easily from its frame could eliminate the weight problem so long as the frame structure is difficult to move, such as concrete or buried poles, preventing it from being stolen. Alternative materials such as plastics and nylon would prevent pumps from rusting. The Approtec pumps in Kenya rust away after two years, however, farmers purchase another one straight away having seen their benefits (Donaldson, 2001).

Most farmers who saw and used the pumps wanted one for themselves. Treadle pumps are a practical method of decreasing irrigation time and effort for small-scale farmers, and the farmers tended to recognise this. There is a section of these farmers who have, however, been introduced to modern pumping and sprinklers techniques. These farmers would probably see treadle pumps as a step backwards in technology. This is not always the case. A farmer from the Eastern Cape who was using a diesel pump was very keen to convert to a treadle pump having seen a demonstration. He had a small plot and was struggling to make enough profit to purchase diesel fuel for his pump. He saw the treadle pump as the exact technology that he had been looking for. It is farmers like this, as well as farmers who have never had any contact with other forms of irrigation technologies, that would be the target market for treadle pump promoters. This is confirmed by van Koppen (2000) who states that treadle pumps self-select the poor.

An aspect that requires more attention is the impact that the introduction of treadle pumps into the small-scale farming sector would have on the water resources of South Africa. It is the author's opinion that most farmers who purchase and use pumps will not significantly increase their plot sizes therefore requiring the use of more water, but will merely use the pumps to eliminate the laborious task of carrying water. Some farmers will expand and grow alternative crops, moving away from the subsistence farmer category and becoming small commercial farmers. However, it is thought that these farmers would be in the minority and would therefore not impact greatly on the water resources. This aspect requires more research.

It was disappointing to see the attitudes of both farmers and people from the business sector that were interacted with in the project. While many farmers were keen to purchase pumps, others still have the mind-set that everything will be given to them for free. Many shop assistants were helpful until they heard that the project involved assisting small-scale farmers, passing comments such as "it will never work because small farmers expect everything for free" or that such farmers are "too lazy to stand and pump all day". This sort of attitude needs to be changed if the small-scale sector is to be a success in South Africa.

6.2 Treadle Pump Quantitative Assessments

Because it uses a human energy source of variable and unknown power, it is not normally practical to test the efficiency of a treadle pump. However, a number of tests and measurements are possible to check whether the ergonomic, mechanical and hydraulic efficiencies are tolerable to most growers. It was possible to test these under laboratory conditions as it was the relative performance of rival pumps, rather than the absolute performance of a single pump, that was required.

The results of the laboratory tests that were carried out at the Institute for Agricultural Engineering are not necessarily results that would be obtained if these six treadle pumps were used by other operators in the field. However, the pumps were all tested under the same conditions and the results can therefore be compared. The operators were unfit when compared to the average human being, and farmers in the field would probably have greater fitness levels. The operators also had nothing to gain by pumping faster or slower, as they knew that they were just required to pump for ten minutes. A farmer in the field would know how much water he requires for irrigation and would therefore probably pump at a faster pace, until that volume is achieved.

All the pumps that were tested showed positive and negative qualities. Perhaps the most important factor to consider when designing treadle pumps is the cost. It would be easy to design and build a perfect treadle pump for a specific situation with an unlimited budget. However, as the pumps are targeted at the poorer farming sector, it is vital that they are as cheap as possible yet remain robust, reliable and serviceable. The IDE and KB pumps from Asia cost substantially less than all the African pumps. Even though they did not give the best performance in the tests they are very cheap, allowing poor farmers to purchase them. Farmers would probably be willing to sacrifice some efficiency for a pump that is significantly cheaper. The "best" treadle pump is therefore not the most efficient treadle pump, nor the pump that pumped the highest volume, nor the pump that pumped the greatest head. All these aspects need to be balanced with price. Treadle pumps were a success in Asia not because they were more efficient than other pumps, but because they were cheaper, but still had a reasonable output. The Approtec pump is the cheapest African pump. It is still in a price range that farmers in Kenya can afford to purchase it by themselves. The

Swazi, Platform and Swiss pumps probably fall outside that price range. While they are of a high quality and can be maintained relatively easily in the field, their price does make them unavailable to the majority of poor farmers, the target group for treadle pumps. These farmers would require aid to purchase such pumps, and this policy has not been successful in the past.

One should therefore look at every component of the treadle pumps with the intention of keeping the cost down, but still maintaining a relatively high standard of quality. The operators stated that they preferred the pumps with a built-in handle. They had, however, not purchased the pumps with their own money. New Dawn Engineering quoted that the price of the handle and pulley component was a quarter of the price of the entire construction cost of the Swazi pump. Most farmers would surely rather erect a structure that they could hold on to than pay that much extra for a handle.

There was no preference for wooden or steel treadles. The lowest price in the particular country would dictate this component. The length of treadles does, however, affect the mechanical advantage. Treadles should not be placed too close together, as this is uncomfortable for larger people. The foot position should be wide enough so that the operator feels comfortable, and treadles should not become slippery when they get wet. They should not be too high off the ground so that the operator struggles to climb onto them. The treadle height is, however, usually dependant on the cylinder height. If the treadles are high, farmers could construct a means of climbing up, such as a mound of sand next to the pump, rocks used as steps, or they could lower the pump into the ground. It should be recognised that treadle pumps will mainly be used by older women and this should be taken into consideration for new designs. Pumps should also be designed in such a way that farmers do not feel awkward while pumping, as they already feel exposed by being raised off the ground.

Cylinder materials would also depend on what is cheapest in a particular country. The PVC pipe of the Swiss pump functioned as well as the steel cylinders of all the other pumps. PVC has a major advantage over steel in that it does not rust. Rolled steel, which is welded in place, results in a seam in the cylinders, which could damage piston cups or break the vacuum if not welded correctly. Steel piping should rather be used if obtainable. Pumps should then be carefully stored when they are not in use so as not to rust.

The diameter and height of the cylinders partly determine the volume of water that can be pumped and also determines the stroke length. The larger the diameter, the lower the cylinders and the shorter the stroke length, for the same volume of water. However, larger diameter cylinders require more human effort as this pressure is related to force and area. Cylinder size should also depend on the size of the piston cups that can be easily obtained. A stroke length of between 150 and 200 mm is comfortable to sustain over a length of time. Operators usually revert to this stroke length, even if the cylinder height allows for a longer stroke length. This means that for longer cylinders, a portion of the cylinder is not used, and therefore material is wasted.

Leather piston cups would probably be the most suitable for South Africa as they are available in most farming stores. However, the hose pipe seal of the Swiss suction pump worked well, and is also easily replaceable. What is vital though is that the piston cups have a very tight fit inside the cylinders. It is also important that the piston rods rise in a vertical position so as not to break the vacuum created between the piston cups and cylinder walls. This appears easier to manage with the chain and rocker system than with the pulley and rope system. The piston rod of a single cylinder pump should be tightly sealed so that no air leaks in at the top of the cylinder.

The valves are the other determination of the volume of water that can be pumped. The friction through the pump is also affected by the valves. Rubber flaps appear to be the cheapest method available. It is important to match the volume of water desired from the pump to the size of the holes creating the valves. The rubber flaps should also seal precisely. The Swazi pump is the most efficient pump because of its larger valve area. The Approtec pump has very small holes through which the water must travel, increasing the friction through the pump. A small amount of friction through the pump is, however, needed for better ergonomics. A pump that is too easy to operate increases the strain on the muscles as no resistance is provided and therefore muscle power and not human weight is used for pumping. The foot valve should also have a large area through which the water can pass. The brass foot valves obtained from most irrigation shops appear to work well, but they are fairly expensive.

The size of the inlet and outlet pipes also effects the volume of water that can be pumped. Smaller sized pipes result in a greater head-loss due to friction. Larger pipes are, however, expensive. 40 mm diameter pipe is suitable for most irrigation requirements. However, 40 mm pipe is heavy and difficult to move around small irrigation plots. Low-pressure flexible hose would be the most suitable but is not easily available in South Africa. Class 6 pipe is necessary for the suction side as class 3 collapses at higher suction heads.

The Approtec pump has smaller inlet and outlet pipes and a smaller valve area than most pumps, therefore decreasing the volume of water pumped. It did, however, pump the greatest head, with no other imported pump coming close to the 13 metres of head pressure that the Approtec could pump. The Approtec pump designers felt that in Kenya, it was better to have a pump that produces a little less water involving a little more effort as long as it can pull up six metres maximum and then push a further seven metres, than to have a pump which is easier to operate and moves a lot of water but cannot pull from that depth nor push that height.

The frame of a treadle pump should also be built such that it is light enough to carry and easy to manage. A frame that can be easily dismantled, like the Approtec pump, is better for farmers who might want to take the important components, such as the pistons, home and leave the rest of the pump in the field. Pumps, such as the IDE pump, where the operators purchase the cylinder and piston mechanism and are then required to build the frame themselves, are cheaper. There should, however, be some form of training and back up assistance to build the frame.

Another aspect for design purposes is the input power and cadence values. The tests showed an average cadence value of 57 strokes per minute for all the operators. A value of about 60 strokes per minute, or one stroke per second, should therefore be used in a design. The average input power assumed should be approximately 50 Watts.

The laboratory tests carried out on the six pumps provided a useful insight into the technical aspects of treadle pumps. The further results from the field-testing phase confirmed these.

The results of the trial held at Boschkloof show that it is the slope and shape of the furrows that determines the success and efficiency of furrow irrigation. Treadle pumps will work as a method of placing water into the furrows, even if their flow rate is as low as about 0.7 litres per second. Farmers should pump directly into the furrows rather than attach an outlet pipe to the suction pumps. An attached outlet pipe slows the flow rate down. However, this method would require moving of the pump after every row is completed. Therefore, the pumps should be light enough for farmers to carry them. Pumping for thirty-minute sessions was obtainable for all the pumps except for the KB pump where the farmer needed to rest after every ten minutes. Pressure pumps can also work well with furrow irrigation, if the outlet pipe is not attached. One person could carry out the irrigation session provided they make sure that each furrow is clear before they start pumping. They could also pump for ten minutes and then have a brief rest while they check whether or not the water is adequately flowing in the furrows.

The results from the Kwaggafontein test show that the treadle pump can operate a hose pipe system. However, farmers should take care not to apply too much water resulting from the change to an easier and less time consuming method. If the hose pipe method is used, farmers will need to work together so that one person handles the pipe while the other pumps. In the case of a community garden, it is not necessary for each individual farmer to own a pump. If a few farmers share a pump, they could combine finances to purchase it. They could then schedule their irrigation sessions so that each farmer has an equal opportunity to use the pump.

From the results of the set of trials held at Tshepo's homestead, it can be seen that treadle pumps can operate a small sprinkler system. This would eliminate the need for two people as required by the hose pipe system. Gardena sprinklers deliver a higher volume than impact sprinklers when connected to a treadle pump. Treadle pumps can pump out of a grey water tank directly into a bucket drip irrigation kit, provided the water is filtered before entering the bucket.

6.3 Treadle Pump Prototype Development

The complexities of designing appropriate technology should not be underestimated. There are many factors that require balancing to produce the most suitable design. Most of the criteria resulting from the laboratory and field testing phase were used in the design of the two prototype pumps with the ergonomic aspects taking preference over pump efficiencies. The basic concepts of the imported pumps were used. It was decided to mount the valves externally as they would be easier to reach and it was desired that a welded unit be avoided.

The parts used were all locally available with the intention that anyone could assemble a pump, and that fewer tools and no specialised equipment would be required for production. The second prototype was a refinement of the first as it was cheaper and easier to make. The results of testing both prototypes compared favourably to those of the imported pumps. A basic working design was created and now requires follow up before introduction to farmers can take place.

6.4 Potential Areas of Application of Treadle Pumps

The meetings and site visits held in the early part of the project yielded results showing possible areas of applications for treadle pumps in South Africa. The treadle pump has made the greatest impact in countries with an abundance of surface water or shallow water tables which apparently limits its application in South Africa. However, on closer inspection it has been found that this is not the case as there are many areas where the pumps could still be used.

These include tens of thousands of community or individually owned gardens, near to surface water sources, currently being watered by hand by women who find the water where they can. In many cases, this is transported in buckets carried on the head or pushed by children on wheelbarrows. These water sources consist of large rivers and dams, small perennial streams and wetlands. As the farmers are usually carrying the water, the gardens are often situated fairly close to the water source and this is usually within the limiting height and distance factors of treadle pumps.

A second area of application exists where gardens are near to springs. There are also some areas in South Africa with shallow aquifers. Using pumps with these water sources could result in the easier transfer of water to gardens. Many community gardens already contain a powered pump and reservoir system. However, many of these reservoirs have been incorrectly sited due to the fact that farmers believe the reservoir belongs to the garden and should therefore be situated on the inside of the garden's fence. This incorrect siting results in a lack of pressure and farmers can therefore not use the irrigation system for the purpose it was designed. Treadle pumps could pump out of these reservoirs and provide the pressure to irrigate using hose pipes.

In the northern provinces, perennial streams have been artificially created by the creation of canals. There are approximately 250 irrigation schemes in the communal land tenure areas in various stages of deterioration that are due to be handed over in the course of time to the farming participants. Some of these schemes use sprinkler irrigation while others use flood irrigation. Most of them are served by canals. The rivers and dams and the canals themselves provide perennial sources of water. As a consequence of the deterioration of infrastructure and fields, conventional methods of water application are severely impaired. The treadle pump offers an interim solution to this problem and can facilitate the progressive redevelopment of the irrigation activities. In the case of many schemes the production of food for own use was forbidden in order to facilitate the production of uniform grain crops. A consequence of this was the development of private gardens along the canals. Suction pumps should be sufficient to irrigate these gardens, drawing water from the canals and spilling it directly into a supply furrow.

Another application that is currently gaining favour throughout Africa is the potential of rainwater harvesting and the reuse of grey water from kitchens and bathrooms. Once gathered in storage tanks, treadle pumps could transfer this water to nearby homestead gardens. This recycling of water would encourage efficiency in water scarce areas as well as promote gardening and hence food security.

6.5 Future Introduction Strategy of Treadle Pumps

It is believed that treadle pumps should be regarded as one component in the development of an effective small-scale, irrigated sector in South Africa. However, additional research into aspects concerning such farmers should be carried out before pump introduction and adoption can take place. If grower adoption is to be successful, the introduction strategy should be based on sound engineering and commercial practices and should recognise the need for participatory approaches. If it is not done properly, the technology could be blamed and this could have harmful consequences for the technology. For example, if farmers are introduced to a treadle pump that has not been thoroughly tested, and therefore breaks within the first month of use, they will always relate the treadle pump concept with that particular pump's failure.

Firstly, the potential market for these pumps needs to be established. The introduction strategy will differ greatly whether 1000 or 10 000 pumps are sold within the first year and thereafter. There is very limited information as to how many gardens exist that would use the pumps. Data is available on the gardens and irrigation schemes that have been established and assisted by government departments or other organisations. However, while some of these gardens might convert to using treadle pumps, it is not these gardens that will be the initial primary target market as they have already been introduced to more advanced forms of irrigation technologies such as diesel pumps and sprinklers. Research needs to be conducted into how many "unofficial" gardens exist where rural farmers, usually women, are transporting water by hand for irrigation. In addition to this, it is necessary to know where these gardens are situated in relation to the water sources, and how the farmers are currently irrigating.

A number of methods could be used to gather this information. The quickest, most accurate way would probably be to use existing extension officers that operate in the areas. It is believed that they would have the greatest knowledge of a particular region and could be used to sketch rough diagrams of all the gardens in their area (Crosby, 2001). A qualitative rather than exact survey would be sufficient to estimate the potential market.

The irrigated systems should be marketed as two products, namely, (a) commercially manufactured units and (b) low-cost starter pumps sold in a kit form for assembly by local groups and individuals. However, both these types of pumps require distribution into the remote rural areas and research into how this distribution will take place is required. In order to advise on the marketing and servicing of pumps, it is necessary to understand available distribution channels as well as to review the institutional arrangements for distributing pumps in countries where introduction has been a success. The quickest method to establish possible distribution channels would be to investigate how equipment such as farm machinery, brick and block making equipment, hand tools and general inputs are currently being distributed. Another aspect that requires attention is how credit options for poor farmers could be accessed and negotiated.

It appears that a major factor in the success of treadle pump adoption in Bangladesh was their low-cost and simplicity. A product with similar characteristics should find a niche starter market in South Africa. In addition local assembly from a core kit is desirable as it will promote rural industry and give farmers easier access to maintenance and spare parts. The second prototype pump developed in this project holds strong promise in meeting these requirements in that the frame can be easily fabricated from local timbers and few tools are required for assembly. All the pump components are composed of various polymers that will not rust and are easily replaceable. This pump still requires further development before it reaches final prototype stage. This will include more in-depth performance testing and durability and fatigue testing using an appropriate rig.

It is recommended that once a satisfactory prototype has been established, a limited number of units are produced and sold at special prices to selected assemblers and distributors for sale to farmers. Organisations such as Agricultural Departments and NGO's should then be involved in the on-farm evaluation of the units. After significant use, a customer use evaluation should be undertaken by the marketing organisation. Once the market is established an ongoing impact analysis should be undertaken.

6.6 Drip Irrigation Kit Qualitative Assessments

The qualitative evaluations of the drip irrigation kits were not as successful as the treadle pumps. The immediate benefits of the kits were not visible to farmers. Most farmers were not convinced that the kits supplied sufficient water to their plants. This highlights the necessity for thorough training when introducing the kits to farmers, as drip irrigation is often a new concept for them. A possible reason for the failure in adoption of the kits in the KwaZulu-Natal sites is the greater availability of water in the province. Farmers do not see a necessity to irrigate efficiently, as they are unaware of water scarcity. It will therefore be difficult in the future to convince farmers there to pay for such a technology.

The drip kits should have the greatest impact on areas where water is scarce or where farmers have to pay for their water. There are many parts of South Africa, especially in the Northern Province, where it is very dry and farmers have to walk far to fetch water for household use. These farmers should be encouraged to reuse their grey water to grow vegetables with. It appears that the drip kits would have more success with individual farmers growing in kitchen gardens than farmers growing in community gardens. The latter are worried to leave the kits in the gardens as they might get stolen.

6.7 Drip Irrigation Kit Quantitative Assessments

The results show that the drip irrigation kit is more able to keep the soil water level constant than the other three irrigation techniques. The soil matric pressure was usually less than 200 mm for the drip kit site, except towards the end of the winter season when the 298 mm tensiometer rose to just below 400 mm. The second wettest site is the cooldrink bottle site where the soil matric pressure was always less than 1000 mm. The wetpipe drip irrigation kit was able to keep the soil water at a fairly constant level during the summer season, at below 1000 mm. However, when comparing this result with the reference nest, it shows that rainfall probably had an effect on the wetter soil conditions. The wetpipe kit shows tensions of up to about 6000 mm during the winter season. The watering can site shows the driest soil profile, with the soil matric pressure up to about 6000 mm. However, this is still not as dry as the reference site where the values climb up to above 6000 mm and then loose contact due to the excessively dry conditions.

It should be noted that this trial was carried out on a very small scale, and that results should be checked against future research results. It is the author's opinion that the tensiometers were set up too deep for the level of results that were required and should rather have been at depths of about 200 mm, 350 mm and 500 mm.

6.8 Conclusions and Recommendations

Increasing evidence is showing that irrigation can assist with alleviating poverty and promoting food security for rural people in South Africa. The technologies evaluated in this project are suited for use by emerging farmers and can be used to promote irrigation. However, the choice of any new technology should be done in full consultation and participation with the farmers and no one irrigation technology can solve the needs of all small-scale farmers. Each technology has its own place. The aim is not to replace what is currently being used in South Africa but to increase the number of options available.

A farming systems approach should be used in the introduction of any new technology to farmers. Evaluation of a particular technology on its own will not give a true reflection of the impact that it would have in the future. A technology might work perfectly in a laboratory or a well managed field trial, but might not be the technology required to meet the needs of most farmers. It is vital that the technology be viewed in the context of the small-farmer system. The approach should be such that all the factors that influence the decisions of the farmers are taken into account. Government, extension services, access to markets, economics including credit access, access to the equipment and the role that farming plays in the life of a farmer are just some of the factors to be considered.

There is a great challenge to increase the options for South African farmers to achieve productivity improvements through increased awareness, education and training and the implementation of affordable technologies. Farmers and technical officers need greater exposure to the different irrigation technologies available, and the advantages, disadvantages and implications of adopting a particular technology must be explained to them so that they are able to make an informed decision. South Africa has some excellent applied research resources and facilities in agriculture and these research institutions have an important role in disseminating research results and, perhaps more importantly, demonstrating affordable technologies.

Treadle pumps and drip irrigation kits can play a large role in future irrigation development. Government aims to withdraw assistance from irrigation schemes and community gardens and sustainable technologies will need to be introduced and adopted if failure of these schemes and gardens is to be prevented. Treadle pump and drip kits have an advantage in that they are affordable to farmers, giving them individuality and the ability to make their own decisions instead of constantly relying on others. Community projects have tended to fail in the past and it is recommended that more research be carried out into the advantages of providing assistance and support to individuals instead of entire community initiatives only.

These technologies will also provide a stepping stone for some emerging farmers to move away from merely growing for subsistence, to becoming small commercial growers. Once farmers are more experienced and begin making greater profits, they could then begin using more sophisticated technologies.

This project has provided an initial analysis and study of alternative technologies suitable for use by small-scale farmers. It has been found that most farmers accepted the technologies under certain conditions and therefore there should be a future market for them in South Africa. This initial, limited introduction should now be followed up with further research into technology development and an introduction strategy. An initial expectation has been created amongst farmers who have seen and used the technologies, and this should be followed up soon if disappointment is to be avoided.

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8. APPENDICES

APPENDIX A CONTACT DETAILS OF MANUFACTURERS AND PROMOTERS OF EVALUATED TECHNOLOGIES

Approtec: Approtec pump

Contact: Nick Moon
Address: PO Box 64142
Nairobi
Kenya
Phone number: 09254 278 7380
E-mail address: moon@nbnet.co.ke

BRD Engineering: Swiss pump

Contact: Brian Barry
Address: PO Box 13576
Elspark
1418
Phone number: 011 824 0344
E-mail address: brdeng@global.co.za

Chapin Watermatics: Bucket kit

Contact: Dick Jackson
Address: PO Box 490
Watertown
New York
13605
Phone number: 1 315 782 1174
E-mail address: chapin@gisco.net
Website: http://www.chapindrip.com

International Development Enterprises:	Zambia P, Zambia S and IDE pumps
Contact:	Mukula Makasa
Address:	PO Box 350040 Chilanga Lusaka
Phone number:	09260 123 7685
E-mail Address:	idezambia@zamnet.zm
Website:	http://www.ideorg.org

International Development Enterprises:	Drip kit
Contact:	Dr V. Dixit
Address:	C5/43 Safdarjung Development Area New Delhi India
Phone number:	91 11 696 9812
E-mail address:	ide@ideindia.org

New Dawn Engineering:	Platform and Swazi pumps
Contact:	Crispin Pemberton-Pigott
Address:	PO Box 3223 Manzini Swaziland
Phone number:	09268 518 4164
E-mail address:	crispin@newdawn.sz
Website:	http://www.newdawn-engineering.com

Shree S.K. Industries:	KB pump
Address:	10 Abhishek Plaza Exhibition road Patna

	800001
	India
Phone number:	91 612 427 402
E-mail address:	info@skipumps.com
Website:	http://www.skipumps.com

APPENDIX B PRA RESULTS AND MEETINGS

SITE NAME: Nkululekhu DATE: 11/04/2000 ORGANISATION: Dept of Agriculture

COMMUNITY

1. What is the average age of the farmers? 40 - 50 years
2. Who mainly farms, males or females? females
3. Do the farmers own the plots or are they employed by someone? Chief owned / tribal land
4. How long have they been farming for? 5 - 10 years
5. What are the theft and vandalism levels like? Not too bad, controlled with internal police. Hoses taken home at night.
6. Where does the majority of the community members work? Pietermaritzburg
7. What is the average income of community members? ?
8. What is the politics of the community? IFP
9. Is the farmed area fenced? Yes, with wire and thorny bushes
10. What is the size of the community? ?
11. Are there any NGO's or government organisations working there? Department of Agriculture (KZN) South West Region

MANAGEMENT

1. How well trained are the farmers? Highly, have had intense training
2. What is their level of technical understanding? High, understand sprinkler parts, pipes etc.
3. How well organised is their current system? Good, improved with recent training module
4. Are there ever arguments amongst the farmers, why? No

MARKETING

1. Are most of the crops sold or used for self-consumption? Mostly for self consumption
2. Are the crops that are sold, sold within the community or externally?
3. What is the average current income from the crops that are being sold?
4. Is farming their only source of income or do they have other work? No, have other work
5. What do they spend on growing crops? Buy their own seeds, pesticides, herbicides, fertilizers
6. Are there any subsidies given? No, not after irrigation system was implemented

CROPS

1. What crops do the farmers grow? Mostly vegetables
2. What conditions are the crops in? Very good since improved irrigation
3. When do they grow crops? All year. Departments policy must grow more than 70% of the time
4. Where do they get their seeds and fertilizer?
5. Is there a definite irrigation schedule? Yes
6. How much water do they give to the crops? *
7. What are the reasons for past crop failures? Aphids, poor seasons, pesticides too expensive

CLIMATE, TOPOGRAPHY AND SOILS

1. What is the average rainfall in the area? 800 - 900 mm
2. Is the rainfall short storms or long periods of drizzle? storms
3. What are the temperatures at the site, is there much evaporation? High midday temperatures, valley, light frost in Winter

4. What sort of soil is found at the site? Oakleaf, 7 - 10% clay, 600 - 1000 mm deep
5. Is there a lot of erosion? No, trees around
6. Is the land very sloped? 7 - 8%
7. Does a lot of run off occur? Some, want to plant Vetiver grass to control it
8. What is the size of the area being farmed? 70 x 100 m (about 0.5 ha)
9. Is the area surrounded by trees or out in the open? Some trees

CURRENT INFRASTRUCTURE

1. What is the current method of irrigation? Gravity fed, hdpe mainline, laterals, into Gardena sprinklers
2. Are there any problems with this method? Just been installed
3. What is the water source? Small river
4. Are there taps on the site? Self sealing hydrants
5. How efficient is the current system? very
6. What sort of land preparation do they use? Initially plough with tractor, then hoe

*1 dragline: 40 x 20 m. 1 sprinkler: 5 m diameter. 20 minute stand time

0.8 - 1 m^3/hr: sprinkler delivery. 8 hour day, 16 moves 5 x 5 grid

7 am - 12 am work times

SITE NAME: Zinzelene   DATE: 20/04/2000   ORGANISATION: Farmers Support Group

COMMUNITY

1. What is the average age of the farmers? > 45

2. Who mainly farms, males or females? females

3. Do the farmers own the plots or are they employed by someone? 0.5 community plot, 0.5 individually owned

4. How long have they been farming for? 2nd season

5. What are the theft and vandalism levels like? None

6. Where do the majority of the community members work? Men in towns such as Pietermaritzburg

7. What is the average income of community members? ?

8. What is the politics of the community? Stable, IFP / ANC. Have had problems in the past

9. Is the farmed area fenced? Yes

10. What is the size of the community? 5000 people

11. Are there any NGO's or government organisations working there? Not at the moment, Department of Agriculture (KZN) is trying to get involved

MANAGEMENT

1. How well trained are the farmers? Haven't had courses, know what is going on though.

2. What is their level of technical understanding?

3. How well organised is their current system? Good

4. Are there ever arguments amongst the farmers, why? No, mostly own their own plots

5. Do the farmers seem eager to try new methods? Yes

MARKETING

1. Are most of the crops sold or used for self consumption? Mostly for self consumption, but the excess is sold
2. Are the crops that are sold, sold within the community or externally? locally
3. What is the average current income from the crops that are being sold? R2.50 per cabbage. About R 700
4. Is farming their only source of income or do they have other work? No
5. What do they spend on growing crops? Buy their own seeds, don't use fertilizers
6. Are there any subsidies given? No, recently won some money in a FSG competition for the best community garden

CROPS

1. What crops do the farmers grow? Only vegetables, cabbage, spinach, carrots etc.
2. What conditions are the crops in? Very good
3. When do they grow crops? All year
4. Where do they get their seeds and fertilizer? Seedlings from Umgeni Nursary, use manure and compost
5. Is there a definite irrigation schedule? Depends on the weather, usually twice a day
6. How much water do they give to the crops? Use cans with holes punched in the bottom, use 2 cans (1 litre) per row (4 m)
7. What are the reasons for past crop failures? None

CLIMATE, TOPOGRAPHY AND SOILS

1. What is the average rainfall in the area? 500 - 650 mm
2. Is the rainfall short storms or long periods of drizzle? both, Berg conditions
3. What are the temperatures at the site, is there much evaporation?
4. What sort of soil is found at the site? sandy loam
5. Is there a lot of erosion? No, have planted Vetiver grass
6. Is the land very sloped? 2 - 3%
7. Does a lot of run off occur? No due to Vetiver grass
8. What is the size of the area being farmed? 80 x 35 m
9. Is the area surrounded by trees or out in the open? No trees, in the open

CURRENT INFRASTRUCTURE

1. What is the current method of irrigation? tin cans
2. Are there any problems with this method? very time consuming
3. What is the water source? Small perrenial stream about 10 m from garden
4. Are there taps on the site? No
5. How efficient is the current system? Unknown
6. What sort of land preparation do they use? hand hoed

SITE NAME: Ndaya DATE: 20/04/2000 ORGANISATION: Dept of Ag. South East Region

COMMUNITY

1. What is the average age of the farmers? 55
2. Who mainly farms, males or females? Half male, half females
3. Do the farmers own the plots or are they employed by someone? Each own own plots
4. How long have they been farming for? 1984 began with a small area, extended May 1999
5. What are the theft and vandalism levels like? None
6. Where do the majority of the community members work? Durban and Toti
7. What is the average income of community members? ?
8. What is the politics of the community? IFP
9. Is the farmed area fenced? Yes
10. What is the size of the community? 12000 people
11. Are there any NGO's or government organisations working there? Just the Dept of Agric. The Dept of Works is trying to impliment a new sprinkler system

MANAGEMENT

1. How well trained are the farmers? Fairly experienced, extension service offered
2. What is their level of technical understanding? Not very good, require training
3. How well organised is their current system?
4. Are there ever arguments amongst the farmers, why? No
5. Do the farmers seem eager to try new methods? Yes

MARKETING

1. Are most of the crops sold or used for self consumption? Mostly for self consumption, but the surplus is sold
2. Are the crops that are sold, sold within the community or externally? Locally, market and small shops
3. What is the average current income from the crops that are being sold? R 100 - R 200
4. Is farming their only source of income or do they have other work? No, have other work
5. What do they spend on growing crops? Buy their own seeds and fertilizers
6. Are there any subsidies given? Dept supplies chemicals, otherwise none, try to promote independance

CROPS

1. What crops do the farmers grow? Vegetables, cabbage, spinach, carrots, onions, beetroot, tomatoes
2. What conditions are the crops in? good
3. When do they grow crops? All year
4. Where do they get their seeds and fertilizer? Seeds from Richmond, fertilizers from Eston or Prospection
5. Is there a definite irrigation schedule? No, irrigate when need to
6. How much water do they give to the crops?
7. What are the reasons for past crop failures? Cutworm

CLIMATE, TOPOGRAPHY AND SOILS

1. What is the average rainfall in the area? 600 - 900 mm
2. Is the rainfall short storms or long periods of drizzle? both

3. What are the temperatures at the site, is there much evaporation? High temperatures
4. What sort of soil is found at the site? sandy loam
5. Is there a lot of erosion? Yes
6. Is the land very sloped? Yes
7. Does a lot of run off occur? Yes
8. What is the size of the area being farmed? 10 ha area, only using 0.5 ha
9. Is the area surrounded by trees or out in the open? trees

CURRENT INFRASTRUCTURE

1. What is the current method of irrigation? Fetch water in buckets
2. Are there any problems with this method? A steep walk down a bank to the river and the people are old
3. What is the water source? Umkomaas River
4. Are there taps on the site? Not at the moment. A new sprinkler system is being implemented with hydrants
5. How efficient is the current system? Unknown
6. What sort of land preparation do they use? Hire a tractor to plough

A number of organisations were visited to view their role in assisting and promoting small-scale irrigation in their respective areas. The following are brief summaries of the meetings.

Farmers Support Group

The Farmer's Support Group (FSG) has two offices, one situated on the grounds of the University of Natal in Pietermaritzburg and the other in Shongweni, near Hillcrest. The Pietermaritzburg office works with farmers in the Stoffelton and Escourt areas of KwaZulu-Natal. These farmers all fetch water from nearby water sources and carry it back to irrigate by hand. The Shongweni office works with gardens in the Umlazi catchment and promotes rainwater harvesting by using traditional means. These include building terraces or swales to slow the flow of water down, mulching to decrease evaporation and soil conservation using compost. Most of these gardens have access to water through taps. The farmers pay for the water themselves. Some irrigate using furrows while most use dragline systems. The FSG is eager to promote new technologies providing they are affordable and the farmers can maintain them themselves.
Contact person: Monique Salomon, 033 260 6278, Raymond Auerbach, 031 768 1177.

Department of Agriculture (KwaZulu-Natal)

The Department of Agriculture is installing irrigation systems into many community gardens in KwaZulu-Natal as part of the Chase the Hunger project. The systems consist of high density polyethylene (hdpe) mainlines joined to hdpe laterals connected to hose pipe draglines and procast sprinklers. They reason that the farmers are unsure of what they want and that the Department is therefore providing them with what they feel is best.

The Department is aware that more research should be carried out on the systems. They are however being pressurised to implement systems to give people access to water. They received R48 million in 1999 to assist small farmers in the province. They adopted 200 community gardens, mostly less than four hectares in size. They installed the systems into these gardens. People from communities are used as labour and all the equipment and fencing is paid for by the Department. Some of the gardens are gravity fed but many have received diesel pumps, and a few electrically powered pumps. On a recent visit to one of the gardens it was found that the farmers were again watering by hand. When questioned why, they said that the diesel was too expensive to pay for. The Department however claims that the farmers were informed of the costs before installation.

The Department is eager to adopt the idea of the treadle pump. They felt that while pumps would not be used in gardens that have already received powered pumps at no cost, there could be a place for them in the future in newly developed gardens.
Contact person: Pierre Viljoen: 033 355 9341

University of Zululand

The University assists farmers in the area with extension services. The particular extension worker that was met believes that many farmers in the area do not take farming seriously and merely farm as a hobby. Many of the projects worked with have flourished initially but have deteriorated once the initial assistance has withdrawn. Farmers struggle to sell their produce as the market in the area is limited.

Most farmers irrigate by hand and a few use flood irrigation. Some homesteads have taps near their gardens and irrigate using hose pipes. The extension worker had been promoting the cooldrink bottle drip system and organic farming amongst the farmers.
Contact person: Lawrence Mkaliphi: 035 902 6000.

The Valley Trust

The Valley Trust deals mainly with emerging commercial farmers with a homestead context. They have a training garden situated on their grounds and use it to demonstrate their work to farmers as well as visitors. All the gardens with which they are currently dealing fetch water in buckets from nearby streams and irrigate using buckets or watering cans. While they are interested in promoting low-cost

technologies, they feel that spare parts should be easily available and that the technologies should be locally manufactured.
Contact person: Richard Haige: 031 777 1955

Catholic Church in Marrianhill

The Church currently deals with small, individual farmers based near the south coast of KwaZulu-Natal. It is funded by a German organisation. The church promotes soil and water conservation. This is done by training farmers to use methods such as mulching and planting Vetiver grass. The sizes of the homesteads vary from a quarter of a hectare to three hectares. The farmers avoid purchasing seed by saving seeds from previous crops. They purchase small amounts of fertiliser with money received from pensions or other jobs. The church believes that the focus should change from community gardens to individual farmers, as many community gardens fail and require rehabilitation.
Contact person: Vincent Neussl: 082 659 4637.

The Woman's Leadership and Training Program

The Woman's Leadership and Training Program is based at the Reichenau Mission near Underberg in KwaZulu-Natal. They promote organic gardening, permaculture and water harvesting, including swales and mulching. They work with many nearby communities, dealing mainly with individual homesteads. One such community is the Makolwene community. The farmers are currently fetching water and irrigating with buckets as they are poor and other techniques are too expensive. Some have taps nearby from which they fetch water. The farmers go to the mission for training. They sell their surplus vegetables. It appears that many of the younger community members are not interested in farming work and the Program is attempting to encourage them to get involved.
Contact person: Lihle 033 701 2601

EnvironDev

EnvironDev is working on a land care project, which consists of four sectors. They are working on the medicinal plants sector. The other sectors are food and beverage, craft and soil conservation using Vetiver grass. EnvironDev piloted a community garden, Macimeini, near Empangeni in northern KwaZulu-Natal. The garden is the first in the area to attempt the cultivation of medicinal plants. It has a very high water table and the farmers are currently lifting water out of shallow wells by hand and carrying it to the point of application. EnvironDev is currently looking for alternative, cheaper ways to pump water from the shallow wells to the area where the medicinal plants are planted.
Contact person: Matthew Plaistowe 082 958 3329

Renewable Energy Development Group

The Renewable Energy Development Group is based in Kloof near Durban. They have been working with a community nearby Inanda Dam installing solar panals at schools and shops in order to get power to the area. They have also been involved together with the Brace Research Institute in America, developing a low-cost pump known as a hydrostatic coil pump.
Contact person: Will Caywood 031 764 6292

Farming Systems Consulting Service

The Farming Systems Consulting Service (FSCS) is based in Stellenbosch in the Western Cape. They have been involved with promoting a drip system for small-scale farmers consisting of a 210 litre drum, half filled with layers of stone and sand used as a filter. 15 mm ldpe pipe with holes punched in using a hot nail is used as the dripper lines. String is threaded through the holes and knotted on both ends. The FSCS is aware that the system is not very uniform in terms of the water applied to each plant, but it is cheap and the farmers are growing for self-consumption and not commercial purposes. The area around the Cape Flats near Cape Town, where the FSCS is working is very dry and people often have to walk for several kilometres to fetch water from the nearest tap. The FSCS is using the drum system to show people how dirty water can be reused to grow vegetables. The filter filters out all the soap

and oils found in grey water, cleaning it sufficiently to use on vegetables. The holes in the pipe are unblocked by moving the string back and forth when they block up.
Contact person: Gerrie Albertse 021 886 6148

BRD Engineering

BRD Engineering is situated in Wadeville, Johannesburg. They are currently focusing on producing three pumps, for household water and irrigation. All the pumps work using human energy. They export most of these pumps to countries such as Malawi, Mozambique and Angola. The market for V.L.O.M. Handpumps (Village Level Operation and Maintenance concept established by the World Bank and UNICEF nearly 20 years ago) has recently started picking up in South Africa with more interest being shown.

The first pump, which they produce, is the Afridev hand pump, which is very popular in many other African countries. It can pump water from a borehole up to about 45 m depth. The attraction to this pump is that it can be easily fixed and maintained by the villagers themselves with very few tools. The valves at the bottom of the shaft can be reached very easily and replaced. The hand pump is best suited for household water but it can also be used for irrigation if desired.

Another pump, which BRD has been marketing is the Round-about pump, on which kids can play while pumping water. The pump sells for a total of R 35 000 including the tank and installation.

After a recent conference in Europe where they were introduced to the concrete treadle pump based on the Swiss design, BRD have now started producing treadle pumps. The pump, solely a suction pump, is called a concrete treadle pump due to the concrete encasing holding the PVC cylinders in place. The rest of the pump is supported by a hold, which can either be a steel frame or concrete base. The pistons hold a hose pipe used as a seal, and the valves consist of a rubber flap held in place with two short pieces of bicycle spokes. The parts can easily be replaced and spares are not difficult to find. The pump sells for about R 1500. BRD is getting involved with training individuals to produce the pumps in rural areas.

Contact Person: Brian Barry: 011 824 0344

New Dawn Engineering

New Dawn Engineering is based in the Matsapha Industrial area on the outskirts of Manzini in Swaziland. They were approached by the FAO in June, 2000, to produce 20 treadle pumps based on the Masvingo pump design from Zimbabwe. The pumps were produced with a few minor adjustments, such as a more stable base and thicker steel cylinders, and sold to the FAO to be sold to farmers.

New Dawn then designed a new pump themselves. The new pump is called a Platform pump and consists of a single, double acting cylinder instead of two single acting cylinders. The operator rocks the pump from side to side instead of treadling. The pump was still in the design phase at the time of the visit but will be sold for about R 800 when built. New Dawn prefers to build equipment that will last, even if it is at a slightly higher price. They believe that once the market has been established with better quality treadle pumps, other manufacturers will begin producing "spin offs" allowing the poorer people to also benefit from the technologies.
Contact person: Crispin Pemberton Pigott 09268 518 4194

APPENDIX C PROTOTYPE PUMP COMPONENTS LISTS AND DESIGNS

The first prototype pump was made from galvanised fittings and had a steel frame. The second pump was produced out of nylon fittings and had a wooden frame. Tables 26 through to 29 present the materials required for the different sections of the two pumps.

Table 26. Materials required for the frame of prototype pump one.

LENGTH / AMOUNT	DIMENSIONS	NAME	COST
6 m	38 x 38 x 2 mm	Square Tube	R 77.40
3.5 m	25 x 25 x 2 mm	Square Tube	R 29.39
1 m	16 mm	Round bar	R 5.43
3	16 mm	Bolts with Nuts	R15.00
1 m	10 mm	Threaded Rod	R 6.51
2		Shackles	R 3.54
750 mm		Chain	R 11.60
TOTAL COST OF FRAME			**R 148.87**

Table 27. Materials required for the pump section of prototype pump one.

LENGTH / AMOUNT	DIMENSIONS	NAME	COST
0.5 m	110 mm, class 9	PVC pipe	R 19.32
2	110 mm	PVC end caps	R 10.80
4	110 mm	Cup leathers	R 61.20
2	12 x 30 mm	Eye bolts	R 10.76
6 x 0.01m^2	3 mm	Sheet steel	R 5.34
2	32 mm male thread	Tank connectors	R 52.00
4	32 mm	Galvanised T-pieces	R 23.40
10	32 mm	Galvanised Nipples	R 37.80
2	32 mm	Galvansied Elbows	R 9.00
1	32 mm	Galvanised Union	R 11.26
2	32 mm	Galvanised pipe connectors	R 14.34
20 mm	32 mm male threaded	Galvanised pipe	R15.00
4	32 mm	Brass check valves	R 151.20
TOTAL COST OF PUMP SECTION			**R 421.42**

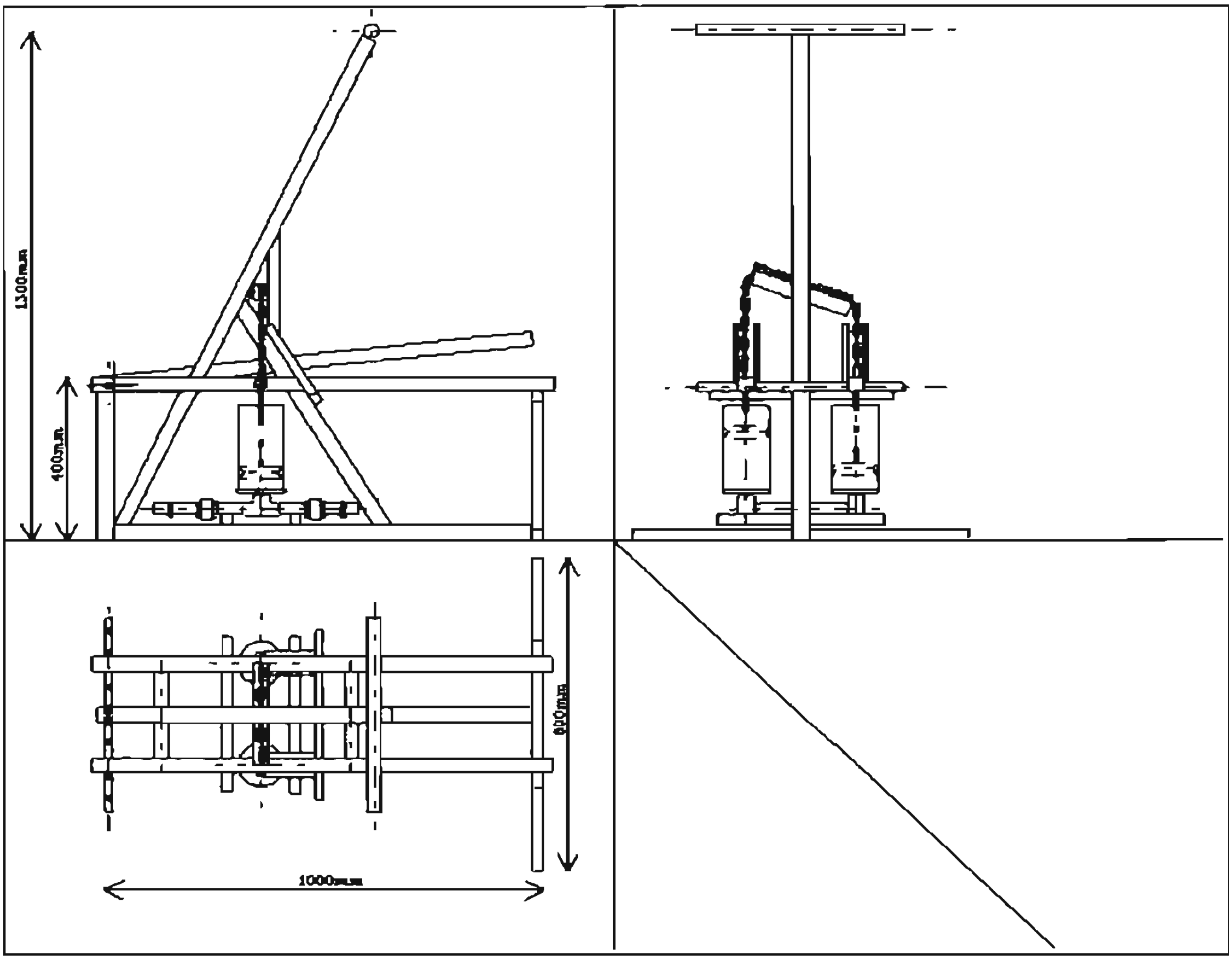

Figure 46. Prototype pump one design.

Figure 47. Two views of the prototype one pump.

Table 28. Materials required for the frame of prototype pump two.

LENGTH / AMOUNT	DIMENSIONS	NAME	COST
9 m	50 – 75 mm	Gum poles	R 54
1 m	16 mm	Round bar	R 5.43
0.5 m		Chain	R 7.70
2		Shackles	R 3.54
1 roll		Steel wire	
2	16 mm	Bolts with Nuts	R10.00
12	M 10	Bolts	R 16.80
0.2 m	3 x 4 mm	Angle iron	R 2.50
TOTAL COST OF FRAME			**R 99.97**

Table 29. Materials required for the pump section of prototype pump two.

LENGTH / AMOUNT	DIMENSIONS	NAME	COST
10	50 – 32 mm	Nylon reducer	R 40
2	32 mm	Nylon elbow	R 7.00
2	32 mm	Nylon T-piece	R 10.60
2	32 mm	Nylon T-piece (female treaded)	R 13.60
1 m	32 mm, class 3	Polyethylene pipe	R 2
0.3 m	50 mm, class 3	Polyethylene pipe	R 2
5	36 mm	Rubber bouncing balls	R 15.00
2	32 mm	Tank connector	R 52
2	110 mm	Push on PVC end caps	R 10.80
0.5 m	110 mm, class 9	PVC pipe	R 19.32
2	12 x 30 mm	Eye bolts	R 10.76
4	110 mm	Cup leathers	R 61.20
6 x 0.01m^2	3 mm	Sheet steel	R 5.34
TOTAL COST OF PUMP SECTION			**R 249.62**

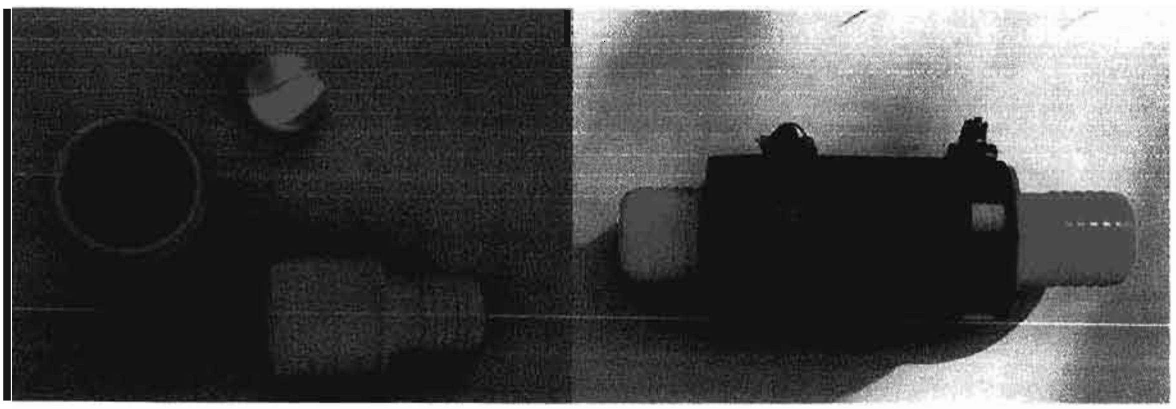

Figure 48. A dismantled and assembled valve from prototype pump two.

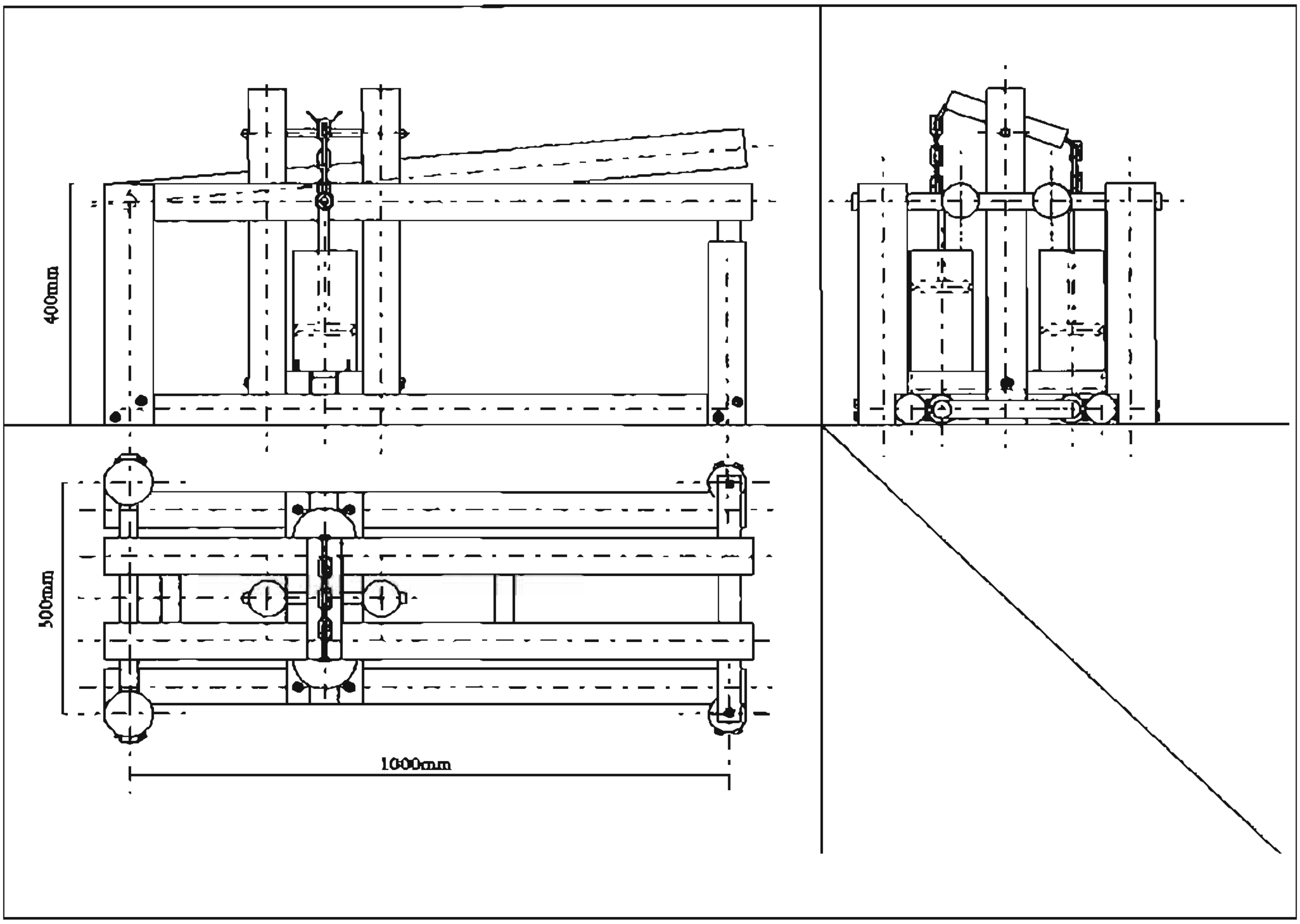

Figure 49. Prototype pump two design.

Figure 50. Two views of the prototype two pump.

APPENDIX D TREADLE PUMP LABORATORY TEST RESULTS

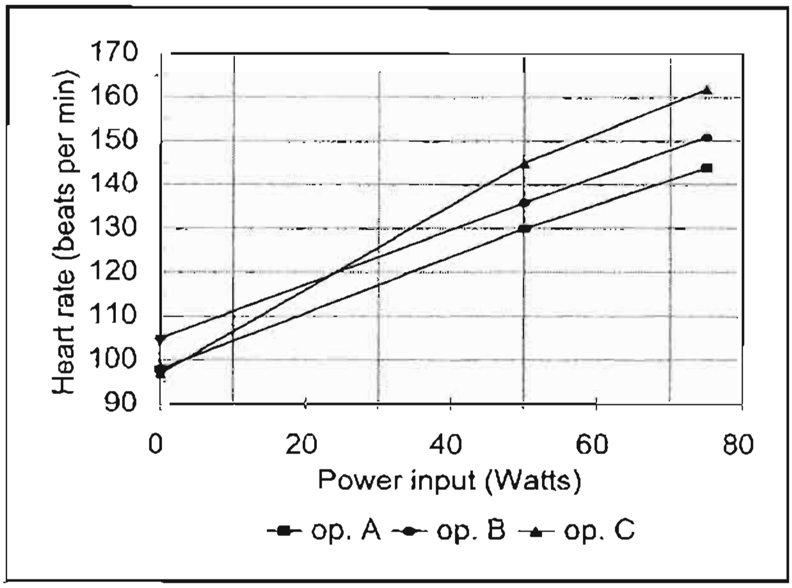

Figure 51. Operator calibration curves.

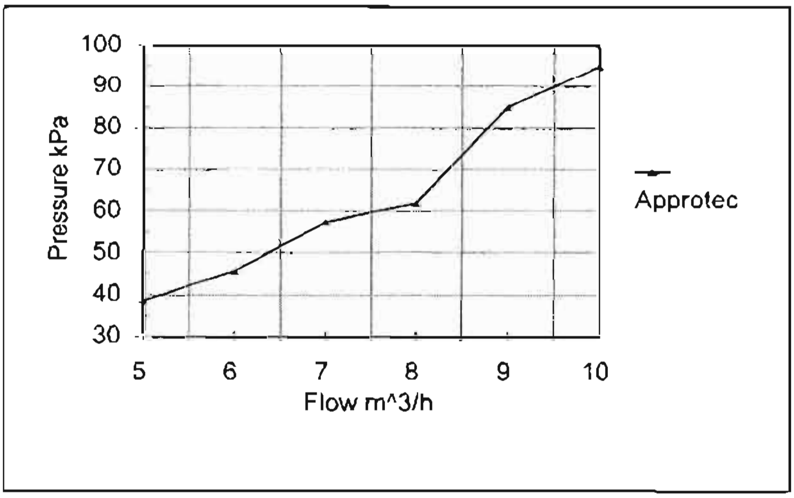

Figure 52. Friction loss curve for the Approtec pump.

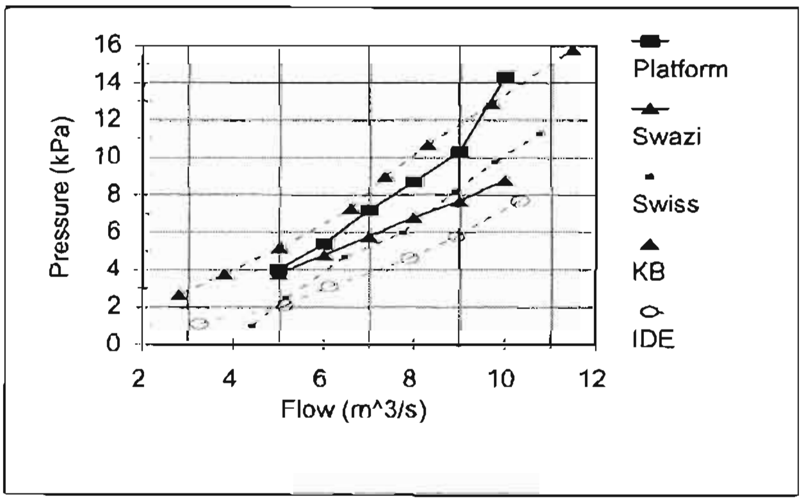

Figure 53. Friction loss curves for the other pumps.

Table 30. Average flow rates, cadence, power and efficiency for combinations of suction and delivery heads for each operator.

Pump	Suction (m)	Delivery (m)	Total (m)	Temp. (°C)	Oper.	Flow (l/s)	Cadence (str/min)	Power (W)	Effic. (%)
Platform	1	2	3	22.3	A	0.763	59	51.07	44.15
Platform	1	6	7	22.9	A	0.19	49	36.65	35.74
Platform	2	2	4	25.4	A	0.485	49	43.94	43.49
Platform	2	4	6	26.1	A	0.277	39	43.94	37.26
Platform	3	2	5	29.2	A	0.327	32	35.51	45.35
Platform	3	4	7	29.2	A	0.095	41	31.94	20.51
Platform	1	2	3	21.9	B	0.74	83	29.20	74.89
Platform	1	6	7	23.5	B	0.208	85	32.78	43.75
Platform	2	2	4	25.4	B	0.17	68	31.64	21.17
Platform	2	4	6	26.1	B	0.122	50	22.20	32.48
Platform	3	2	5	29.1	B	0.108	67	38.48	13.82
Platform	3	4	7	29.2	B	0.14	63	37.99	25.41
Platform	1	2	3	22.5	C	0.922	82	63.18	43.12
Platform	1	6	7	23.9	C	0.327	95	73.41	30.71
Platform	2	2	4	25.7	C	0.2	98	58.07	13.57
Platform	2	4	6	27.1	C	0.243	89	53.75	26.72
Platform	3	2	5	29.1	C	0.175	88	56.59	15.23
Platform	3	4	7	29.2	C	0.167	88	46.82	24.59
Swazi	1	2	3	24.4	A	1.08	64	109.48	29.15
Swazi	1	6	7	25.1	A	0.41	29	49.61	56.98
Swazi	2	2	4	27	A	0.875	49	83.82	41.13
Swazi	2	4	6	27.8	A	0.425	27	46.19	54.38
Swazi	3	2	5	29.3	A	0.755	41	70.14	53.02
Swazi	3	5	8	30.1	A	0.387	19	32.50	93.82
Swazi	4	1	5	31.9	A	0.737	40	68.43	53.04
Swazi	4	2	6	31.9	A	0.522	31	53.03	58.17
Swazi	1	2	3	24.8	B	1.083	49	67.43	47.46
Swazi	1	6	7	25.1	B	0.502	26	35.78	96.74
Swazi	2	2	4	27.5	B	1.218	50	68.80	69.75
Swazi	2	4	6	27.8	B	0.545	26	35.78	90.03
Swazi	3	2	5	28.9	B	0.812	38	52.29	76.48
Swazi	3	5	8	30.1	B	0.34	22	30.27	88.50
Swazi	4	1	5	31.9	B	0.652	31	42.66	75.27
Swazi	4	2	6	32	B	0.567	26	35.78	93.66
Swazi	1	2	3	25	C	1.055	43	52.72	59.13
Swazi	1	6	7	25.2	C	0.368	22	26.98	94.06
Swazi	2	2	4	27.6	C	0.908	37	45.37	78.86
Swazi	2	4	6	27.9	C	0.467	25	30.65	90.04
Swazi	3	2	5	30.1	C	0.775	33	40.46	94.33
Swazi	3	5	8	30.1	C	0.3	19	24.75	95.50
Swazi	4	1	5	31.9	C	0.655	29	35.56	90.72
Swazi	4	2	6	32	C	0.543	27	33.11	96.93

Pump	Suction (m)	Delivery (m)	Total (m)	Temp. (°C)	Oper.	Flow (l/s)	Cadence (str/min)	Power (W)	Effic. (%)
Approtec	2	1	3	20.6	A	0.565	55	57.88	28.85
Approtec	2	4	6	21.4	A	0.423	50	43.45	57.54
Approtec	4	1	5	23.8	A	0.357	52	42.48	41.39
Approtec	4	3	7	23.9	A	0.387	47	44.26	60.29
Approtec	6	4	10	24.1	A	0.29	29	50.10	57.02
Approtec	6	7	13	27	A	0.198	23	37.29	67.99
Approtec	2	1	3	20.8	B	0.51	49	28.39	53.08
Approtec	2	4	6	21.4	B	0.383	48	23.83	94.99
Approtec	4	1	5	23.8	B	0.39	59	27.08	70.93
Approtec	4	3	7	24	B	0.353	53	27.08	89.88
Approtec	6	4	10	26.1	B	0.197	44	34.74	55.86
Approtec	6	7	13	27.3	B	0.177	26	44.51	50.92
Approtec	2	1	3	21.3	C	0.612	69	46.48	38.91
Approtec	2	4	6	21.5	C	0.478	65	48.52	58.22
Approtec	4	1	5	23.9	C	0.388	76	39.89	47.90
Approtec	4	3	7	24	C	0.347	57	46.25	51.73
Approtec	6	4	10	26.5	C	0.292	44	42.05	68.40
Approtec	6	7	13	28	C	0.157	34	44.55	45.13
Swiss	2.8	0	2.8	20.9	A	0.405	49	30.81	36.25
Swiss	3.8	0	3.8	24.9	A	0.433	59	27.57	58.79
Swiss	5.8	0	5.8	25.9	A	0.325	66	43.61	42.58
Swiss	2.8	0	2.8	20.9	B	0.408	51	78.71	14.30
Swiss	3.8	0	3.8	24.9	B	0.587	71	52.98	41.47
Swiss	5.8	0	5.8	25.9	B	0.242	71	58.68	23.56
Swiss	2.8	0	2.8	20.9	C	0.445	93	50.34	24.38
Swiss	3.8	0	3.8	24.9	C	0.452	98	43.18	39.18
Swiss	5.8	0	5.8	25.9	C	0.408	102	48.07	48.49
KB	2.8	0	2.8	34.9	A	0.202	54	46.07	12.09
KB	3.8	0	3.8	32.3	A	0.183	47	39.12	17.51
KB	4.8	0	4.8	31.5	A	0.302	42	65.29	21.87
KB	2.8	0	2.8	35.4	B	0.252	65	69.92	9.94
KB	3.8	0	3.8	34.6	B	0.457	58	54.28	31.51
KB	4.8	0	4.8	32.4	B	0.168	64	39.13	20.30
KB	2.8	0	2.8	34.9	C	0.388	73	42.61	25.11
KB	3.8	0	3.8	35.4	C	0.233	75	64.89	13.44
KB	4.8	0	4.8	31.5	C	0.489	69	67.8	34.10
IDE	2.8	0	2.8	22.2	A	0.428	48	59.5	19.84
IDE	3.8	0	3.8	23.4	A	0.352	52	46.69	28.22
IDE	5.8	0	5.8	26.8	A	0.31	38	40.37	43.87
IDE	2.8	0	2.8	22.2	B	0.307	51	78.71	10.76
IDE	3.8	0	3.8	24.9	B	0.522	60	66.82	29.24
IDE	5.8	0	5.8	26.8	B	0.548	61	76.92	40.70
IDE	2.8	0	2.8	22.2	C	0.475	61	54.43	24.07
IDE	3.8	0	3.8	24.9	C	0.603	67	54.32	41.55
IDE	5.8	0	5.8	26.8	C	0.478	65	51.59	52.93

Table 31. Flow, cadence, power and efficiency for each operator averaged over all total heads.

Pump	Operator	Average flow (l/s)	Average cadence (str/min)	Average power (W)	Average efficiency (%)
Approtec	A	0.37	43	45.91	52.18
Swiss	A	0.39	58	34.00	45.87
IDE	A	0.36	46	48.85	30.64
KB	A	0.23	48	50.16	17.16
Platform	A	0.36	45	40.51	37.75
Swazi	A	0.65	38	64.15	54.96
Approtec	B	0.34	47	30.94	69.28
Swiss	B	0.41	64	63.46	26.44
IDE	B	0.46	57	74.15	26.90
KB	B	0.29	62	54.44	20.58
Platform	B	0.25	69	32.05	35.25
Swazi	B	0.71	34	46.10	79.74
Approtec	C	0.38	58	44.62	51.72
Swiss	C	0.44	98	47.20	37.35
IDE	C	0.52	64	53.45	39.52
KB	C	0.37	72	58.43	24.22
Platform	C	0.34	90	58.64	25.66
Swazi	C	0.63	29	36.20	87.45

Table 32. Flow, cadence, power and efficiency averaged over all total heads and operators.

Pump	Flow (l/s)	Cadence (str/min)	Power (W)	Efficiency (%)
Swazi	0.67	33	48.82	74.05
IDE	0.45	56	58.82	32.35
Swiss	0.41	73	48.22	36.55
Approtec	0.36	49	40.49	57.72
Platform	0.31	68	43.73	32.89
KB	0.3	61	54.35	20.65

Table 33. Flow, cadence, power and efficiency at various total heads averaged over each operator.

Pump	Total head (m)	Flow (l/s)	Cadence (str/min)	Power (W)	Efficiency (%)
Approtec	3	0.56	58	44.25	40.28
Swiss	3	0.42	64	53.29	24.98
IDE	3	0.40	53	64.21	18.22
KB	3	0.28	64	52.87	15.71
Platform	3	0.81	75	47.82	54.05
Swazi	3	1.07	52	76.54	45.25
Swiss	4	0.49	76	41.24	46.48
IDE	4	0.49	60	55.94	33.00
KB	4	0.29	60	52.76	20.82
Platform	4	0.29	72	44.55	26.08
Swazi	4	1.00	45	66.00	63.25
Approtec	5	0.38	62	36.48	53.41
KB	5	0.32	58	57.41	25.42
Platform	5	0.20	62	43.53	24.80
Swazi	5	0.73	35	51.59	73.81
Approtec	6	0.43	54	38.60	70.25
Swiss	6	0.33	80	50.12	38.21
IDE	6	0.45	55	56.29	45.83
Platform	6	0.21	59	39.96	32.15
Swazi	6	0.51	27	39.09	80.54
Approtec	7	0.36	52	39.20	67.30
Platform	7	0.19	70	43.27	30.12
Swazi	7	0.43	26	37.46	82.59
Swazi	8	0.34	20	29.17	92.61
Approtec	10	0.26	39	42.30	60.43
Approtec	13	0.18	21	42.12	54.68

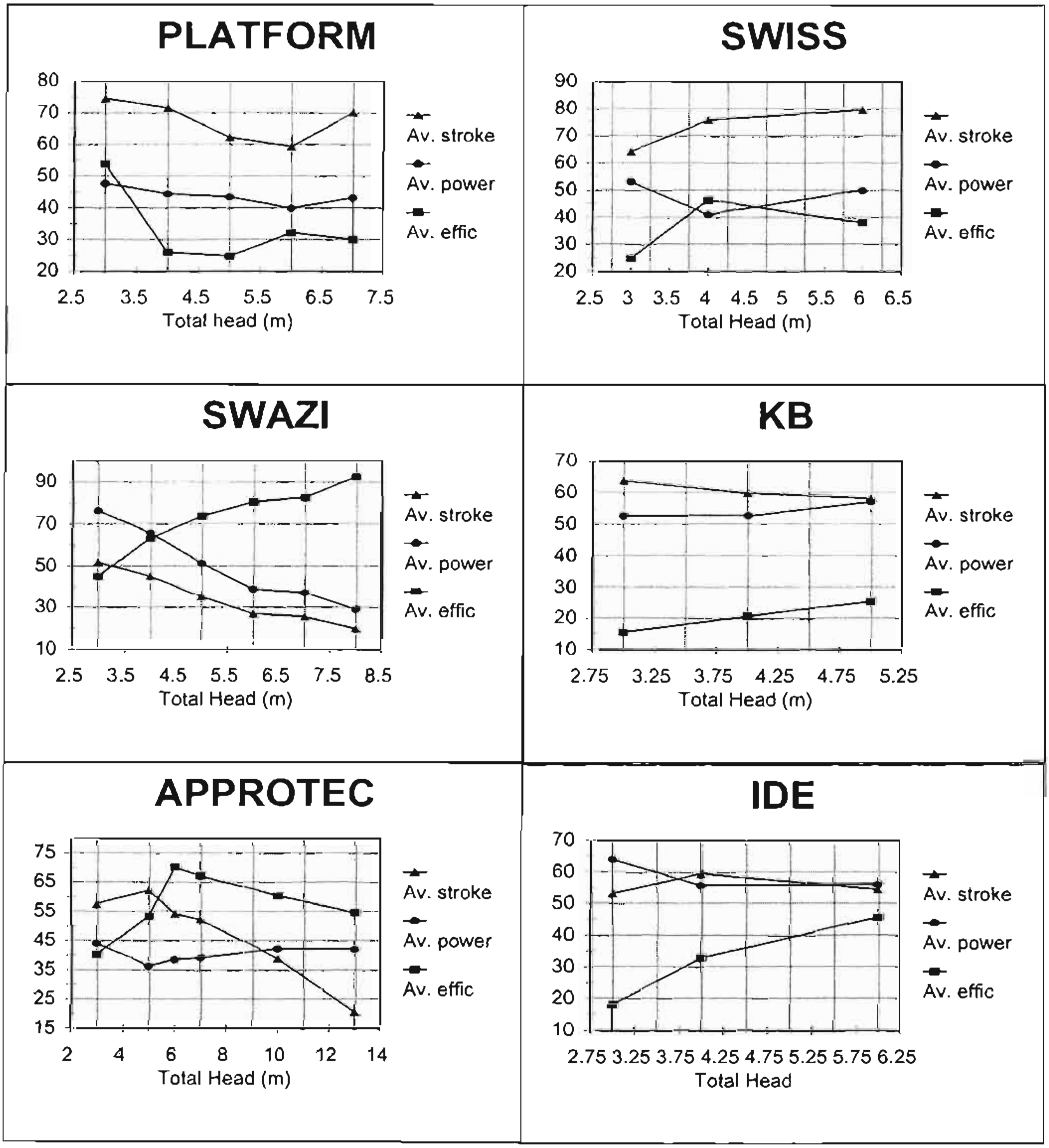

Figure 54. Graphs of average cadence, power and efficiencies at various total heads.

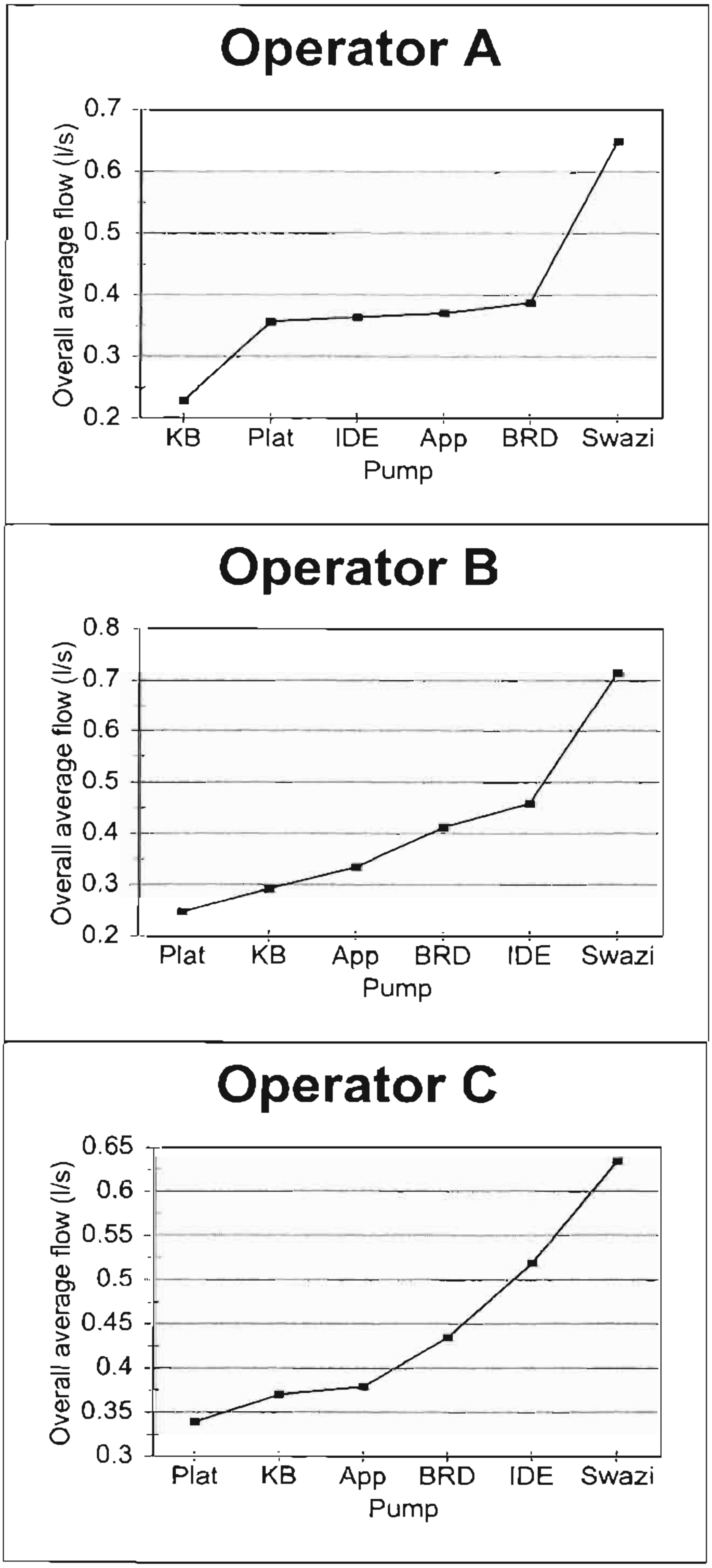

Figure 55. Graphs of overall average flow for each pump.

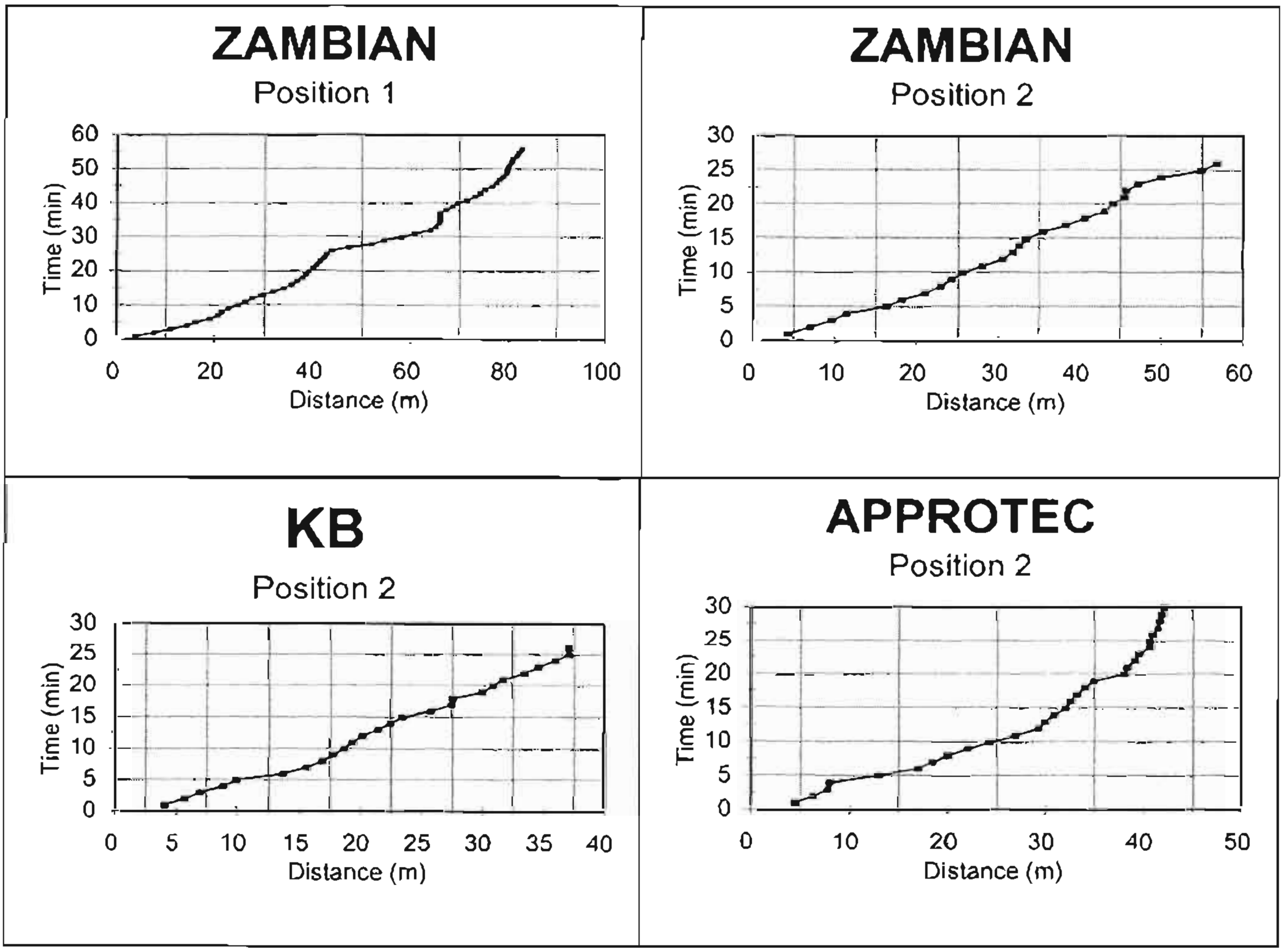

Figure 56. Plots of water front distance against time for the furrow irrigation trial.

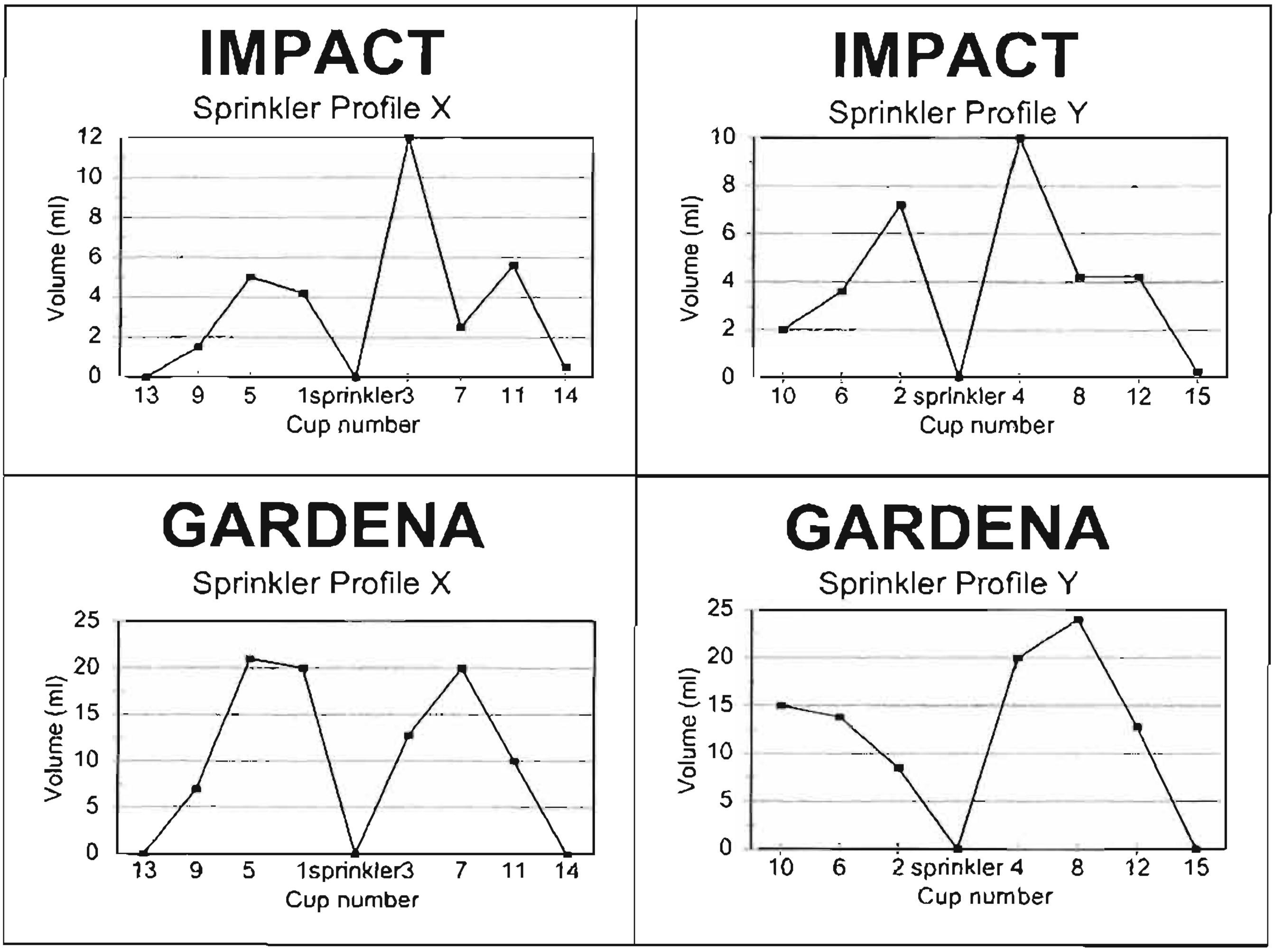

Figure 57. Sprinkler profiles for the two sprinkler trials held at Tshepo's homestead.