Micro-Irrigation for Smallholders

Guidelines for Funders, Planners, Designers and Support Staff in South Africa

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Water Research Commission

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Foreword

The last decade has seen a shift in the approach to development projects in South Africa. Due to a number of initiatives from local institutions, as well as improved access to the international scene, agencies involved in smallholder development started to realise that there was more to rural development than providing physical infrastructure. Even when this infrastructure was designed and installed in accordance with conventional recommendations, and appeared to be a technical success, the project often turned out to be a developmental failure.

During this period, it became increasingly evident that a successful development project needed more than a team of engineers to provide the "correct" solution to the problem at hand. The need to adopt a holistic and integrated approach to the search for appropriate solutions was identified. The importance of taking into account the actual needs opinions and circumstances of communities involved became accepted. Consequently, the engineering fraternity came to acknowledge the need to broaden the expertise contained in their teams, to be able to explore, among others, the sociological and economical dimensions of a development project. As a result, the adoption of a multi-disciplinary approach to has become accepted practice.

In recent years, it also became apparent that providing people with infrastructure without empowering them with the necessary skills, enabling them to use the infrastructure in a sustainable way, was a formula for failure. As a result, the provision of training and aftercare is being considered as part of the planning, design and implementation of development projects.

The present guidelines are rooted in the realisation that a pure technical approach to development is not appropriate. They have been compiled with a diverse audience in mind. Many of the people, we hope, will not be engineers. Yet when dealing with planning and design of irrigation projects, the use of technical terms cannot be avoided. In order to explain the meaning of these terms to readers who do not have an engineering background, we have compiled a glossary, which appears at the end of the document.

The guidelines also contain an index. Often, issues important to the process of irrigation planning and design need to be considered at different stages of the process, or under different headings. In order to avoid repetition whilst still allowing for easy cross-referencing, prominent issues are listed as entries in the index. Each entry is followed by references to the pages where they are discussed.

We hope that these two features will improve ease of use and user friendliness of the guidelines, and assist understanding of the complex nature of irrigation planning and design.

The authors

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1. INTRODUCTION AND BACKGROUND

The guidelines presented in this document were derived from the findings of a research project entitled '*An evaluation of the appropriateness and management requirements of micro-irrigation for small-scale farmers'* (Du Plessis & Van der Stoep, 2001). The project, which was funded by the Water Research Commission, had two main objectives. The first was to document how smallholders experience micro-irrigation, and how they cope with the difficulties they encounter when using this type of irrigation. The second was to identify factors that determine success or failure in smallholder crop production when making use of micro-irrigation.

The proposal for this research project was submitted in 1995. At that time, South Africa was just emerging from a long period of isolation from global research and debate on smallholder development. One of the results of this isolation was that local irrigation planning and design professionals were not exposed to new ideas in rural development in general, and smallholder irrigation development in particular.

South Africa is a dry country that faces water shortages in the near future. Micro-irrigation is known to be an efficient way of applying water to crops. Consequently, it has been presented as a way to assist the country in meeting its future water requirements. In the community concerned with small-scale irrigation development there is growing realisation that the technical approaches used in the past were not always well adapted to the circumstances in which they were applied. The apparent lack of sustainability characterising many historical smallholder irrigation projects created a demand for new approaches. However, among irrigation specialists, there are several who doubt the appropriateness of micro-irrigation for use by smallholder irrigators. As a result, proposals to replace conventional surface and overhead irrigation with micro-irrigation have not always received support. Considering that operation and maintenance of micro-irrigation systems require higher levels of management than is the case for most conventional systems, the doubts that are raised are valid. In reality, smallholder irrigators are often isolated from support services and suppliers of equipment. They often lack electricity. Many of them are part-time farmers. Besides farming, they are also involved in various off-farm or non-farming activities. All of these income-generating activities make demands on the farmer's time and resources. It is obvious that these factors militate against the successful use of micro-irrigation by smallholders. On the other hand, smallholders who practice micro-irrigation successfully do exist. Often they have made ingenious adaptations to their micro-irrigation system to make it suit their particular conditions. For small-scale farming conditions, micro-irrigation has some distinct advantages when compared with conventional surface and overhead systems. These advantages include:

- high irrigation efficiencies and concomitant potential to save water;
- relatively low operating pressure requirements;
- low labour requirements;
- day and night operation;
- versatility in field layout and adaptable to topography; and
- relative ease with which equipment can be moved between fields.

To find out how small-scale irrigators experience micro-irrigation, an empirical investigation into the practical application of micro-sprayer and drip-irrigation by smallholders was conducted. This was accomplished by studying on-farm situations on existing smallholder projects, and on new projects, established by the research team by installing a micro-irrigation system on farmers' lands. During the course of the research project, information was obtained from a total of 30 sites, of which 22 were studied in detail. These 22 cases are discussed in the main report (Du Plessis & Van der Stoep, 2001). Eleven of the 22 projects featuring in the study were projects that existed at the start of the research. The remaining 11 were new projects, which were established by the research team. One of the existing projects that was visited was located in Israel. The 11 new projects were all situated in South Africa. The research team monitored progress of the participating farmers in each of the newly established irrigation projects. Special attention was paid to how participants experienced the new technology. Success, failure, and the underlying causes of both were determined and recorded. These records constituted the empirical body of information used to formulate the present set of guidelines.

Of the 11 projects established by the project team, only four remained in operation at the end of the four-year monitoring period. The other seven had been abandoned, and were considered failures. It follows that the rate of failure was considerable. Of all the factors that contributed to the failing of these projects, low reliability of the water supply was probably the main one. On the other hand, the research team was very encouraged by the success of the irrigation enterprises of selected farmers in Northern Province. These farmers provided evidence that smallholders can overcome the challenges posed by irrigation in general, and small-scale micro-irrigation in particular. In response to the high failure rate observed in micro-irrigation projects, the guidelines have been compiled with risk in mind. Generally, recommendations are aimed at minimising the risk of failure, rather than at realising the full potential offered by available resources.

The guidelines were compiled for a wide audience. Obviously, people and organisations involved in planning and designing smallholder micro-irrigation projects were a primary target, but the guidelines were also aimed at farmer support teams, institutions that provide training and education in irrigation, and suppliers of irrigation equipment. The guidelines contain useful information for policy makers concerned with developing a policy environment that supports a vibrant smallholder sector. By avoiding technical jargon wherever possible, and by explaining the meaning of jargon where its use was necessary, we hope that the guidelines also reach the smallholders, whose interests and success these guidelines were intended to support.

2. DEFINITIONS

To assist the reader of these guidelines, definitions of concepts important to smallholder micro-irrigation are presented here. For a more comprehensive explanation of the meaning of terms used in these guidelines, the reader is referred to the glossary appearing at the end of this document.

In this text, the term **micro-irrigation** refers to pressurised irrigation systems that irrigate part of the soil surface area of a field in a controlled manner, as opposed to other systems designed to apply water to the entire soil surface. This definition limits the choice of equipment to two types only, namely micro-sprayers and drip irrigation. On-farm, these two types of systems are found in a variety of applications. They range from ultra-low flow rates supplying water to very small proportions of the surface area, to high flow rates capable of irrigating the entire soil surface. The term **micro-irrigation system** was understood to include the water pump, the filtration and fertigation equipment, and the in-field water distribution equipment. A schematic representation of a micro-irrigation system is presented in Figure 1.

The term '**water supply system'** refers to the complex of arrangements responsible for the provision of irrigation water to farm or field edge. The term '**water distribution system'** refers to the arrangements responsible for the dispersal of water in the field.

For purposes of this project, a farm was defined as a **smallholding** when it occurred on a field area not exceeding 20 ha. In this text, the use of the terms 'smallholding' when referring to a small-scale farm, and 'smallholder' when referring to a small-scale farmer was preferred, but in both cases the terms are understood to have the same meaning.

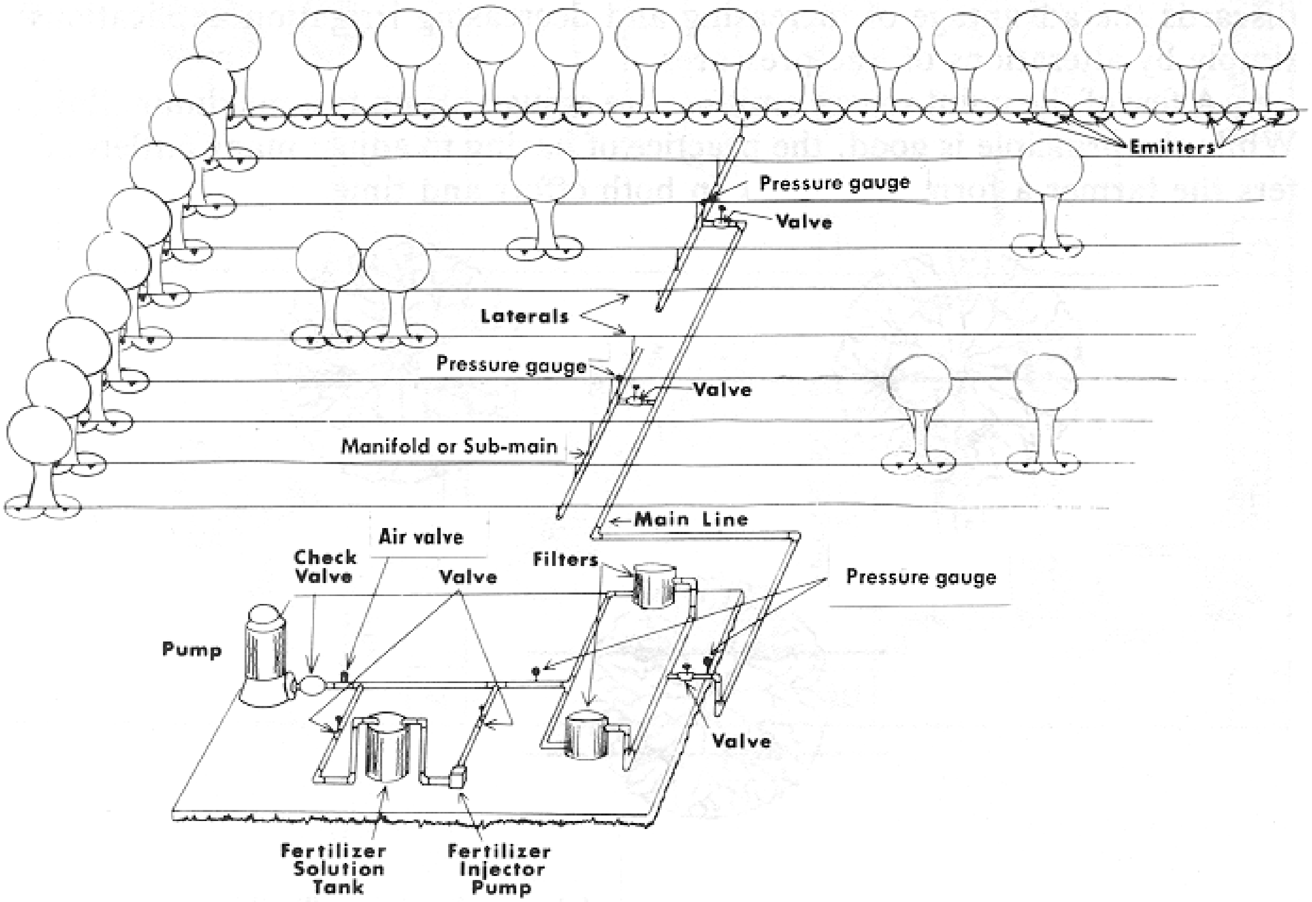

Figure 1 Schematic diagram of a typical micro-irrigation system (Jensen, 1981)

De Lange (1994) divided **small-scale irrigation farmers** into three groups, namely:

- **Independent farmers** who grew crops on land that was not part of an irrigation scheme. In most cases, the farmers concerned did not have title to their farmland.
- **Scheme farmers** who operated on an irrigation scheme, sharing infrastructure, a source of water, and sometimes irrigation equipment with other members of the scheme.
- **Garden or food-plot farmers** who usually formed part of community garden projects, who farmed on very small plots, about a hundred square meters in size, and who shared irrigation equipment and a common source of water.

During the course of this project, a fourth group of small-scale irrigation farmers was identified. They operated on small plots, which were similar in scale as those of garden or food-plot farmers, but they did not form part of a group. Instead, they conducted their farming on the garden part of their residential sites, which they had converted into irrigation plots. They had independent access to water for domestic purposes, and allocated part of this water to farming. In the main report, these farmers are referred to as backyard farmers. Other researchers refer to this group as home-garden farmers, and this is the term that will be used in these guidelines.

3. FACTORS DETERMINING SUCCESS AND FAILURE IN SMALLHOLDER IRRIGATION

3.1 INTRODUCTION

The main body of information used to develop an overview of the factors determining success and failure in small-scale irrigation consisted of the empirical data obtained during the monitoring of existing and newly established projects. These data are presented in the main report (Du Plessis & Van der Stoep, 2001). Additional information was obtained from selected secondary sources on the subject. Discussions with people known to have expert knowledge on the topic of smallholder irrigation, and with practitioners, who had real-life experience in smallholder irrigation, were also used to obtain information.

To guide the discussion, the various factors that were identified have been grouped into six categories. In each of these categories, the factors the research team considered as critical to success or failure in smallholder micro-irrigation have been highlighted. A summary of the discussion is presented in Table 1.

3.2 CATEGORY OF FACTORS RELATED TO TRAITS AND ATTITUDES OF FARMERS AND GENERAL FARMING CONDITIONS

The research team found that personal traits and attitudes of farmers influenced success and failure in smallholder micro-irrigation. Three elements were identified as important. The level of literacy of farmers determined how effective they were in the use of written information, and influenced their ability to maintain essential records. Real-life experience in irrigation, or exposure to training in irrigation, be it formal or informal, increased the likelihood of farmers adopting micro-irrigation successfully. Adoption was also influenced by the initial attitude of farmers towards micro-irrigation. The research team found that farmers who were sceptical towards micro-irrigation when introduced to the technology ended up failing to make appropriate use of the system when it was implemented on their farms.

The circumstances under which farming occurred had an influence on success or failure in micro-irrigation. The projects that were used by the research team for data collection represented a variety of circumstances. Geographic location of the smallholding was important. Farmers operating in remote rural areas were affected negatively by a lack of access to support services. Those working on farms located in areas where climatic conditions were not favourable, or those farming on land that was marginally suited for irrigation, were subjected to high levels of risk. Under such conditions, risk was increased even more when the supply of irrigation water was not reliable.

The size of the smallholdings studied by the research team varied widely, from less than 0.1 ha to slightly larger than 20 ha. Ownership of land and equipment was also diverse, and included irrigation schemes, community gardens, private and rented land. However, the team observed that success or failure in micro-irrigation was closely linked to the way the system supplying the farm with irrigation water was operated and maintained, irrespective of farm size or type of ownership over farmland. When the supply of water to a micro-irrigation project proved unreliable, the project was very likely to fail.

The research team also observed that micro-irrigation projects of farmers whose livelihood was dependent on income generated by their farm were more likely to succeed than when this was not the case.

Category	Critical factors
The farmer and his or her circumstances	Level of literacy Irrigation farming experience Irrigation farming training Attitude of farmer towards micro-irrigation Geographic location of the farm Suitability of climate Production potential of the soil Size of operation Land ownership Degree of dependency on farm income
Water supply	Amount of irrigation water available Reliability of the water supply system Quality of the irrigation water Degree of responsibility of the farmer for the supply of water Frequency of the supply of water Management of supply
Irrigation system	Pump and on-farm water distribution system Suitability of the in-field system Filtration Fertiliser application System installation Performance relative to other systems used or known by the farmer Innovation and adaptation in problem solving
General management	Utilisation of system Maintenance of system Irrigation scheduling practices Crop management Labour requirements Time management Record-keeping
Infrastructural, institutional, social and extension factors	Physical infrastructure available to the farmer Extension services Institutional arrangements social standing and engagement of the farmer
Economic and financial factors	Cost of the system Cost of water supply Scale of the production unit Access to and use of finance and credit Cash-flow on and off farm Marketing

Table 1 Categories of critical factors in smallholder irrigation

3.3 CATEGORY OF FACTORS RELATED TO WATER SUPPLY AND WATER QUALITY

The supply of water to the farm or field edge was a critical factor in micro-irrigation. Overall, an abundant and reliable supply of water enhanced the likelihood of success, because it compensated for the teething problems farmers experienced when using micro-irrigation for the first time. Conversely, in situations where the supply of water was limited or not reliable, projects often failed.

In cases where farmers were personally responsible for the supply of water to field edge, a lack of understanding and technical knowledge to operate and maintain the supply system often resulted in serious setbacks. Subsequent failure of the projects usually followed. For this reason, the team identified the training of farmers in the operation and maintenance of their water supply system as a critical factor determining success or failure in smallholder micro-irrigation.

None of the projects that were monitored by the research team failed because the quality of the water was poor. However, over time, the negative effects of using poor-quality irrigation water were expected to become more prominent, and the sustainability of projects that made use of poor-quality water was doubtful.

3.4 CATEGORY OF FACTORS RELATED TO MICRO-IRRIGATION EQUIPMENT

The micro-irrigation equipment was understood to include the water pump, the filtration and fertigation equipment, and the in-field water distribution equipment.

All projects where farmers were responsible for the pumping of water proved problematic, mainly because farmers lacked the necessary skills to attend to mechanical faults in the pump or in the engine that powered the pump. In most instances, inadequate operation and maintenance procedures were the cause of pump failure. Once the pump became inoperative, the supply of water to crops in the field was interrupted, causing water stress and reductions in yield and quality of the crop.

Generally, farmers appreciated the importance of filtering irrigation water before allowing it to enter the in-field distribution system. The research team did not identify any farmers who experienced serious problems with this component of the micro-irrigation system.

Overall, farmers did not experience major problems with the equipment used for in-field water distribution. A minor issue of concern was the difficulties farmers had to develop a thorough understanding of the mechanism of micro-irrigation in general, and drip irrigation in particular.

Insufficient information was obtained to make definitive statements about fertigation and nutrient supply in smallholder micro-irrigation, and additional research is needed.

The research team identified installation of the equipment as an ideal opportunity for farmer training. As the various components of the system were laid out on the farm, their function and operation was explained to the farmer. This was also the time to explain the importance of maintenance, and to clarify the procedures to follow in the maintenance of the various components of the system. Presence of the farmer during the installation of a micro-irrigation system was important, but the same applied to the farmer support team. In most cases the only member of this team was the public extension service supplied by the provincial Department of Agriculture, but there were also instances where local non-governmental organisations were mandated to support farmers. The team found that knowledge of micro-irrigation equipment and its operation and maintenance was often very limited, even among the extension officers. Installation of the micro-irrigation system represented an ideal occasion for both farmer and his or her support team to learn about the technology. When both attended training during installation, they ended up sharing the same knowledge. This ensured good understanding between them, and facilitated subsequent exchanges of information. For this reason, the team concluded that hands-on training offered to farmer and support team during installation of the irrigation equipment made an important contribution to success and sustainability of a micro-irrigation project. The team also found that a lack of understanding and knowledge among farmers and support staff was common in situations where systems other than micro-irrigation were used.

3.5 FACTORS RELATED TO GENERAL FARM MANAGEMENT

At most of the monitoring sites, the full potential of the micro-irrigation systems was not exploited. Managerial problems were identified as the root cause of this ineffectiveness. In most cases, the underlying causes of managerial problems were an attitude of risk avoidance or a lack of understanding of the new system among farmers concerned. Generally, the research team gained the impression that many farmers were hesitant towards innovation, in this case experimentation with a new irrigation system, because they were afraid to expose the source of their livelihood to additional risk. Also, instructions on how to use the systems given to farmers by the research team were often not understood, and therefore also not followed. It appeared that failure of farmers to understand the team's users instructions was caused primarily by their lack of knowledge of the basic principles of soil-plant-water interactions.

In most cases, farmers failed to give adequate attention to maintenance of the components of their micro-irrigation system. There were, however, no instances where a lack of maintenance was the only cause of project failure.

The research team continuously supported farmers by providing guidelines and advice on irrigation scheduling. However, the team did not apply much pressure on the farmers to follow this advice aimed at scheduling irrigation more accurately, and the farmers were left free to decide when to irrigate, and how much water to apply. Abundance and reliability of the water supply were a major factor determining the irrigation scheduling practices of farmers. Where water was abundantly available, farmers tended to irrigate in excess of crop requirements. The opposite occurred where the water supply was limited or erratic.

None of the farmers monitored by the research team reported micro-irrigation to have brought about a saving in labour, probably due to the small scale of their operations. However, in most instances, record keeping was deficient or non-existent. Consequently, this finding was based mainly on farmers' perceptions.

3.6 GEOGRAPHICAL, INSTITUTIONAL AND ORGANISATIONAL FACTORS

Remoteness of a project was identified as a distinct disadvantage, because it limited access to input and produce markets, services and communication.

The availability of a team that supported farmers was found an important factor, but much depended on the effectiveness of the team. As was indicated in the previous section, in many cases members of the team needed to be trained first before they could assist farmers effectively. With reference to micro-irrigation, one way of achieving this was by ensuring that members of the farmer support team were present during the installation of the equipment.

Van Averbeke, M'Marete, Igodan and Belete (1998) discussed the importance of institutional and organisational factors in smallholder irrigation using a selection of Eastern Cape schemes as case studies. In the current study, these factors were important when farmers formed part of projects or schemes, and shared all or part of the natural and capital resources needed for irrigated agriculture.

Experiences in India and the Middle East, among others, have demonstrated the importance of farmer organisations, farmer-to-farmer knowledge exchanges, participation of local government in farming issues, and overall policy environment. Generally, many of these factors were found deficient in contemporary South Africa. The research team gained the impression that smallholder agriculture would benefit from these deficiencies being addressed.

3.7 ECONOMIC AND FINANCIAL FACTORS

One of the important concerns of irrigation economics is the transformation of water into consumer goods. This transformation is achieved by removing the environmental limitation of water deficits in the production of crops used for fibre or food. Relative to many other irrigation systems, the capital outlay per unit area needed to install a micro-irrigation system is known to be high. This can be an obstacle preventing smallholders from selecting micro-irrigation. Moreover, in micro-irrigation the capital cost per unit area increases as the area covered by the system is reduced. This militates against the adoption of micro-irrigation by smallholders, because inherently the scale of their operations is small. Yet, potentially smallholders are able to derive benefits from selecting micro-irrigation over other systems. The saving of labour is one of these potential benefits, although farmers who were monitored by the research team failed to identify this particular benefit.

The cost of water is an essential concern in irrigation economics. In South Africa, the real cost of water is increasingly being realised, because of water scarcity and increasing demand for water by non-agricultural users. Few of the farmers monitored by the research team were concerned about the actual or hidden cost of water. The team postulated that the lack of such concerns was caused by the way water was priced. Some farmers obtained their water free of charge, whilst others paid a fixed rate per unit time, irrespective of the amount of water they used. The team was left with the impression that farmers perceived payment of a fixed rate as a license to unlimited water consumption. Overall, farmers did not demonstrate awareness of the need to conserve water.

Most farmers participating in the study were keen to expand their area under irrigation, but they considered the opportunity to do so as extremely limited. In most instances, farmers identified the lack of personal financial means to pay for expansion as an important constraint. For this reason, they perceived the risk associated to expansion as too great. There were examples of farmers who financed expansion on credit. Most of these involved farmers who did not hold title to their farmland. However, the research team observed that the cash flow of smallholders was generally poor, casting doubts on farmers' ability to service substantial loans. Based on the observations obtained during the monitoring of the project, the research team learnt that smallholder cash flows were subject to substantial improvement. The research team was of the opinion that this could be achieved by improving the production-planning and marketing skills of smallholder farmers.

3.8 SOCIAL FACTORS

The team identified three social factors that were important. The first was the role of farming in the livelihood strategy of the farming household. Where farming formed part of a multiple livelihood strategy, and other sources of income buffered the impact of setbacks on the farm, success in micro-irrigation was less likely than in cases where the household was heavily dependent on farm income for survival. For this reason, the team concluded that an analysis of the livelihoods of farmers needed to form part of irrigation planning.

The second important social factor was to determine who in the farming household was responsible for the day-to-day farming activities. Whereas the head of household was responsible for decisions on the farm, work on the farm was often conducted by another member of the family, or even by a hired help. It became clear to the team that the person who executed the farming activities needed to be a prime target for training. The team also learnt that an analysis of the relationship between this person and the head of household was important, especially in terms of the bundle of rewards the person received for providing labour on the farm. The team observed that when this bundle was perceived to be inadequate, it was likely that the person left the farm as soon as a more rewarding opportunity presented itself. Whenever this happened, there was usually a collapse of the micro-irrigation enterprise; because gone with the person was also the knowledge of the enterprise. The team concluded that in cases where a person other than the head of the farming household was responsible for day-to-day farming, it was important to extend training to more than just that person.

The third important factor was the relationship of the farmer household with people in the community he or she formed part of. The team found that close relationships with other members in the community allowed farmers to claim time and expertise from some of these members. Teachers, for example, could be approached to assist in explaining written information, or act as translators. The team concluded that situations where farmers related well to their community were favourable for farming in general, and micro-irrigation in particular.

4. GUIDELINES FOR PLANNING, DESIGN, AND MANAGEMENT OF SMALLHOLDER MICRO-IRRIGATION PROJECTS

4.1 INTRODUCTION

Using the results of the research project entitled '*An evaluation of the appropriateness and management requirements of micro-irrigation for small-scale farmers* (Du Plessis & Van der Stoep, 2001), the research team compiled a set of guidelines for planning, design, and management of smallholder irrigation projects. These guidelines apply specifically to smallholder conditions, and complement information found in existing manuals that guide planning and design of conventional irrigation projects, and large-scale micro-irrigation projects.

During the course of the project, understanding of smallholder micro-irrigation farming among members of the research team increased progressively. This resulted in a review of some of the preconceptions held by the team at the start of the project. One of these preconceptions was that researchers would mainly observe farmers' struggle with technical aspects of micro-irrigation. This proved not to be the case. Farmers toiled with a broad range of challenges, many of them generic to contemporary South African smallholder agriculture at large. In several instances, it was the inability of farmers to overcome these generic challenges, which prevented them from succeeding in their new micro-irrigation enterprise. Consequently, the research team decided to add to the guidelines referring specifically to smallholder micro-irrigation some important guidelines that apply to smallholder agriculture at large.

To assist use of the guidelines, they have been structured into five main categories, namely:

- system planning;
- system design;
- system installation and training;
- system operation and maintenance; and
- financial aspects

Some of the guidelines fit in more than one category, and need to be considered accordingly.

4.2 SYSTEM PLANNING

4.2.1 General issues

The approach adopted by planners of a project had a considerable influence on the development and potential for success of the project. It was the team's experience that an approach, which kept farmers informed regularly and continuously of developments and progress, worked well.

At project initiation, planners should compile an inventory of existing information. In addition to standard information, which is of specific importance to irrigation planning, the inventory should also contain information on other development initiatives in the area, both current and historical. Sharing the content of the inventory with farmers and other stakeholders in local development creates awareness, and helps to remove or avoid confusion on who is doing what in the area of operation.

Agricultural extension officers assigned to support smallholder farmers constitute an important link in the communication between planners and farmers. Inclusion of these officers in the planning process is highly recommended, because it has two important advantages. Usually, farmers know the extension officer assigned to support them, and this assists communication between planners and farmers. In many instances, the designated extension officer is the only person who maintains regular contact with the farmer community. Secondly, extension officers usually have good knowledge and understanding of the communities they serve. Access to this knowledge enables planners to develop an appreciation of the diversity among farmers in terms of capabilities and attitudes, and of the important constraints local farmers experience.

Enriched with knowledge on the local development scene, and with a general understanding of the local smallholder community, planners should engage in a process of participatory planning with farmers. This process should start with an exploration of the life histories, socio-economic conditions, capabilities, attitudes, and expectations of farmers, individually, and as a group. Attention needs to be given to the historical successes and failures of the farmers, and the factors farmers perceive to have influenced these outcomes. It is important also to understand the objectives of the farmers' agricultural activities, and how these fit within the overall livelihood strategies of farmer households. For their livelihoods, South African smallholders typically rely on multiple sources of income, including off-farm and non-farm. The way they view the current and future role of farming in their overall livelihood strategies will influence their attitudes to expansion, investment and risk. Planners must incorporate the findings of this exploration in the plans for the project. As indicated earlier, it is expected that the exploration of situations and conditions will reveal a considerable degree of diversity. Planners need to respond to this diversity by building flexibility into their plans, thus allowing projects to respond to future change.

It is very important that planners present farmers with a realistic portrait of micro-irrigation, and refrain from creating expectations of instant success. The findings of the team suggest that it was realistic to present the first season of operation to farmers as an opportunity to learn to use the system, and that farmers should not expect much in terms of financial returns. On the other hand, planning should ensure that during the first season, farmers do enjoy regular and reliable support, to ensure that problems with the new system are discussed and addressed as they present themselves. It is during this process that the roles of trainers and members of the support team are crucial.

Presenting farmers with a realistic portrait of what to expect from micro-irrigation does not mean that production during the first season should be allowed to fail. On the contrary, the first season needs to reveal to farmers the benefits they can derive from using micro-irrigation, including harvests that are larger and of better quality than those obtained by other means. Planning needs to take this need into account, by selecting crops and associated management practises, which are not overly demanding. The crops planted during the first season should be known to tolerate sub-optimal management, and not be too sensitive to errors, which farmers are bound to make because of a lack of experience. As farmers gain confidence in the use of their micro-irrigation system, a review of previous experiences should be used to introduce more demanding and more lucrative crops.

Table 2 Summary of guidelines for system planning: General Issues

Background information	➢ Collect standard information required for planning irrigation; assess the data for accuracy and reliability; resolve conflicting facts; compile and communicate findings. ➢ Collect information on current and historical development initiatives; verify the information for accuracy; resolve conflicting facts; compile and communicate findings. ➢ Share the information obtained among local stakeholders and among farmers intended to benefit from the irrigation project. ➢ Collect information on farmer households, including histories, livelihoods, division of labour, financial resources, education and life experiences, attitudes, and expectations with reference to the irrigation project being planned. ➢ Incorporate findings into the planning of the irrigation project. ➢ Build flexibility into the plan to allow for existing diversity, and future change.
Introduction and implementation of micro-irrigation	➢ Apply a phased approach to planning and implementation of micro-irrigation. Too much too soon is likely to undermine farmer confidence. ➢ Present farmers with a realistic portrait of what can be expected from micro-irrigation during the first and subsequent years. ➢ Provide an explanation of the advantages and disadvantages of micro-irrigation, and clearly demonstrate what will be expected from farmers if they wish to become successful. ➢ Ensure that farmers understand the proposed project, and allow for their inputs. ➢ In participation with farmers, develop principles and procedures that will be adhered to by all during implementation of the project. Prepare and distribute copies of the outcomes of these negotiations among stakeholders, and ensure good understanding among all concerned. Once rules have been formulated and accepted, insist on adherence by all involved.
Engagement of farmer support services	➢ Identify the local farmer support or extension agencies mandated to serve the farmers involved with the project. ➢ Encourage the formation of a small project support team, committed to assist farmers during implementation and operation of the irrigation project. ➢ Acknowledge the importance of the project support team, by informing them of all developments in the project, and involving them in all the stages of planning and implementation, including physical presence during lay-out and installation of the equipment. (continued overleaf)

	➢ Assign a central role to the dedicated staff in the project support team. ➢ Plan and programme for continuity of the provision of support in the form of an after-care service. Ideally this service should involve the full project support team, and be sustained for about two years after implementation of the micro-irrigation system. As with implementation, develop principles and procedures to govern the interaction between farmers and support services.

4.2.2 Planning with farmers: the central role of the end-users of technology

Monitoring and evaluation of the projects showed a close relationship between smallholder success in micro-irrigation and the life experiences of smallholders with irrigated agriculture. In many instances smallholders obtained irrigation experience whilst working as a farm labourer on a white-owned commercial farm. Familiarity with irrigation and crop management provided smallholders with confidence about their ability to grow crops successfully. When confronted with a new technology, such as micro-irrigation, they were able to focus most of their attention on the challenges imposed by the innovation, without being overly concerned about other aspects of their crop production enterprise. The team found that when farmers lacked previous irrigation experience, they became overwhelmed by the multitude of problems associated with irrigated crop production, causing initial results to be very disappointing. Under such conditions, the likelihood of smallholders abandoning their micro-irrigation enterprise was high.

When working with inexperienced farmers, an evolutionary or phased approach to irrigation is probably the most likely way in which reasonable rates of success can be assured. However, introducing irrigated farming in the form of a learning package is very expensive, because of the high cost of the training, and the initial lack of substantial monetary returns on overall investment. After all, the team's experiences were that the training period required to provide farmers with adequate knowledge, skills and confidence could easily last for two years, or even longer in some cases. For this reason, the research team has proposed two ways in which phasing-in can be implemented in situations where funds to finance the training phase are not available. The first is to introduce smallholders to irrigated farming using conventional irrigation technology, such as overhead irrigation using moveable sprinklers, or surface irrigation using short furrows. The second proposed way is to limit the initial area put under micro-irrigation to a small plot of about 100 m^2. This makes the new technology relatively easy to manage, and allows the farmer to maintain an overview of the status of his or her crop. Once the farmer has gained sufficient experience and confidence, the scale of the micro-irrigation enterprise may be enlarged.

The research team also observed that farmers with irrigation experience had less difficulty in executing basic technical and mechanical interventions, necessary to keep the micro-irrigation system in operation. This reduced the dependency of the smallholder on maintenance and repair services, increasing the reliability of the system and reducing cost. However, it was the research team's finding that the technical responsibilities of farmers needed to be limited as much as possible, to enable them to focus their attention on crop production and irrigation.

The head of the household was not always the person who conducted the day-to-day farming activities. In some instances a family member did the farming, and in others it was a hired help or farm labourer. In these guidelines we refer to such a person as an operator. The team found that the operator needed to be the target of training and information supply. Also, in cases where the operator was not likely to remain on the farm for very long, it was necessary to include a replacement in the training programmes.

On smallholder schemes, the team encountered dedicated persons who were responsible for the execution of specific tasks related to irrigation. Often this included taking care of the supply of water. We refer to these persons as operators also. As in the case of farm workers discussed in the previous paragraph, these operators played a very important role in the irrigation scheme, and were identified as prime targets for training.

In terms of education, the team found that functional literacy was not a pre-requisite for farmers to be successful in micro-irrigation. When smallholders were functionally illiterate, the process of transferring information had to be adapted accordingly. In such cases, emphasis needed to be on oral communication accompanied by hands-on demonstration. Where appropriate technology was available, basic face-to-face communication could be added to, for example by using narrated video images.

When planning a smallholder micro-irrigation project, the designers should take into account the role of farming in the livelihood strategy of the smallholder household. When a farmer household was highly dependent on farm income for his or her livelihood, the fear of failure tended to be greater than when farming supplemented other substantial and reliable sources of income. In other words, dependence on farming for survival tended to make a farmer and his household risk-adverse. In such cases, the use of a phased approach proved very attractive, even when the farmer had good irrigation experience. This involved the initial introduction of micro-irrigation on a small part of the farm only, followed by expansion of the area under micro-irrigation when the farmer had developed sufficient confidence. Whereas a high level of dependence on farming for survival tended to make farmers risk adverse, the team found that it increased the likelihood of successful adoption of micro-irrigation. The team concluded, therefore, that this type of farming households were a very attractive target group for micro-irrigation development, but planning needed to consider their adversity to risk and pursue a phased approach to the introduction of this technology.

The team found that it was important to explain the content of the evolving plans to farmers, because farmers usually did not know what to expect from micro-irrigation. Planners, on the other hand, had the advantage of knowing the various challenges farmers would be confronted with when they engaged in crop production using micro-irrigation. After providing farmers with detailed explanations, planners should ensure that farmers are satisfied that they understand why particular elements have been incorporated in the plan. Thereafter, planners should encourage farmers to voice their opinions and make inputs into the plans.

Table 3 Summary of guidelines for system planning: Planning with farmers

Farmer experience	➢ Determine the life experience of the intended end-users, with special reference to the skills required to conduct a micro-irrigation enterprise successfully. Give specific attention to agricultural and irrigation experience, technological experience, and experience in basic record-keeping and marketing of agricultural products. ➢ Plan implementation of production in accordance with the findings on farmers' experience, allowing for a phasing-in of micro-irrigation in cases where farmer experience is lacking. The introduction of micro-irrigation on a small area of 100 m^2 or less is recommended during the first phase for farmers who lack basic experience ➢ Plan for rapid progress in cases where a phased-in approach is necessary, by ensuring intensive monitoring and advisory support during the initial phases.
Technical experience	➢ Plan design, and operation and maintenance of the micro-irrigation system in accordance with the technical and mechanical knowledge and skills of farmers. ➢ Limit the responsibilities of farmers in terms of system operation and maintenance as much as possible. ➢ Prepare and implement a hands-on training programme to provide farmers with the ability and confidence to execute the technical and mechanical tasks allocated to them by the overall plan.
System operator	➢ Make use of a system operator where possible, especially in the case of irrigation schemes. The operator needs to have the necessary technical and mechanical know-how to operate and maintain the irrigation system. This is even more important in cases of experimental or demonstration farms/plots and schemes involving part-time farmers. ➢ Involve farmers and other stakeholders in the negotiation leading to a decision on remuneration for the system operator, which should be adequate to motivate his/ her sustained commitment to performance. ➢ Plan for the replacement of the system operator, especially when indications are that the operator may leave the project when more lucrative employment opportunities present themselves.
Financial dependency	➢ Determine the degree to which farmers are dependent on the income derived from irrigated cropping, especially in cases where micro-irrigation is to replace an existing irrigation system. When the level of dependency is high, plan for phased-in conversion of the irrigation system. This will enable farmers to maintain income derived from the irrigation practises they are familiar with, whilst they develop confidence in the use of micro-irrigation on a small plot. (continued overleaf)
Communication skills	➢ Develop an appropriate way of communicating knowledge and information by taking into account language proficiency and level of literacy of the farmers.

4.2.3 Water and soil quality, farm size, and water supply system

Using micro-irrigation, it is possible to produce high yields and products of high quality under conditions where conventional ways of irrigating a crop would not yield good results. Examples of such conditions are areas with poor-quality soils, or situations where the availability of water is low. However, farming under such conditions is very demanding, and poses a high risk to the inexperienced irrigator. For this reason, the team recommends that the implementation of smallholder micro-irrigation should not be considered under such conditions, unless there is clear proof of excellent support services and adequate supply of water.

During planning, the quality of water and soil should be evaluated using the standard procedures and guidelines that apply for irrigation planning, such as those supplied by the Department of Water Affairs and Forestry (1996). Feasibility of the irrigation project will depend on the need to ameliorate water and soil quality in the same way as it does for other irrigation projects, because of the high cost of such interventions.

Observations by the research team suggested that the size or scale of a micro-irrigation enterprise was an important factor. The team found that when the scale of a micro-irrigation enterprise was intermediate, i.e. ranging in area between 0.1 ha and 1 ha, the benefits expected from the use of a micro-irrigation system were not as evident as in the case of very small (i.e. smaller than 0.1 ha) or relatively large (i.e. larger than 1 ha) enterprises. In the case of the very small plots, farmers can exploit the opportunity created by the decrease in labour demand due to the change in irrigation method, to expand crop production and cultivate a larger area. In the case of large farms, the decrease in demand for labour, usually supplied by hired workers, is appealing to farmers, because it reduces cost of production.

It is important that the source of the water supply for irrigation is assessed very carefully. Based on the findings of the research team, successful implementation of micro-irrigation is closely linked to this factor. In the beginning, when farmers start using micro-irrigation, they tend to waste water. When the source is sufficiently abundant to allow for a degree of wasting of water, irrigation enterprises will not be affected too much by utilisation of water that is sub-optimal. When this is not the case, and the adequacy of the water supply depends on high levels of efficiency in water use, the probability of failure is increased. When planning the area to be irrigated, the design team should consider the various uses to which the source of irrigation water is put, and also the variability of the supply in relation to seasonal effects. This information should be used to determine the maximum area for irrigation, ensuring ample supply even under conditions when supply is at its lowest level. This particular recommendation assigns priority to the need to limit risk over the need to extract maximum benefit from the available water resources. Where suitable land for expansion is available, future increases in the efficiency of water use by farmers can be accommodated for in the design of the micro-irrigation system. This option is discussed in more detail in section 4.3 of these guidelines, and is particularly relevant for smallholder projects that enjoy grant funding.

The team found that reliability of the water supply is even more important to success in smallholder micro-irrigation than its adequacy. Of all the factors that were identified as influencing success, the reliability of the water supply was the most important. In nearly all the cases in which reliability of the supply was suspect, failure of the micro-irrigation project followed.

Conditions in which adequacy and reliability of the water supply are especially critical include the use of coarse textured and or shallow soils, and the use of drip irrigation. Coarse textured soils and shallow soils have low water holding capacities, thus increasing the need for frequent irrigation. Drip irrigation systems supply small quantities of water at a time, and interruptions in the supply of water tend to have severe effects on crop yield and quality. Even a single interruption in the supply of water may cause crop failure when this occurs during a critical stage of growth of the crop. On large-scale farms such emergencies are usually attended to at once, but lack of financial resources, and general isolation from support systems are factors, which appear to prevent smallholders from doing the same.

When the supply system is pressurised (sufficient pressure to drive a micro-irrigation system), but the pressure and or flow rate is subject to much fluctuation, and therefore not considered reliable, the desirability of implementing micro-irrigation must be questioned seriously. In micro-irrigation, flow rate and pressure characteristics are built into the design of the system for each irrigation block. When the conditions vary from these built into the design, variability in the application of water will occur within the block, resulting in poor crop performance.

Farmer participation in decision-making on water supply management issues is important. Ideally, a capable and experienced operator is made responsible for the management of water supply. The team found that the probability of success in smallholder irrigation is increased as the degree of responsibility for the supply of water allocated to farmers or their farm workers is reduced. In the case of schemes, the appointment and training of a suitable operator is important. When a dedicated operator is not available or not affordable, the person(s) operating and maintaining the supply of water should enjoy good support to enable quick and efficient response to failures or emergencies.

In the case of individual farmers or farm workers being responsible for water supply, adequate technical training must be provided. Where individual farmers or farm workers are also responsible for pumping water, and electricity is available, an electrical motor should be used to drive the pump, and the farmer or farm worker should be trained in the operation and maintenance of pump and motor. Where electricity for pumping is not available, micro-irrigation should not be considered, unless the farmer or farm worker has proven mechanical skills, and reasonable access to a source of spare parts. At the time of the research, pumping systems powered by fossil fuel engines were on average three times more expensive per unit water pumped than electrically powered systems. Compared to electrical motors, engines using fossil fuel required more intensive and more frequent maintenance, and the cost of a single maintenance service was also significantly higher.

In the environments where the research was conducted, theft of equipment and irrigation system components was a threat to success in small-scale irrigation. Generally, the team assessed the implementation of theft-preventing installation procedures, such as the burying of pipes, to be expensive. Instead it considered the use of components made of materials that do not have an inherent resale value to be a useful approach to prevent system damage by theft. Components made of materials that have an inherent value, such as brass and copper, are more likely to be stolen.

Table 4 Summary of guidelines for system planning: water, soil and farm size

Soil and water quality	➢ Assess the quality of water and soil in accordance with standard guidelines and procedures. This evaluation should influence decision on design parameters. The cost of any soil or water quality amelioration should be considered when assessing project feasibility.
Project scale	➢ Determine the supply of water, considering uses other than irrigation from the source that has been identified. ➢ Use expected minimum supply, as determined by seasonal or other variations, as a design parameter ➢ Allow for a liberal safety margin of at least 30% less than the minimum amount of water available at all times when determining the maximum area to be irrigated from the available source of water. ➢ Use this safety margin to determine the size of the project for implementation at the initial stage. However, design for the full area that can be irrigated from the available supply, enabling expansion of the project when appropriate. ➢ Take into account that the benefits expected from using micro-irrigation are least evident when the scale of the operation is intermediate, i.e. ranges between 0.1 and 1 ha.
Water supply	➢ Assess the reliability of the water supply. In cases where the supply is not reliable, determine the cause thereof. If the cause cannot be addressed adequately by means of technical or managerial interventions, a decision against the implementation of micro-irrigation is recommended. ➢ Take into account that the reliability of the water supply is most critical in climates characterised by high evaporative demand, or when soils have a low water holding capacity. ➢ Avoid the use of drip irrigation when the reliability of the water supply is not ensured, when dealing with soils with low water holding capacity, or in areas where evaporative demand is high. ➢ Base the choice of system on the total volume of water required during the various stages of growth of the crops to be grown, the flow rate and the pressure available. ➢ Subdivide irrigation blocks into smaller sub-units when pressure or flow rates of water supplied to the block are subject to considerable variations. Subdivision into small units will enable acceptable irrigation practise in each of the sub-units separately, even when pressure or flow rate are inadequate to do so on the entire irrigation block. (continued overleaf)

	➢ Build safety measures into the design of the system when the reliability of the water supply is suspect. This can include the building of a small water storage facility. ➢ Consider seriously the option of installing a low-cost (plastic) valve at the entry to each lateral when designing small systems. This enables maintenance of adequate pressure and flow rate during periods of problems with these factors. The valves will also be useful in future when diversification of the micro-irrigation enterprise, achieved by planting a range of crops with different water requirements, demands irrigation to areas supplied by different laterals to be adapted to specific requirements. ➢ Allocate responsibility of informing farmers timely about water use restrictions and the application of contingency measures to deal with such situations, especially when the water supply system is pressurised.
Water supply management	➢ Pursue the option of having the water supply managed by a capable and experienced operator. ➢ Ensure for a well-functioning support system when a capable and experienced operator to manage the supply system is not available.
Energy for pumping	➢ Avoid the use of pumps that are driven by engines powered by fossil fuel. ➢ Ensure that operators of pump systems receive adequate hands-on training to perform routine maintenance and simple repairs, especially when conditions dictate the use of pumps powered by engines using fossil fuel.
Security considerations	➢ Use components made of materials that have no inherent resale value wherever possible; in order to discourage theft. ➢ Allow for the locking away of expensive system components in the plan and design of the project. ➢ Plan for sub-surface installation of those system components, which do not require moving, but avoid any measures which compromise system flexibility. ➢ Plan the system to allow for convenient moving of in-field irrigation equipment, especially when dealing with a food-plot scheme.
Learning phase	➢ Plan for the planting of crops, which are relatively insensitive to sub-optimal water supply, during the initial phases of implementation. This will allow farmers to develop the required confidence to try out high-value crops, which are more sensitive to water stress. (continued overleaf)

	➢ Take into account the financial risk to farmers should the first planting develop into a failure, and evaluate the effect of such an event on the survival of the farmers' enterprise as a whole. When this risk is unacceptably high, introduce intermediate steps (small introduction plots) or when this is not feasible, reconsider the desirability of micro-irrigation.

4.2.4 Crop production

As indicated earlier, using micro-irrigation, it is possible to produce high yields and products of high quality under conditions where conventional ways of irrigating a crop would not yield good results. This applies particularly to conditions of poor-quality soils, poor-quality water, and limited availability of water. It was also pointed out that success in micro-irrigation under such conditions is highly dependent on the skills and management ability of farmers. Therefore, such conditions represent risk, which needs to be avoided, especially when planning for smallholders who lack these attributes. When conditions are sub-optimal, a degree of risk can be removed by selecting an appropriate crop. Depending on the prevailing limitation, crops can be selected for their salt tolerance or their resistance to occasional water stress. The Department of Water Affairs and Forestry (1996) provides advice on the salt tolerance of a range of crops.

There are many crops that can be grown equally well with micro-spray and drip irrigation systems, but it some cases the choice of crop will favour a particular system. For example, in the case of tomatoes, drip irrigation will be preferred over micro jets because it prevents water coming into contact with the leaves of the plant, thereby reducing the risk of fungal diseases.

Farmers must be supplied with appropriate guidelines on the spacing of crops when using micro-irrigation. In many cases these will differ substantially from the practices of the farmer, which were developed for use in conventional irrigation. Sub-optimal spacing of the plants may have a detrimental effect on yield and economic returns, preventing expected benefits from being realised.

When planting perennial crops, such as fruit trees, several years may go by before any financial returns are realised. In such cases, the planting of an intermediate crop between the rows of the perennial crop should be considered seriously during the first few years after establishment of the perennial. This will enable farmers to derive income during the period when returns from the perennial crop are being awaited. It requires an adapted design of the in-field system, but is not necessarily more expensive to implement than a design suited for perennials or annuals only.

Table 5 Summary of guidelines for system planning: Crop production

Choice of crops	➢ Encourage farmers to grow the crops with which they are familiar, especially during the first few years after implementation. This recommendation should be ignored only when excellent and reliable advisory support is available and committed to guide farmers during the first few years of production of a new crop. ➢ Allow the selection of crops to be guided by the availability and reliability of the water supply, the quality of water and soils, the experience of the farmers, the reliance of farmers on income from irrigated cropping, and the existing marketing opportunities.
Choice of in-field system	➢ Select between micro-spray and drip irrigation by considering the quality of water and soils, and the selection of crops to be grown
Spacing of crops	➢ Advise farmers on the optimum spacing of crops under micro-irrigation. When using drip-irrigation the spacing of the plants should preferably be adapted to the spacing of the emitters. This is especially important in the case of seedlings.
Intercropping	➢ Consider the use of intercropping when planting perennial crops, which do not supply financial returns during the first few years after establishment, and adapt the design of the in-field system to enable the pursuit of such a strategy.

4.3 SYSTEM DESIGN

4.3.1 General issues

Smallholder micro-irrigation differs from its large-scale equivalent in several ways. Some of these differences influence the approach to system design. These include the scale of the project; the cash flow, and access to finance by farmers. Based on its observations, the research team considers a modular approach to system design as the preferred option. This approach increases the total capital investment per unit area, but limits investments made on any one occasion, making it easier for farmers to service loans. A modular or incremental approach to system design also accommodates the need for many smallholders to go through a learning phase to get familiar with irrigation in general, and micro-irrigation in particular. This need was discussed in section 4.2 of these guidelines.

When considering the design of the system, due consideration should be given to income and cash flow of the smallholder. A modular system allowing for incremental growth in the area under micro-irrigation will allow variable costs of production to be kept low at the start, because only a small area of land is put to micro-irrigation. At this stage, the repayment of loans may far exceed the returns on the investment made in a micro-irrigation system. However, when loan repayment rates are matched to the total income of farmers, including sources of income other than micro-irrigation, it becomes possible for farmers to carry a lack of adequate returns on their investment in micro-irrigation during the first few years. It is, therefore, important to determine the various sources of income of the farmers, including on-farm, off-farm, and non-farm.

The cost of laterals and emitters largely determine the cost of the in-field system. Farmers agreeing to a system that requires laterals to be moved around the field, or between rows, can reduce the cost of their in-field system. This option needs to be discussed carefully with the farmer. Time available to the farmer, and his or her willingness to accept the drudgery associated with moving laterals, need to feature prominently in the discussions.

Work conducted thus far was insufficient to make conclusions about in-field design tolerances. Consequently, it is suggested that conventional design tolerance standards, such as those presented in the Irrigation Design Manual (Agricultural

Research Council – Institute for Agricultural Engineering, 1996) (ARC-ILI) be applied. There may be situations where less strict design tolerances may lead to considerable capital cost savings. One example of a situation where this opportunity occurs is when the design of the system allows for the use of one sub-main instead of two. However, any consideration to deviate from recommended design norms must be subjected to extreme caution.

The design of the system should consider possible future desires of farmers to expand their system. Expansion can be accommodated to a limited extent by incorporating the option of additional laterals. To incorporate a similar option along laterals, by designing the system to enable the addition of emitters along the lateral, can add considerably to the cost of the system if such an option requires the installation of larger-size pipes. It is important, therefore, that system design and choice of components allow for such expansion.

Water requirements and system capacity can be determined by means of standard procedures, such as those described in the Irrigation Design Manual by ARC-ILI (1996). However, when planning irrigation scheduling, the time available to the farmers needs to be considered carefully. Since micro-irrigation is expensive, the ultimate goal of scheduling should be to minimise the time the system is idle.

Table 6 Summary of guidelines for system design: General issues

Approach to system design	➢ Explore the opportunity to adopt a modular approach, allowing for the area under irrigation to grow incrementally. If a modular approach is desirable, the equipment and pipe sizes should be selected accordingly. ➢ Favour the minimising of variable costs at the expense of minimising total capital cost in system design, when the development cost of the project is supported by means of a grant. Since farmers are not required to repay capital cost, designing for low variable costs will assist them financially.
In-field system cost	➢ Explore the desirability of a design that requires the movement of laterals between crop rows (two to three rows per lateral), because it reduces capital cost. The decision depends on the farmer's time to move laterals, and on the farmer's willingness to accept the drudgery of engaging in this practise. ➢ Ensure that the sub-main design accommodates for one lateral per row, even in cases where a design requiring the moving of laterals is adopted.

Options for system extension	➢ Incorporate in the design the option to extend the system where other factors allow for this option to be exercised. In practise, this requires incorporation in the design of the option of adding one or two additional laterals on the sub-main. Care should be exercised that this option falls within the tolerance limits of the system.
In-field design tolerances	➢ Apply standard ARC-ILI norms for in-field design. ➢ Investigate the possibility to reduce capital cost by lowering the EU-values. Until current knowledge is improved, a minimum EU value of 85% should be maintained. (continued overleaf)
Water requirements	➢ Apply the standard procedures recommended in the Irrigation Design Manual (ARC–ILI, 1996), to determine water requirements and system capacity. The SAPWAT procedures (Crosby & Crosby, 1999) produce good results. ➢ Optimise irrigation scheduling taking into account the time available to the farmer, and future extensions to the system.

4.3.2 In-field system

Based on observations during the research project, the team considers the type of emitter selected and the spacing of the emitters as factors that influence success in micro-irrigation. Emitters differ in terms of their maintenance requirements. This applies to both micro-sprayers and drippers. In the case of micro-sprayers the maintenance requirement is determined mainly by the need to clean the nozzle, and the way the sprayer spreads the water. In the case of drippers, maintenance requirements depend mainly on whether the emitters are pressure-compensated or not. Selection of the type of emitter and the spacing between emitters should aim at reducing the risk of failure. Consequently, farmer experience and farming conditions need to be considered carefully when making these decisions.

System management is simplified when compensated emitters are selected for installation. Compensating emitters reduce the likelihood of blockages, and compensate for variable pressure in the supply system. Consequently, a system characterised by good distribution uniformity is obtained. The application of standard design procedures, in designs that involve the use of compensating emitters, allows for large pressure variations to occur whilst good application uniformity in the block is maintained. From a management perspective, this is a major advantage.

Table 7: Summary of guidelines for system design: In-field system

Type and spacing of emitters	➢ Favour the installation of static micro-sprayers over rotating micro-sprayers, unless the crop demands the rotating kind. Rotating micro-sprayers are more expensive than the static types, require more weed control because plants can prevent rotation, and the moving parts can be damaged or get lost. ➢ Space emitters closer than required when designing a drip system. It is worth the extra cost incurred since it reduces the risk of seedlings not receiving water because they are too far from an emitter.
System management	➢ Elect for the use of compensating emitters if at all affordable. ➢ Use procedures that apply to designs with non-compensating emitters, when installing compen-sated emitters on laterals shorter than 100 meters.

4.3.3 Filtration and control components

Unless irrigation water is purified before off-take, as is the case in municipal water, all farm micro-irrigation systems require filtration of the water. Even when a farmer is not the operator of the system, he or she needs to understand the importance of filtration, and needs to have knowledge on how the filter works. Procedures required to ensure proper functioning of the filters are time consuming and not particularly pleasant, because the person conducting the procedures usually gets wet. As a result, there is a tendency for operators to postpone this task or even neglect it.

The team preferred the use of disc-filters to that of mesh-filters in smallholder micro-irrigation. The reason was that initial minor damage to mesh-filters is difficult to detect. However, when initial damage is not identified and repaired, irreversible harm may be caused to the in-field system, especially when drip irrigation is practised. Sand-filters were also not favoured by the team, because they are expensive, and their cleaning is complicated and difficult to comprehend fully. As with mesh-filters, inadequate maintenance brought about by a lack of understanding, experience, or technical expertise may lead to serious damage to the in-field system.

It is important that farmers are trained to a level where they are confident to inspect the condition of the filter, and to execute maintenance procedures. The farmer must develop the necessary expertise to identify and repair basic faults. These arise mainly when components of the filter are tampered with. The team witnessed two scenarios where this occurred. In one case, some of the filter rings had been removed. This increased the gap between the filters. In the other case, the screws on the filter element were not tightened sufficiently. In both instances, the need to flush the filter was reduced, because impurities were now able to pass through the filter. The team found that in both cases the operator of the system was quite pleased with the reduction in workload, and was unaware that damage was being caused to the in-field system. It follows that farmers need to have adequate knowledge about the filtration system, its operation and its maintenance. Whereas instructions on fixed flushing cycles are of great help; they are meaningful only under conditions where the sediment load of the water remains more or less constant.

For optimum operation of the micro-irrigation system, it is important that the pressure downstream of the control valve of the block is maintained as closely as possible to the pressure recommended as part of the design. This pressure may vary for a number of reasons. The most common reasons are fluctuations in the pressure at the water source, and a reduction in pressure caused by a soiled filter. Leaks in pipelines upstream and downstream of the control valve can also cause variation in pressure. It is, therefore, important to include in the system the necessary measuring equipment to enable farmers to monitor the functioning of the system, and identify anomalies.

Table 8 Summary of guidelines for system design: Filtration

Filtration	➢ Incorporate a filter in the system, unless the supply of filtered water is assured. ➢ Make use of disk-filters wherever possible. ➢ Select a filter that has a capacity that exceeds system needs by about 30%. This will reduce cleaning requirements, and will allow for possible expansion of the system in future. ➢ Install a pressure gauge upstream and downstream of the filter to enable the farmer to monitor the condition of the filter. Monitoring of the pressure gauges will enable the farmer to identify when the filter is clogged. ➢ Train the farmer in the operation and maintenance of the filter.
Maintaining design pressure	➢ Include a schrader valve to monitor pressure downstream of the control valve of the block ➢ Include a secondary valve for pressure control when the supply pressure is subject to considerable variation. An inexpensive ball

	valve can be used as the primary valve, and a gate valve can act as the secondary valve. ➢ Consider equipping each lateral with a valve when dealing with a small system. This will be very useful to adjust irrigation to the requirements and growth stages of different crops being planted.

4.4 SYSTEM INSTALLATION AND TRAINING

4.4.1 Installation and commissioning

Training of farmer and support team must be incorporated into the installation of a smallholder micro-irrigation system. During the installation process, these two stakeholders must receive hands-on training in the connection of the various components, and the role of each component in the system. This training serves to demystify the operation of a micro-irrigation system. It will help farmer and extension agent to acquire knowledge for use when repairs to system components are required, reducing their dependency on external agencies for these tasks.

It is also extremely important that installation is performed by a qualified and experienced person, or under the supervision of such a person. The involvement of this person is required during the entire installation process, from source to last emitter. The objective is to ensure that installation is of superior quality throughout. This is necessary because faulty workmanship, such as leaking fittings, plastic pipes disengaging, or suction problems of pumps will leave the farmer at a loss. When farmers become disappointed in the system during the early stages, the likelihood of total failure of the project increases considerably. For this reason, the team strongly recommends that excellence in workmanship must be specified explicitly in the contracts governing the installation of smallholder micro-irrigation systems.

Once the micro-irrigation system has been installed, it is time for the commissioning of the system. Commissioning refers to the process of preparing the system for operation in order to hand it over to the client. As with installation, commissioning needs to be incorporated in the training programme. Farmer and extension agent attend are shown how to set pressure and other variables, and are given an opportunity to manipulate the system to achieve the correct settings. This phase of the training prepares the farmer to proceed on his own system operation

Table 9 Summary of guidelines: Installation and commissioning

Installation	➢ Use the installation process to train farmer and extension agent. ➢ Ensure that the entire installation is conducted under the supervision of a qualified and experienced person. ➢ Involve farmer and extension agent in the conduct of installation activities in a hands-on way. ➢ Specify excellence in workmanship in the installation contract. (continued overleaf)
Commissioning	➢ Demonstrate to farmer and extension agent on how to operate the system in accordance with design specifications. ➢ Ensure that farmer and extension agent understand that extensions and alterations to the system, for which the system was not designed, should be avoided totally.

4.4.2 Training

The important role of training as a factor determining success in smallholder micro-irrigation cannot be over emphasised. From the project, the research team learnt that many smallholders lack the knowledge and experience to install and operate a micro-irrigation system without training, even when supplied with comprehensive documentation on both processes. Similarly, it was the team's experience that many extension agents are in a position of knowledge and experience similar to that of farmers when it comes to micro-irrigation. For this reason, the team strongly recommends that the installation of the micro-irrigation system be organised as a hands-on training session for these two important actors. This means that the person leading and supervising the installation must accept the role of trainer also. At the time of installation and training, a comprehensive set of relevant documentation must be made available to both farmer and extension agent. This documentation must be referred to as the process of installation evolves.

Farmer and extension agent must also be supplied with a comprehensive set of contact details of the suppliers of each of the different components in the irrigation system. The suppliers must be provided with a file containing the exact specifications of each of the components contained in the irrigation system. This will facilitate communication between farmer or extension agent and suppliers, enabling fast and effective response when the system requires repairs or replacement of one or more components.

Inexperienced farmers will face a major problem when confronted with damage to or break down of their irrigation system. Installation can be used to demonstrate basic repair procedures to farmer and extension agent. Farmers should receive advice on the range of spare parts to keep in stock, so that they can attend immediately to the faults most commonly experienced in micro-irrigation. Specific advice on executing repairs and useful spare parts is provided in the synthesis table, which follows this text.

It was the team's experience that farmers find it difficult to comprehend the concept of drip irrigation. The reason for this appeared to be that the supply of water to the crop is not very visible. Demonstration and explanation of the process needs to form part of the initial phases of the project. The team found that this helped to avoid damage to the components of the drip system, such as puncturing of pipes. It is also important to explain and demonstrate to farmers that the root volume of plants growing under drip irrigation is concentrated in the zone wetted by the dripper. This causes a reduction in the effectiveness of rainfall events, which needs to be understood by the farmer. The team found that farmers who did not comprehend this adequately tended to delay irrigation after a rainfall event for too long.

In cases where the laterals need to be moved from time to time, it is important to train the farmer to execute this task in a way that prevents dirt from entering into the components.

Table 10: Summary of guidelines: Training

Information and documentation	➢ Supply farmer and extension agent with a file that contains sketches of the components of the irrigation system, and the cost of these components. ➢ Include in the file a comprehensive list containing the contact details of all the suppliers of components that were incorporated into the irrigation system. ➢ Include in the file a list of useful suppliers of other services. This could include repair services, suppliers of agricultural chemicals, fertiliser suppliers, and marketing agents. A list of the types of possible suppliers to be included in the file is presented in Appendix C. ➢ Ensure that the files for the farmer and extension agent are available at the start of the installation process. ➢ Provide each of the suppliers of components

	of the irrigation system a list of all the components and their exact specifications.
Training (understanding the system)	➢ Plan the installation well in advance, and ensure farmer and extension agent are committed to be present for the duration. ➢ Involve the operator of the system in the training during installation in cases where the farmer is not the responsible person. (continued overleaf)
Training (Executing repairs)	➢ Train the farmer (and extension agent) to execute basic repairs. These training should cover at least the following aspects: ❖ Fixing of laterals (normally PE pipes) ❖ Fixing of sub-mains (normally PE pipes) ❖ Fixing of main pipes (normally PVC pipes) ❖ Replacing emitters ❖ Rejoining a lateral to a sub-main ➢ Prepare a list of spare parts the farmer should keep in stock, to enable him or her to execute basic repairs immediately. Ensure that these spares have been purchased at installation of the system. The spares should include at least the following items: ❖ Couplings for all sizes of pipes in laterals (2), sub-mains (1) and main pipes (1) ❖ In the case of a drip system, 5 emitters or 10 meter of dripper line ❖ For a micro-jet system, 5 emitter stops ❖ Wire (to use with insert connecters). ➢ Supply the farmer with a troubleshooting checklist, designed to respond to 'what if' questions. This checklist should provide detailed advice on how to solve the most common problems a farmer may encounter with a particular type of micro-irrigation system. This may include a number of emergency actions, consisting of temporary solutions to problems, which enable continuation of the use of the system whilst more permanent solutions are pursued. A list of topics that may be included in this checklist is presented in Appendix D.
Drip irrigation	➢ Explain and demonstrate the concept of drip irrigation early in the project. This should cover at least the aspects of discharge in a drip system, and the distribution of water below the dripper. Discharge is best explained by placing a container below a dripper, relating the release of water to the expiry of time. The distribution of water in the soil below the dripper can be

	demonstrated by digging narrow trenches along the dripper line and across the line at the position of a dripper. ➢ Make the farmer aware of the distribution of plant roots when demonstrating the water distribution in the soil below a dripper. Link the concentrated distribution of the roots to the reduction in rainfall effectiveness experienced when using a drip system. (continued overleaf)
Prevention of clogging	➢ Explain to farmer and extension agent the detrimental effect of dirt entering the micro-irrigation system. ➢ Demonstrate to farmer and extension agent how to prevent dirt from entering the irrigation system. Very important is a demonstration of how to move the system in a way that prevents the entry of dirt and subsequent clogging.

4.5 SYSTEM OPERATION AND MAINTENANCE

4.5.1 General issues

Compared to conventional irrigation, it is expected from micro-irrigation that it reduces the amount of labour and time a farmer has to spend irrigating his or her crops. These benefits may not necessarily become evident immediately after converting from conventional to micro-irrigation. Over time, when the farmer has become used to operating the system, savings in time and labour will materialise. Farmers should be encouraged to invest these savings in additional profitable activities, for example by expanding the area under irrigation.

All practises for system maintenance regarded as standard by the industry (ARC-ILI, 1996) also apply to a smallholder micro-irrigation system. Among others, these practises include the flushing of mains, sub-mains, and laterals, and correcting the position of laterals and micro-jets. Users of these guidelines are referred to other suitable publications for comprehensive guidelines on standard maintenance practises in micro-irrigation systems. Users are also reminded to carefully consider the maintenance practices and procedures recommended by the manufacturers of a specific system.

The team found that few smallholders kept records. The few farmers who kept records did so in a haphazard manner, reducing the potential value of this activity.

The team also noted that record keeping was not an essential factor for success in micro-irrigation.

Farmers should be encouraged to keep records of maintenance procedures. The use of a simple form guiding the entry of records is encouraged. However, the usefulness of record keeping needs to be demonstrated to the farmer. This is achieved by having the project support team analyse the record, and use this analysis to detect faults and their underlying causes. In this process, the support team needs to show to the farmer how the records enable diagnosis of problems, and how this diagnosis is used to solve problems. The research team encourages annual sessions where the project support team analyses the records and formulates recommendations.

Table 11 Summary of guidelines: General operation and maintenance

Standard maintenance practices	➢ Apply the standard practises for system maintenance in micro-irrigation as recommended in the Irrigation Design Manual (ARC-ILI, 1996) ➢ Encourage farmers to practise chemical weed control, because this reduces the hazard of system damage caused by mechanical cultivation. ➢ Explain and demonstrate the damage likely to be caused when practising mechanical cultivation, and demonstrate how such damage should be repaired.
Time and labour savings	➢ Explain to farmers how the micro-irrigation system should be used to save time and labour. ➢ Explore with farmers the potential for additional profitable activities, which can be undertaken using the spare time and labour that has become available.
Record keeping	➢ Provide farmers with simple forms on which to enter records. ➢ Encourage farmers to keep records, and explain the potential benefits that can be derived from keeping accurate records. ➢ Train the farmer to fill in the forms, and address the difficulties farmers experience with filling in the forms by means of regular follow-up visits. ➢ Arrange an annual review event, during which the records are analysed in the presence of the farmer, and ensure that this leads to conclusions and recommendations for improved management.

4.5.2 Water supply system and in-field irrigation system

Regular flushing of main pipes, sub-mains, and laterals is necessary to ensure long-term functioning of a micro-irrigation system. It is, therefore, important that farmer and extension agent develop confidence in the execution of these procedures. The positive effect of flushing needs to be explained during installation. As installation proceeds, and the different components are positioned in the system, farmer and extension agent are show what flushing does to the various components, and what happens to the components when this necessary practice is ignored. Commissioning is the best time to train farmer and extension agent in the correct flushing procedures. Clear guidelines on these procedures should form part of the files supplied to farmer and extension agent.

Cleaning of emitters is also important for sustained functioning of the system. Cleaning procedures need to be demonstrated, and guidelines need to be included in the file supplied to farmer and extension agent.

Generally, the maintenance of micro-jet systems is assisted by the visibility of the effects of clogging and blockages in the system. A reduction in the size of the jet or spray is an indication that dirt may be blocking the water flow in part or all of the system.

Visible evidence of clogging or blockages is less obvious in drip systems, because the emission of water from a dripper is slow by design. Usually, problems are only detected when emission from the dripper comes to a total halt. This causes water stress in the plant irrigated by the dripper, a condition that is quite easy to detect. However, by this stage, yield and quality of the crop have been affected negatively. It is, therefore, important that the farmer executes a monitoring programme to ensure optimum functioning of the drippers. The use of containers placed under drippers, and the measurement of water released per unit time by means of a stopwatch and a measuring cylinder, are recommended. Regular testing of a drip system is recommended procedure, because drippers tend to get clogged over time as a matter of course.

Table 12 Summary of guidelines: Supply and irrigation system O&M

Flushing of the irrigation system	➢ Advise farmers on standard SAII procedures applied to maintain good functioning of the micro-irrigation system. These procedures need to be adapted to the scale of the project. ➢ Provide farmer and extension agent with clear guidelines on these procedures. ➢ Train farmer and extension agent in the conduct of the procedures. (continued overleaf)
Blockages in drip systems	➢ Explain to farmers that over time, drippers tend to clog as a matter of course, necessitating a monitoring programme aimed at detecting reductions in the emission of water. ➢ Mark with white paint three or more drippers distributed over the length of a lateral, and determine the flow rate at each of the drippers. Repeat this procedure for at least three laterals in each block. Develop the details of a monitoring programme, and explain what to do when a reduction in the flow rate is detected.
Cleaning of emitters	➢ In the case of micro jets, provide the farmer with a set of pins, of which the diameter is smaller than the orifice of the emitter, to clean or unblock the micro jets. ➢ In the case of drippers, demonstrate to the farmer how to unblock a dripper, i.e. by knocking the drippers or by applying external pressure on them.

4.5.3 Application of fertilisers

Research results obtained by the team were inadequate to make recommendations on best practise in the application of fertilisers for the various micro-irrigation systems. The methods and equipment used by large-scale farmers are designed to apply large quantities of fertiliser on large areas of land. They are expensive, and their use makes economic sense only when the size of the operation is sufficiently large. For smallholders these systems are not economical. Consequently they have to explore alternative ways of applying nutrients to their crops. The team recommends that additional work be conducted on this aspect of micro-irrigation for smallholders.

Table 13: Summary of guidelines: Application of fertilisers

Application of fertilisers	➢ In all cases, farmers must be supplied with clear guidelines and recommendations on the type of fertiliser to use, the application rate, and the time of

	application. ➢ In drip irrigation on a small scale (less than 2000 m^2) the application by hand of granular fertiliser will yield fairly good results. Ideally, after application, the fertiliser should be worked into the soil using a garden fork or spade. ➢ In small-scale micro-spray systems (less than 2000 m^2), acceptable results are obtained when granular fertiliser is spread by hand on the surface of the soil. (continued overleaf) ➢ In micro-irrigation on a scale larger than 2000 m^2, several options are available. These form part of the range of options considered standard in micro-irrigation (ARC-ILI, 1996). These include the use of a Venturi apparatus, a fertiliser tank, hydraulic injectors, electrical injectors, and the mixing of fertilisers in a storage tank at the water source.

4.5.4 Irrigation scheduling and monitoring of water supply to crops

Guidelines for the scheduling of irrigation need to be formulated for the specific conditions that apply to the farm where micro-irrigation is being implemented. Factors that need to be considered when formulating the guidelines are climatic conditions, the crops that will be grown, the relationships between stage of growth and water requirement of these crops, and the cultivation practises.

Use of instruments or procedures to monitor and guide irrigation scheduling is good practise. However, instruments such as a Class-A evaporation pans, and tensiometers, require substantial maintenance to ensure reliable results. Similarly, the results of monitoring procedures require careful interpretation. For these reasons, the team suggests that during the initial phases farmers are not burdened with a system of scheduling that responds to monitoring. Instead, farmer should be presented with fairly simple but adequate scheduling guidelines, which are easy to understand and follow. Later on, when farmers have developed confidence in their micro-irrigation enterprise, refinement based on monitoring can be considered.

During the fieldwork of this project the research team observed that smallholders tended to water their crops in excess of what was required for optimum growth. This was particularly the case when the supply of water was abundant. Generally, farmers appeared unaware of potential negative effects of over-irrigation, such as the leaching of nutrients, and the creation of anaerobic conditions in the root zone when dealing with soils characterised by sub-optimal drainage.

Table 14: Summary of guidelines: Irrigation scheduling

Irrigation scheduling	➢ Formulate an irrigation schedule adapted to the various local and on-farm factors affecting irrigation requirements. ➢ Transform the irrigation schedule into a set of elementary guidelines for use by the farmer, and supply a copy to both farmer and extension agent. Ensure that the farmer understands the underlying principles of the scheduling guidelines. Also ensure that the farmer understands how to apply the guidelines. ➢ Introduce monitoring instruments and procedures when the farmer has gained confidence in the use of micro-irrigation to refine scheduling. Introduce these on a trial basis on a small part of the farm, and evaluate impact and usefulness.
Exceeding irrigation requirements	➢ Explain to farmer and extension agent the potential negative effects of irrigating in excess of crop requirements. ➢ Demonstrate how soil water can be assessed by means of an auger or by digging a small soil pit.

4.5.5 Troubleshooting and the role of support services

The probability of success in smallholder irrigation is greatly enhanced by the availability of an effective after-care service. Overall, this may add considerably to the cost of micro-irrigation. The cost of an after-care service may be prohibitive when it has to be carried by the farmer. For this reason consideration should be given to including the cost of technical after-care in the cost of the total project. The state and the irrigation equipment suppliers should be asked to consider covering or contributing to the cost of the after-care service. The learning phase is most critical in micro-irrigation, and usually lasts for about two years. When a smallholder succeeds in passing through this phase, he or she is likely to progress well thereafter. Success is likely to lead to farmers expanding their area under irrigation. It may also encourage neighbour farmers to convert to micro-irrigation. State and suppliers of irrigation equipment, therefore, have long-term interests in supporting pioneer projects among smallholders.

Table 15: Summary of guidelines: Farmer support

After-care service	➢ Try to sustain the involvement of the project support team over a period of at least two years. ➢ Ensure that when the cost of such a service is negotiated it is incorporated in the total cost of the project.
Early success	➢ Ensure a concerted effort of all support services to ensure farmers make a success of the first few seasons. This usually provides farmers with the necessary confidence to proceed without extraordinary support. Since success among farmers also determines success among other stakeholders, the importance of first-stage support cannot be over-emphasised.
Communication	➢ Obtain a contact (telephone or cell) number where the farmer can be contacted as soon as possible after the project idea has been accepted. Where possible, obtain one or more alternative contact numbers. ➢ Provide the farmer with the contact details, including telephone or cell numbers, of the appropriate team members to contact when an emergency occurs. ➢ Arrange for farmers to come in contact with other users of micro-irrigation operating in his or her area, to facilitate discussion and sharing of experiences. ➢ Prepare a checklist of issues to raise on every scheduled visit. During these visits, open the discussions to any issues that are of concern to the farmer. A selection of issues that may feature on the checklist appears in Appendix C ➢ Include an inspection of the stock of spare parts on the agenda of the scheduled visits. ➢ Enquire about the usefulness of the troubleshooting checklist, and make notes on issues that should be included in subsequent versions of the checklist.

4.6 FINANCIAL ISSUES

4.6.1 Capital costs

Few smallholders are in a financial position to convert from conventional irrigation to micro-irrigation without some form of financial assistance. The same constraint also applies to farmers who are new to irrigation. When implementation of micro-irrigation on a smallholding does not form part of a development project that enjoys grant support, the farmer will need to obtain credit. This credit will be needed for both capital and production costs. This is not always easy, because in many cases smallholders may not have title to the land they farm. The Land Bank has a mandate to provide access to finance by smallholders. It has introduced programmes enabling non-title holder farmers to qualify for loans. However, it was the team's experience that the rural financial products and systems available at the time the fieldwork was conducted were still inadequate to meet the needs of smallholders in South Africa.

Micro-irrigation systems are expensive in terms of capital outlay per unit area. The team recommends that when planning and designing for smallholders, tried and tested micro-irrigation systems are used, and novel technology is avoided until their reliability has been proven. The high capital cost of micro-irrigation per unit area demands that utilisation of the system is optimised. This implies that the time the water supply and in-field systems are left idle is minimised. If this principle is taken into account during planning and design, and is implemented effectively on-farm, the capital cost of micro-irrigation per unit area can be reduced to about a quarter of the standard cost.

Table 16: Summary of guidelines: Capital costs

Conversion from conventional to micro-irrigation	➢ Make a concerted effort to address financial and technology transfer issues within the available policy and support frameworks.
Finance	➢ Assist farmers in negotiation on finance. Title to farmland may no longer be a pre-requisite for farmers to qualify for loans, but written proof of the assurance that they have medium to long term access to farmland may still be important.
High cost of micro-irrigation	➢ Elect for the use of good quality tested components in the design and installation of micro-irrigation on smallholdings. ➢ Avoid the use of cheap but inferior materials and the use of novel components, which have yet to prove their worth. ➢ Minimise idle time of water supply and in-field systems by considering the need to move laterals, because this can reduce the unit capital cost of micro-irrigation considerably.

4.6.2 Crops

Considering the capital investment required to install a micro-irrigation system, it is likely that all or part of the crops grown by the farmer will be marketed. The team recommends that a planting roster be worked out in consultation with the farmer. In addition, it is important to compile guidelines on the procedures that the farmer needs to follow before planting a specific crop. Later on, when the farmer has gained sufficient confidence to make his or her own decisions, this planting roster can be modified or abandoned totally. However, during the first few seasons, it will assist the farmer in organising his or her activities. It is also a good base document for use in discussions between farmers and support service representatives.

The selection of crops, especially those that will be marketed, is very important for the economic viability of the project. Localised markets are the easiest to access, but the size of the local demand for a particular crop needs to be well understood, before decisions are made on the size of the area to be planted to that crop. Major South African agricultural markets are shared by smallholders and large commercial farmers, and are characterised by price fluctuations. Niche markets may present a competitive advantage to smallholders. Often these are created by the ability of smallholders to minimise transaction costs. When marketing agencies are available, perishable crops can be grown for distant markets without undue risk. In the absence of a substantial local market or a marketing agency, it may be prudent to avoid the selection of perishable crops. Such situations characterise projects located in remote areas. Under these circumstances, the team recommends the planting of crops which can be stored for long periods, and to which the farmer can add value. Generally, the aim should be to produce a high-value low-bulk product.

One of the important roles of the project support team is to assist farmers in the identification of suitable markets. By bringing farmers in contact with persons who purchase agricultural produce, and by helping farmers to negotiate and formalise acceptable conditions, the project support team can remove much of the risk of farmers being unable to sell what they have produced. An analysis of available markets should also influence the choice of crop.

In cases where farmers operate micro-irrigation on an area that exceeds 2 ha, the planting of perennial crops needs to be considered carefully. Factors to be taken into account are climate, resources, and current and predicted markets. The planting of perennial crops, such as fruit trees, will enable the farmer to develop expertise in the production of such crops. One of the problems of perennial crops is that they usually do not generate income during the first few years. This creates cash flow problems, especially for smallholders who most often already struggle to make ends meet. For this reason, the team recommends that during the first years opportunities are created to enable the farmer to derive income from sources other than the perennial crop. Several options exist, including off-farm and non-farm sources of income. On-farm options include the introduction of intercropping, whereby cash crops are planted between the rows of perennials, until such time the closing canopy of the perennial crop prevents this from being continued. Alternatively, only part of the land could be planted to a perennial under micro-irrigation, whilst the rest is set aside for the production of annual cash crops. The annuals could also be grown under micro-irrigation, or by using conventional ways, to which the farmer is used. When considering the intercrop option, it is important that the farmer receives good guidelines on production and irrigation practise, especially when both perennial and annual crops are irrigated with the same system. Special attention should be given to the demonstration of the correct way of moving parts of the irrigation system around, to ensure that the water requirements of both crops are met, and soiling of the system components is avoided.

Table 17: Summary of guidelines: Crops

Crops and planting roster	➢ Discuss carefully with the farmer the choice of crops to be planted. ➢ Pay special attention to the crops selected for marketing (cash crops). ➢ Evaluate the potential of local (niche) markets, and the size of these markets, and when opportune, match production to demand, including the possibility of staggered planting. ➢ Evaluate the availability of marketing agents, and their requirements, and consider the option of contract farming, leaving the farmer to deal with production issues only. ➢ Evaluate the potential of cash crops for distant markets using the following list of decreasing suitability: i. Crops that can be stored over a fairly long period, and to which the farmer can add value. An example is paprika, which can be dried before marketing. ii. Crops yielding a high-value low-bulk product, which can be stored on-farm, are well suited for planting on remote smallholdings, because they allow marketing to be done when an opportunity arises. iii. Crops that allow for storage for a few months, before being marketed when an opportunity arises. Examples are pumpkins and melons. iv. Perishable crops, which can be stored for short periods. For example cabbage, green peppers and potatoes. (continued overleaf)

	v. Perishable crops requiring immediate marketing. For example green beans and tomatoes. ➢ Develop a planting roster in participation with the farmer. For each crop, elaborate on the preparations that are needed before planting. Include issues such as soil preparation, ordering of planting material, fertilisers, and chemicals for weed, disease, and pest control.
Permanent crops	➢ Consider seriously the establishment of permanent or perennial crops on part or all of the farm, especially when the area under micro-irrigation exceeds 2 ha. ➢ Evaluate carefully the cash flow of the farmer, and in participation with the farmer develop a suitable way of managing cash flow for sustainability, taking into account the full range of sources of income available to the farmer's family. ➢ Consider carefully the opportunity to practise intercropping, whereby cash crops are grown between the rows of the permanent crop during the first few years after establishment of the permanent crop.

4.6.3 Water

The team found that most smallholders lack awareness about the need to conserve water, and to use this resource as efficiently as possible. Since conservation of water is of economical and environmental importance, the team recommends that the need to use water as efficiently as possible should be explained carefully to the farmer. The research team found that the pricing of irrigation water in most smallholder irrigation projects failed to acknowledge the real cost of water. Generally, the two arrangements that applied included free access to irrigation water or the charging of a fixed rate per unit time. It was the team's opinion that the introduction of payment per unit water used would encourage responsible and efficient use of this resource.

On a limited scale, the use of municipal water for micro-irrigation can be viable, provided the layout of the project, and the production programme are planned carefully. Care must be taken that the use of municipal water for irrigation purposes can be accommodated in the overall water plan of the municipality. Projects involving the use of municipal water are usually food garden project, which may play an important role in maintaining or improving human nutrition and health, especially among poor people. In such projects it is important to plan for year-round harvesting of fresh and nutritious produce. Economic considerations are a major factor when evaluating the potential of exploiting ground water resources instead of using municipal water. Scale of the project and depth of the ground water table are two important factors, which will influence the decision on which source of water to use.

The team found that the use of grey water had potential for the irrigation of small (30 – 50 m^2) plots, which typically feature in home garden farming. Grey water is water that has been used for domestic purposes first, such as washing and cooking water, before it is used to irrigate a crop. However, the exploitation of this particular opportunity in micro-irrigation requires additional research.

Table 18: Summary of guidelines: Water

Measuring water use	➢ Encourage institutional arrangements for payment of water, which are based on actual water consumption. Such arrangements necessitate the measurement of water use by individual farmers, for example by means of water meters.
Municipal water	➢ Assess the potential of using municipal water in food garden or home garden projects, and if feasible, plan production for year-round harvest of fresh produce, including multiple plantings per year on the same area of land. ➢ Assess the potential of using groundwater instead of municipal water when the scale of the food garden or home garden projects warrants such an investigation.
Grey water	➢ Encourage the use of grey water in home gardening. Select micro-irrigation systems designed for the use of grey water, such as the wagon wheel system and its modifications developed by Albertse (2000)

4.7 CONCLUDING THOUGHTS

The research work that provided the content of these guidelines showed that micro-irrigation is not a panacea for all the limitations and constraints in smallholder irrigation. On occasions, the team found that the installation of micro-irrigation on a smallholding left farmers worse off than they were before. This emphasises the need for careful planning by the engineer or designer of the system. Before encouraging smallholders to invest in a micro-irrigation system, there is a need to assess the full range of factors, which combine into an overall degree of risk. Only when the degree of risk is manageable and acceptable by the farmer should planning and design of the project proceed. The case studies, which contributed to these guidelines, showed that micro-irrigation could be implemented successfully on smallholdings of various scales. Generally, farmers did not experience undue problems with the micro-irrigation systems installed on their farms, as long as the quality of the components and the workmanship during installation was good, and operation of the system followed the guidelines provided.

Among the technical factors affecting success in smallholder micro-irrigation, adequacy and reliability of the water supply was the most critical. Among the human factors, level of training was the most critical. In several cases, lack of training was the factor that caused the failure of a project.

Work conducted by the research team showed that a hands-on approach to training of smallholders and extension agents was best. It was the team's experience that classroom approaches, which lacked a strong practical component, but which resulted in formal qualifications, were not very effective. The implication of recommending a hands-on approach to training of farmers and extension agents is that a complete training module in micro-irrigation cannot be produced. Diverse situations and circumstances require trainers to adapt the content of the training to suit the particular set of conditions at hand. For this reason, the team emphasised the need to conduct a situation and needs analysis in preparation of system planning and design, and farmer training. Meeting all of these requirements adds to the overall cost of a project, but it is the team's opinion that these requirements must be met to ensure a reasonable probability of success.

For most involved, participation in the development, implementation and initiation of a micro-irrigation project represents a period of intense learning. Farmers in particular are exposed to a wide range of unfamiliar concepts during this period. Planning and design of the system, its installation, and starting the first season's production, are phases during which the farmer has to acquire a lot of new generic and applied knowledge. Building the farmer's confidence throughout this period of learning is important for long-term success of the project. The trainer plays an important role in support of this process. It is the role of the trainer to carefully tailor the training programme to the evolving needs of the farmer. The team hopes that the current guidelines will provide trainers with insight into the range of important issues in micro-irrigation, and help them to decide on the content of their training programmes.

When dealing with smallholder farmers the attitude of the trainer is also very important. It was the team's experience that a top-down approach does not work. Farmers should not be regarded as empty vessels in which knowledge is poured. Instead, an approach of learning together is recommended. This encourages farmers to discuss their concerns, and encourages their participation in reflection and decision-making. This may be a lot to ask from the providers of training services, and the building of expertise and experience among those involved in such activities in South Africa may need support.

In smallholder farming, success is often determined by the way modern and conventional technologies are combined. The use of on-farm resources can contribute considerably to economic viability of a project. It is important that trainers and advisers take into account farmer knowledge and on-farm resources, even when these do not feature in what is considered standard farming and micro-irrigation practise.

It is the hope of the research team that these guidelines will assist growth and development of micro-irrigation among smallholders. The team has tried to make the guidelines as practical as possible. This was done to assist planners and designers of micro-irrigation systems, trainers of farmers, suppliers of irrigation equipment, and suppliers of farmer support and advisory services, in their quest to contribute to the success of small holders using micro-irrigation, and avoid some of the errors made in the past. The team also hopes that the guidelines may assist the development and implementation of policies aimed at increasing successful smallholder agriculture in South Africa.

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Glossary

Concepts printed in *italics* in the body of the text have been entered separately in the glossary. In the glossary the meaning of these concepts is explained. For additional explanations and definitions of concepts, readers are referred to Chapter 2 of the Irrigation Design Manual (ARC-ILI, 1996).

Application rate

Application rate refers to the amount of water that is applied to the soil surface per unit time, and is usually expressed in mm/hr.

Backyard farmer

A person who grows crops on land that forms part of his or her residential site. In South Africa, irrigated backyard farming is found mainly in urban or peri-urban areas, and usually involves the application of water that was intended for domestic use, such as municipal water.

Ball valve

A *valve* where the flow is cut off or opened by turning the lever through 90° (a quarter turn).

Class A evaporation pan

Also called an A-pan. A device used for the measurement of the amount of water lost through evaporation from an open water surface during a specific period of time. Generally, the measurements are expressed in mm evaporation per day (mm/day). They can be used to estimate the consumptive water use of a crop, thus assisting irrigation scheduling.

Compensating emitter

Also called a pressure compensating *emitter*. An emitter found in a *micro-irrigation* system, which is fitted with a pressure regulating mechanism that limits the emitter discharge to a specific rate regardless of pressure fluctuations in the laterals. The operation of the pressure regulating device is usually subject to a minimum required pressure. Therefore, even if the system is operated at the wrong pressure, the emitter discharge will stay as intended.

Control valve

A *valve* that is used to control some aspect of the flow in a pipeline (for instance, a pressure control valve can be set to regulate the pressure, or a flow control valve can control the discharge at a certain point).

Design of irrigation systems

The application of engineering principles, techniques, approaches and equations to determine the size and position of the physical components and water bearing structures used for the transportation of irrigation water from the source to the crop in order to apply it uniformly for use by the crop.

Design pressure

The pressure at which the irrigation system should be operated according to the design, so that the emitters can irrigate the crop at the required rate.

Disk filter

A *filter* consisting of a number of grooved circular plastic disks, which are stacked tightly together to form a cylinder. The stack of disks is enclosed in a nylon or steel casing. Water flows from between the casing and the outside of the cylinder, through the grooves on the disks, to the inside of the cylinder. The filter retains all particles larger than the spaces between the grooved disks. The filter is cleaned by reversing the flow through the disks (back-washing), or by opening the filter and cleaning the rings with a brush.

Distribution uniformity (DU)

Also called emission uniformity (EU). It is a statistical parameter that is calculated to establish the expected uniformity of the discharge of the emitters within an irrigation block. It is used in design to ensure a certain standard of design.

Drip irrigation system

An irrigation system that supplies water to a crop through very small *emitters* (less than 2 mm in diameter) spaced at regular distances from each other (e.g. 0.30 m). These outlets occur in a polyethylene pipe positioned on the soil surface next to the plants being irrigated. The discharge through the outlets is very low (1 to 10 liters per hour), and the water literally “drips ” out of the outlets in the pipe. The *application rate* of each *emitter* should be within certain limits within a particular *irrigation block* to achieve acceptable *distribution uniformity*.

Drum & Drip micro-irrigation system

Is a modification of the *Wagon wheel irrigation system*, in which the six irrigation pipes have been arranged parallel to each other. This modification enabled the use of the *Wagon wheel irrigation system* under conditions where the land available for crop production is very limited.

Emitter

A device designed to transmit water from a pipeline to the soil surface. The design of these devices ensures that at a specific design pressure water is applied to the soil surface at a known rate. Examples of emitters are drippers, micro-jets, micro sprinklers, sprinklers, etc.

EU-value

See *Distribution uniformity*.

Small-scale farmer

See *Smallholder*.

Filter

A device that prevents the blocking of *emitters* by removing particles larger than a certain size from the irrigation water. The type of filter that has been installed determines the size of the particles being removed from the water.

Filter ring

Another name for a disk in a disk filter. See *Disk filter*.

Filtration

The process of removing particles such as sand, silt, and plant material from irrigation water to prevent the blocking of *emitters*.

Food plot farmer

A person cultivating crops on a small area of land, usually ranging between 100 m^2 and 2 500 m^2, which usually forms part of a larger irrigation project established specifically to enable people to produce their own food. Community gardens are an example of such projects. Food plot farmers typically share a *water supply system*. Also see *Smallholder*.

Grey water

Refers to water that has been used, usually for domestic purposes, such as washing of clothes and dishes, or water used for personal hygiene. In dry areas where water available for domestic purposes is limited such water can be used to irrigate small areas of land using simple *micro-irrigation systems*, such as the *Wagon-wheel* and the *Drum & Drip system*, whereby particles are filtered out of the water by means of a sand and stone filter.

Home-garden farmer

See *Backyard farmer*.

In-field water distribution system

The pipelines or other water bearing structures (such as canals or furrows) which distribute the water in an *irrigation block*. In the case of *micro-irrigation*, it usually consists of the *manifold* or branch line, as well as the *laterals*.

Irrigation block

A part of an irrigation system which is designed as a unit, and which is irrigated at the same time with a single *control valve*.

Irrigation efficiency

Is a measure, usually expressed as a percentage value, which indicate how well an amount of water from a certain source is made available through a *water supply system* and an irrigation system to the root zone of a crop. In other words, it is a quantitative expression of the relation between the amount of water abstracted at the source and the amount of water actually made available to the crop. A value of 100% indicates that all the water that is abstracted at the source reaches the crop in the field, and none of it is wasted.

Lateral

A pipeline in an irrigation system to which *emitters* are connected.

Main (Main line)

A pipeline in the *water supply system* that links the *pump,* or water source*,* to the different irrigation blocks.

Manifold

Also called a branch line. The pipeline in the *in-field water distribution system* from which the *laterals* branch off.

Mesh filter

A *filter* which has a filtration element that consists of a permeable membrane made from stainless steel or nylon.

Micro-irrigation

A collective term for irrigation with drippers (drip irrigation) and micro sprayers (micro spray irrigation). In both cases, only part of the soil surface is normally wetted. Irrigation takes place regularly (a short cycle is followed), and the discharge of the *emitters* is relatively low compared to other types of irrigation. *Micro-irrigation* typically requires low *operating pressures* and enable high *irrigation efficiencies*.

Micro-irrigation system

Refers to the set of physical components, such as *filters, pipelines, valves, and emitters,* required to practise *micro-irrigation.*

Micro-jet irrigation system

See *Micro-spray irrigation system*.

Micro spray irrigation system

A *micro-irrigation system* where the *emitters* apply water to the soil surface through a spray action, usually covering a circular area around the *emitters,* which has a diameter that ranges between 1 m and 10 m. Typically the discharge rate of a single micro-spray emitter ranges between 20 and 250 l/hr.

Operator

Refers to a person other than the farmer who is responsible for operating an irrigation system. The operator may be a paid employee or a junior member of the farmer household. Typically, an operator is not responsible for making strategic farming decisions such as choice of crop.

Planning of irrigation projects

The process conducted in preparation for an irrigation *design*. The process includes gathering information on the environmental factors that apply, such as topography, water resources, soils, climate, and crops, on the agricultural and management practices by the intended users of the irrigation project, on the available and required irrigation infrastructure, on financial and economic aspects, and on system operation and maintenance.

Pump

A device driven by a motor usually powered by electricity or a liquid fuel, such as diesel, needed to transfer water from the water source to the irrigation system. During the *design* of the irrigation system a pump is selected to transfer water at a specified rate of flow or to maintain a specified pressure in the pipe system.

Regulated emitter

See *compensating emitter*.

Salt tolerance

Refers to the ability of crops to grow under saline conditions. Saline conditions occur when the soil solution or soil water contains a high concentration of salts. Typically, saline conditions may occur in dry areas where the rainfall is too low to wash the salts out of the soil. They may also be created when irrigating with water that contains a high concentration of salts. When salinity is a problem, the growing of salt tolerant crops is one way of managing this limitation.

Scheduling

Refers to the process of deciding on the timing and amount of irrigation water to apply to a crop.

Schrader valve

Is a device that is very similar to the one used to inflate motor vehicle tyres. In the case of an irrigation system, the device is fitted on a pipeline, enabling determination of the pressure in the pipe at that specific point by means of a portable pressure gauge can be connected to the, in order to. The main advantage of using a Schrader valves is that only one pressure gauge is needed to measure the pressure at a multitude of locations within the irrigation system.

Smallholder

In these guidelines the term smallholder refers to a full-time or part-time farmer who cultivates an area of land that is less than 20 hectares in size, and which is referred to as a *smallholding*. Inherent to the smallholder concept is that the size of the smallholding is still subject to considerable diversity, because included are small garden plots, typically ranging between 10 m^2 and 100 m^2 in size (see backyard farmer) to fairly substantial farms which may be larger than 10 ha. The land may or may not be privately owned by the farmer. Similarly, farming and irrigation equipment and infrastructure may be private property of the farmer, or may be held in some form of common property by a group of farmers. Smallholders may farm independently or as a group through membership of an irrigation project, such as a food plot scheme or an irrigated community garden project.

Smallholding

Is a small area of land, less than 20 ha in size, on which cultivation is practised.

Soil quality

Is a term that refers to the overall suitability of a soil for the purpose of (irrigated) crop production. Soils differ in terms of their overall suitability for crop production as a result of limiting factors, such as shallow soil depth, unfavourable particle size distribution, or undesirable chemical properties. Some crops are more sensitive to particular limitations than others. The quality of a soil is evaluated by means of physical observation of the soil profile in a profile pit or by means of a soil auger, and by means of laboratory analyses.

Sub-main

See *manifold.*

Support team

In these guidelines the concept ‘support team’ refers to a group of people, who have specific or general knowledge on issues affecting irrigated smallholder agriculture, and to which the smallholder has relatively easy access to ask for advice on a multitude of aspects related to his irrigated farming enterprise. Fields of knowledge held by individuals in the group may include among others agronomy, soil science, irrigation, engineering, government, farm and financial management, and marketing. Members of the support team do not have to be employed by the same organization.

Tensiometer

A device used to measure soil water (matrix) potential, which, in turn, can be used to estimate soil water content. Tensiometers can help farmers in the process of deciding when next to irrigate a crop.

Valve

A device in a pipeline that is used to start, stop or control the flow of water.

Wagon wheel irrigation system

A simple, low-cost, locally developed *drip irrigation system* used to grow vegetables and crops on small plots of about 50 m^2. Water (sometimes *grey water*) is collected in a 210 litre drum made of galvanised steel positioned upright in the center of the plot. Six plastic irrigation pipes are connected by means of plastic T-connections to a *main*, which forms a circle around the drum, and which is made of the same pipe material as the irrigation pipes. The *main* is linked to the drum by means of a valve positioned near the base of the drum. The spatial arrangement of the pipes is similar to that of the spokes of a wheel with the drum in the center. Emitters are inserted at regular distances in the pipes by perforating the pipes with a heated nail, and threading a short piece of string through each of the opposing perforations. The string is used to clean the emitters when clogging has occurred. Crops are planted on both sides of the six irrigation pipes (see also *Drum & Drip micro-irrigation system*).

Water quality

In these guidelines water quality refers to the suitability of water for the irrigation of crops. Not all water is suitable for irrigation. For example, in some water the concentration of salts is too high for use in irrigation. Some crops are more sensitive to limiting properties of irrigation water than others. Water quality is assessed by means of laboratory analyses.

Water supply system

The infrastructure that is required to convey water from the source to the different *irrigation blocks* where it is applied.

Water use efficiency

Refers to the yield of a crop per unit water consumed. The degree to which the application of water is scheduled by the farmer in such a way that as little as possible of the water goes to waste through either run-off from the soil surface, or infiltration beyond the reach of the crop's roots. To obtain a high degree of efficiency in water use, the farmer needs to be skilled and experienced in managing the water content in the soil by providing as close as possible to the required amount at the required time.

APPENDIX A

PROVISIONAL CHECKLIST OF TYPICAL SERVICES NEEDED BY THE FARMER WITH REGARDS TO HIS IRRIGATION SYSTEM (SERVICE SUPPLIERS)

The following list of items are additional to the normal aspects that needs to be taken into account for commercial irrigation projects.

- **Water supply**

  - Water authority
  - Provincial Department of Water Affairs and Forestry

- **Soil preparation and maintenance of lands**

  - Extension officer
  - Contractor with tractor and implements
  - Builder

- **Electricity supply**

  - Escom
  - Electrician

- **Farming needs and markets**

  - Provincial department of Agriculture
  - Extension officer
  - Fertilizer supplier
  - Weed control supplier
  - Seed supplier
  - Research units (ARC)
  - NGO's

- **Irrigation system**

  - Closest supplier of: Pumps spares
AC, PVC-, and PE pipes
Fittings (including all system components)
Irrigation designer / company

- **Irrigation practices**

  - Provincial Department of Agriculture
  - Extension officer
  - Research units
  - Irrigation designer / company

APPENDIX B

PROVISIONAL INFORMATION SHEET (CHECK LIST) TO BE USED DURING FIELD VISITS

- **Water supply**
  - Extent of any shortage experienced and reasons thereof
  - How does the situation for the rest of the season look

- **Plant growth**
  - Is plant growth satisfactorily
  - The need for remedial actions

- **Weed control**
  - Are the applied techniques successful
  - The need for remedial actions

- **Fertilizer application**
  - Was application until now according to schedule
  - Is the remaining fertilizer (or credit) sufficient to see the crop through
  - Problems experienced with the method of application

- **Irrigation system**
  - Standard maintenance applied during system operation
  - Problems experienced with pump and on-farm distribution system
  - Problems experienced with water quality and filtration
  - Infield system problems
  - The need for servicing of equipment, and spare parts to be held in stock

- **Irrigation scheduling**

  - How effective does the farmer and his system cope with the irrigation demand
  - The need for changes to schedule followed
  - Possible improved soil moisture monitoring procedures to be applied by the farmer

- **Marketing**

  - Is the marketing of products done according to planning
  - Are prices according to expectation
  - The need for changing the marketing strategy, and how to approach it

- **The need for training, as well as for additional support services**

  - For each of the above mentioned subjects it must be established if additional training, which is practically achievable, can improve the situation of the farmer. This also applies to the introduction of additional support services.

APPENDIX C

PROVISIONAL "WHAT-IF" CHECKLIST TO BE USED BY THE FARMER DURING SYSTEM OPERATION

Each of the items in the following checklist will have to be sub-divided into more items (depending on the particular circumstances) in order to direct the farmer more clearly to the problem which he experiences.

- **Water supply**

  - External supply interruption
  - Insufficient flow and / or pressure received from external supply
  - Shortage of water at the source

- **Electricity supply**

  - No supply
  - No supply at pump
  - Electric cables damaged

- **Irrigation system**

  - Motor/Engine does not start
  - Motor/Engine starts, but pump does not deliver sufficient flow/pressure
  - Mechanical maintenance of pumping equipment is evident
  - Water quality (physical and/or chemical) is of concern, or creates problems
  - Problem which may be experienced (due to damage, malfunctioning, or lack of proper maintenance) with the different components of the irrigation system, i.e. the on-farm distribution system, filtration- and fertigation equipment, valves, sub-mains, laterals and emitters
  - Difficulties are experienced with the scheduling of the system
  - In-field system needs to be moved to a new area
  - In-field system needs to be extended

- **Crop production**

  - Weed control is not effective
  - Diseases in crops
  - Growth/production/quality of crop is not satisfactorily
  - Marketing problems