A review of planning and design procedures applicable to small-scale farmer irrigation projects

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Report to the Water Research Commission on the Project:
"Evaluation of irrigation techniques used by small-scale farmers"

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS v

ABBREVIATIONS vi

EXECUTIVE SUMMARY

1. INTRODUCTION ix
2. OBJECTIVES x
3. HISTORY OF PROJECT DEVELOPMENT xi
4. REVIEW OF CHAPTERS IN THE REPORT xii
5. THE CONTRIBUTION OF THE PROJECT xix
6. RECOMMENDATIONS xx

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION 1.1
1.2 OBJECTIVES 1.2
1.3 HISTORY OF PROJECT DEVELOPMENT 1.3
1.4 REVIEW OF CHAPTERS IN THE REPORT 1.4
1.5 SMALL-SCALE IRRIGATION IN SOUTH AFRICA 1.5
1.6 IRRIGATION TECHNOLOGY IN SMALL-SCALE AGRICULTURE 1.9
1.7 ISSUES AROUND SMALL-SCALE IRRIGATION 1.13
1.8 S A STATE OF THE ART: IRRIGATION DESIGN MANUAL 1.16

CHAPTER 2: PRE-FEASIBILITY AND FEASIBILITY STUDIES

2.1 INTRODUCTION 2-1
2.1 PRE-FEASIBILITY STUDIES 2-2
2.2 FEASIBILITY STUDIES 2-10
2.3 QUESTIONS FEASIBILITY STUDIES SHOULD ANSWER 2-16
2.4 GENERAL CONCLUSIONS AND RECOMMENDATIONS 2-36

CHAPTER 3: PARTICIPATORY IRRIGATION PLANNING

3.1 INTRODUCTION 3-1
3.2 QUALITATIVE RESEARCH 3-1
3.3 PARTICIPATORY IRRIGATION PLANNING 3-8
3.4 THE WAY FORWARD 3-11
3.5 CONCLUSIONS AND RECOMMENDATIONS 3-14

CHAPTER 4: MANAGING CROP WATER REQUIREMENTS

4.1 INTRODUCTION 4-1
4.2 CROP PRODUCTION UNDER IRRIGATION 4-2
4.3 ESTIMATING CROP EVAPOTRANSPIRATION 4-7
4.4 CROP FACTORS APPROPRIATE TO SMALL-SCALE IRRIGATION 4-13

4.5 DESIGNING FOR IRRIGATION MANAGEMENT 4-13
4.6 GENERAL CONCLUSIONS AND RECOMMENDATIONS 4-22

CHAPTER 5: WATER SUPPLY AND MANAGEMENT
5.1 INTRODUCTION 5-1
5.2 OBSERVATIONS DERIVED FROM THE FIELDWORK 5-2
5.3 THE CONCEPT OF INDIGENOUS IRRIGATION SCHEMES 5-9
5.4 WATER SUPPLY AND IRRIGATION SCHEDULES 5-11
5.5 DEVELOPING A WATER SUPPLY SCHEDULE IN PRACTICE 5-15
5.6 WATER DELIVERY CONTROL, FLEXIBILITY AND RELIABILITY 5-18
5.7 IRRIGATION EFFICIENCY 5-21
5.8 PUMPING 5-22
5.9 CONCLUSIONS AND RECOMMENDATIONS 5-24

CHAPTER 6: PRESSURISED SYSTEMS FOR SMALL-SCALE FARMER IRRIGATION
6.1 INTRODUCTION 6-1
6.2 APPLICATION OF PRESSURISED SYSTEMS IN SMALL-SCALE FARMER IRRIGATION 6-1
6.3 PRESSURISED SYSTEMS IN PRACTICE IN SMALL-FARMER IRRIGATION 6-4
6.4 SPRINKLER CHARACTERISTICS: DESIGN AND MANAGEMENT 6-9
6.5 DESIGN NORMS AND INNOVATIVE POSSIBILITIES 6-16
6.6 UPTAKE OF TECHNOLOGY 6-27
6.7 CONCLUSIONS AND RECOMMENDATIONS 6-30

CHAPTER 7: SHORT-FUROW IRRIGATION
7.1 INTRODUCTION 7-1
7.2 SHORT-FURROW IRRIGATION IN PRACTICE 7-2
7.3 LAYING OUT SHORT-FURROW SCHEMES 7-4
7.4 LOSSES IN SUPPLY FURROWS 7-19
7.5 DISTRIBUTION UNIFORMITY IN SHORT FURROWS 7-30
7.6 RECOMMENDATIONS FOR DESIGN 7-31
7.7 CONCLUSIONS AND RECOMMENDATIONS 7-32

CHAPTER 8: COMMUNITY GARDENS
8.1 INTRODUCTION 8-1
8.2 REVIEW OF FIELD INVESTIGATIONS 8-2
8.3 CONCLUSIONS AND RECOMMENDATIONS 8-15

REFERENCES

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ABBREVIATIONS

ARC =	Agricultural Research Council.
ARDC =	Agricultural and Rural Development Corporation
BEWAB =	Computer program (Bennie).
CBOs =	Community-based organisations
CLIMWAT =	FAO database.
CMAs =	Catchment Management Agencies.
CPA =	Communal Property Association.
CROPWAT =	Computer program (Smith).
Cu =	Coefficient of uniformity.
DBSA =	Development Bank of Southern Africa.
DIY =	Do-it-yourself.
DMSV =	Digital Multi-Spectral Video System.
DOA =	Department of Agriculture.
DS =	Development Strategy.
Du =	Distribution uniformity.
DWAF =	Department of Water Affairs and Forestry.
EDITT =	Evolutionary Development Initiated through Training.
ET =	Evapotranspiration (mm).
ETcrop =	Evapotranspiration (mm) of a particular crop.
ETo =	Reference evapotranspiration.
FAO =	Food and Agricultural Organisation of the United Nations.
FSP =	Farmer Support Programme.
GIS =	Geographic Information System
GPS =	Global Positioning System.
IAC =	Irrigation Action Committee.
ICID =	International Commission on Irrigation and Drainage.
IMT =	Irrigation management transfer.
IR =	Irrigation requirement.
IWMI =	International Water Management Institute.
LAC =	Lebowa Agricultural Corporation.
MIDA =	Mechanisation and Irrigation in Developing Areas.
NGO =	Non-government organisation.
NPFA =	Needs, Problems, Fears and Aspirations.
NPFE =	Needs, Problems, Fears and Expectations.
O & M =	Operation and Maintenance.
OECD =	Organization for Economic Cooperation and Development.
PAWC =	Profile available water capacity.
PIP =	Participatory Irrigation Planning.
PRA =	Participatory Rural Appraisal.
PUKA =	Computer program (Eckard).
PVC =	Polyvinylchloride.
RAM =	Random access memory.
RDP =	Reconstruction and Development Programme.
RRA =	Rapid Rural Appraisal.
RTO =	Right to Occupy.
RTP =	Road to Progress.
SAII =	South African Irrigation Institute.
SANCID =	South African National Committee for Irrigation and Drainage.
SAPFACT =	Computer program (Crosby).
SAPSPRNK =	Computer program (CP Crosby)
SAPWAT =	A computer program (Crosby *et al*).
SECOSAF =	The Secretariat of the Economic Community of Southern Africa.
SMMEs =	Small, micro and medium enterprises.
WICARDI =	Computer program
WRC =	Water Research Commission.
WUAs =	Water User Associations.

EXECUTIVE SUMMARY

TABLE OF CONTENTS

1. INTRODUCTION IX
2. OBJECTIVES X
3. HISTORY OF PROJECT DEVELOPMENT XI
4. REVIEW OF CHAPTERS IN THE REPORT XII
5. THE CONTRIBUTION OF THE PROJECT XIX
6. RECOMMENDATIONS XX

Small-scale irrigation farmers in the communal land tenure areas can be categorised in terms of their water supply as follows:

- farmers on irrigation schemes;
- vegetable gardeners (served by communal water supply infrastructures); and
- independent farmers, each with 'private' water supply.

A further distinction should be made between full-time and part-time farmers, in order to understand the technology requirements. Irrigated agriculture is almost invariably aimed at generating a cash income or at least replacing expenditure on food through own production. Even individuals growing vegetables in community gardens normally only use a small portion of their produce for home consumption: The bulk is sold to augment the family income.

Irrigation methods and design. The full range of irrigation systems is found on schemes, viz. flood, sprinkler, centre pivot, micro and drip irrigation. Sprinkler irrigation is most commonly found. An indigenous flood irrigation system of short furrows is widely used and very popular because of its manageability and maintainability without sophisticated equipment. Gender is of major importance, the bulk of the farmers are women and this is seldom recognised in design.

Management systems. A World Bank study into successful irrigation projects in the Sahel (West Africa) concluded that there are two models that are sometimes successful, namely, (i) small privately-owned enterprises and (ii) large irrigation estates, employing paid labour. Problems are encountered where these two concepts are mixed, as was the case of schemes in South Africa, namely, when so-called 'farmers' are settled on centrally-managed estates, where the 'farmer' has no decision-making power, yet carries the risks of failure.

Management of water supplies. The sharing of a common water source by a group of farmers limits members' flexibility in terms of irrigation, so the choice of suitable technology is important to ensure as much flexibility for each individual farmer as possible A crucial element in the successful sharing of a water source is that the group of farmers be well organised and equipped (trained) to control, operate and maintain their infrastructure and manage their finances.

Small- and micro-scale vegetable farmers. These farmers represent an important sector of irrigation farming in rural and urban areas. It is estimated that at least 150 000 growers participate in community gardening projects in South Africa, and an unknown number grow food in home gardens. Community gardens are the market gardens of rural and sometimes urban areas, so that millions of people benefit from the availability of locally produced fresh vegetables at reasonable prices, while growers augment the family budget.

Community gardens. These are similar to irrigation schemes in that a group of farmers shares infrastructure for water supply. These 'irrigated food plots' constitute one of the biggest success stories in agricultural development in South Africa, and their success is in sharp contrast to the problems of many of the sophisticated top-down managed larger irrigation schemes

Lack of support services. In most areas there is a serious lack of support services for independent irrigation farmers. The most serious of these is a lack of specialised irrigation extension technicians who can advise them in regard to cropping aspects, as well as lack of technical advice on engineering aspects. Maintenance support services are often poor or non-existent. Problems are encountered regarding the availability of inputs such as seed, fertilisers and pesticides

Manageability of the system. The suitability of an irrigation system is particularly related to the manageability of the system for a specific set of circumstances. The distance from the fields, the priority the irrigation farming enjoys in the life of the farmer, and the size of the enterprise should all influence the recommendations.

Realistic crop water requirements. The WRC project team believes that there is a great need to look urgently at real crop water requirements under the conditions prevailing in some small-farmer irrigation areas. The limited irrigation/low planting density situation is an example. It is highly unlikely that crop water requirements under these conditions will be the same as the requirements under intensive full irrigation. Over-estimation of the crop water requirements can lead to waterlogging, low irrigation water use efficiency and unnecessarily large and expensive irrigation systems.

1. INTRODUCTION

There is a perception that irrigation is a first step in promoting development in impoverished rural areas. This is applied in the context not only of large schemes but also to the establishment of landless people as emergent farmers and the creation of food plots and community gardens to promote food security both in deep rural areas and adjacent to major population centres. This is not new; the origins go back some fifty years.

Van Averbeke *et al* (1998) have reviewed the origin of the irrigation schemes in the communal land tenure areas.

> In the former 'Bantustans' or 'Native Areas', minor irrigation developments occurred before 1950, but most irrigation schemes were started after the publication in 1955 of the Report of the Commission for the Socio-economic Development of the Bantustans, the so-called Tomlinson Commission. The Commission estimated the total area under irrigation in the 'Bantustans' at 11 400 ha farmed by 7 538 plot-holders, resulting in an average irrigated land holding of about l.5 ha per farmer.
>
> Based on information collected at existing schemes, the Commission suggested that irrigated holdings of 1,3 to 1,7 ha were adequate to 'provide a family with a living that would satisfy them, whereby the whole family would work on the holding'. Preliminary surveys suggested that the irrigable potential of the Bantustans was about 54 000 ha, sufficient to settle 36 000 farming families, a very attractive rural development strategy.
>
> The Commission recommended that action be taken to improve and replan all existing schemes, so that each holding could provide a full-time living to a Bantu family; and that new schemes, which could be operated by simple diversion weirs and furrows, be developed during the next 10 years. In the early years the schemes under the management of dedicated Department of Bantu Affairs officials were largely efficient and productive. Unfortunately this 'top down' approach was not sustainable.
>
> During the 1970s political and administrative independence of the Bantustans was encouraged. Before the advent of the homelands the emphasis was on concrete-lined canals and flood irrigation. When capital became freely available and the emphasis was on homeland development at any cost an attempt was made to 'facilitate' the process by automating the technical and management aspects by introducing centralised pumping facilities and sprinkler and micro irrigation. This approach to facilitating community adaptation to technology and its use has failed, one of the reasons being that it is difficult to maintain sophisticated equipment in the deep rural areas where maintenance infrastructure is not readily available.

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

Small-scale irrigation farmers in South Africa can be categorised in terms of their water supply as farmers on irrigation schemes, vegetable gardeners (served by communal water supply infrastructures); and independent farmers, each with a 'private' water supply. There are examples of very successful independent farmers and community garden operations despite the problems that must be overcome but they are in the minority. Access to appropriate equipment and technical support is a major problem.

The initial objective of this project was essentially technical and the intention was to evaluate existing irrigation techniques and equipment used by small-scale farmers with a view to establishing design methods and norms that would facilitate the future planning and development of small-scale farmer irrigation projects.

Field visits paid to small-farmer irrigation schemes and farms across South Africa afforded the research team an invaluable opportunity for observation and discussion. Evaluations of irrigation systems were carried out in field during normal operation and the team came to realise that the purely technical evaluation of irrigation systems as a basis for design norms is not enough. It is essential to adopt a participatory 'bottom up' approach to irrigation planning. However, technical aspects remain important. The successful development of small-scale farmer irrigation requires exceptionally high technical and organisational proficiency on the part of planners, designers and implementing agencies.

2. OBJECTIVES

The origins of the project can be traced back to the South African Institute for Agricultural Engineers initiatives for promoting Mechanisation and Irrigation in Developing Areas (MIDA). The first MIDA symposium took place in 1986 and became an annual event. By 1992 it had become clear that adequately funded in-depth investigations were essential if progress was to be achieved.

The Water Research Commission's Co-ordinating Committee for Irrigation Research confirmed that a thorough investigation of the irrigation practices and problems of subsistence and emergent small-scale farmers was a high priority research need. An appropriate research proposal was subsequently submitted and approved.

The objectives of the project were:

- To evaluate existing irrigation applications, techniques and equipment as used by subsistence and emerging farmers; and
- To establish design methods and norms that would promote the effective planning and application of irrigation in development.

The original proposal and initial work focused on short-furrow and sprinkler irrigation, because of their general application in the small-scale irrigation sector.

One year into the project, the team reported their findings and preliminary recommendations to a workshop in which developers, academics, government officials, NGOs, policy advisors and small-scale farmers participated. The general consensus at the workshop was that the team was following an appropriate approach and that the original objectives could all be met. It was considered that the research team was positioned to add a further dimension to the research. It was consequently recommended that the duration of the project be extended in order to attend to the following additional aspects.

- The development of guidelines for the rehabilitation and/or transformation of existing irrigation schemes, i.e., investigation of the need for innovative approaches to the transformation of schemes from a 'top-down' to a 'farmer-managed' situation for small-scale irrigation, and for successful subdivision and management of existing single-owner farms. The next step would be the development of the approaches, in addition to an investigation into the training requirements and organisations for the rehabilitation and transformation of existing schemes.
- The compilation of a code of practice for the development of community garden projects. The initial project had clearly identified the importance of community gardens from a food supply point of view, and there was a need for clear-cut guidelines regarding the development, sustainability and management of these gardens.

In retrospect the assumption that it would be possible to reduce the complexities of small-scale farmer irrigation development to a series of tidy engineering norms, guidelines and codes of practice was naïve. The project was initiated in 1992 and it was impossible, at that time, to foresee all the changes in policy and circumstances that have taken place over a very short period.

However, the project gave the research team the opportunity to become, and remain, participants in the process of change. Project funding and time made it possible for the team to gain the knowledge and experience between 1993 and 1995 that subsequently placed them in a position to play a proactive role in the development of small-scale farmer irrigation. This included the public consultation and legal drafting processes that preceded the National Water Act (No. 36 of 1998) and the development of irrigation policy, the establishment of Catchment Management Agencies and Water

User Associations and the much-needed links between Government Departments and agencies actively involved in rural development. Throughout concentration has been on the little understood situation and needs of small-scale farmers.

There is a close relationship with the Department of Water Affairs and Forestry and the Department of National Agriculture, the Agricultural Research Council and the Provincial Departments of Agriculture, particularly the Northern Province Department of Agriculture and Environment. There is active liaison with consultants and NGOs concerned with planning and implementing small-scale farmer irrigation. International liaison is expanding rapidly with increased recognition being given to the South African initiatives.

It will be appreciated that there has been a paradigm shift in water management policy; the position of the previously disadvantaged and the role of government in financing development and this has necessitated a similar shift in policy and implementation in respect of small-scale farmer irrigation. This is still in process but the research team have been privileged to play a part in configuring the "new" approach. This report deals with the information that the team has acquired over the years and includes case studies derived from practice. Where possible and in line with the original objectives of the project the report has been confined to technical aspects but it is recognised that institutional and land settlement and tenure issues are of key importance.

The project has, since its inception, contributed to providing the inputs originally identified by the South African Institute of Agricultural Engineers. Papers and poster presentations by team members have become a regular feature at the annual symposiums of the Institute

This report should be read in conjunction with the following parallel Water Research Commission reports developed by MBB Consulting Engineers:

DE LANGE, M; ADENDORFF, J and CROSBY, C T (2000). *Developing Sustainable Small-Scale Farmer Irrigation in Poor Rural Communities-Guidelines and Checklists for Trainers and Development Facilitators.*

DU PLESSIS, F J and VAN DER STOEP, I (2000). *Evaluation of the appropriateness and management requirements of micro irrigation systems in small-scale farming.*

CROSBY, C T and CROSBY, C P (1999). *SAPWAT – A computer program for establishing irrigation requirements and scheduling strategies in South Africa.*

3. HISTORY OF PROJECT DEVELOPMENT

The project was approved in 1992 and the work programme for 1993 was aimed at:

- Establishing appropriate evaluation techniques and identifying suitable circumstances and locations for detailed evaluations in the second year;
- Establishing an overview of irrigation as practised by small farmers;
- Initial physical evaluations of flood and sprinkler irrigation systems;
- Initial rapid rural evaluations to gain insight into the technical needs of small farmers and to learn from their experience.

A work session was organised under the auspices of the Water Research Commission and held on 28 January 1994 at the Directorate Irrigation Engineering, Silverton, to share preliminary findings and elicit recommendations for further research. More than 40 people representing a wide range of interests attended the session.

On recommendation of the March 1994 WRC Steering Committee meeting, the content of the 1993 interim report was adapted for use by students in land use planning at the University of Pretoria and further refined for publication by the WRC as the *Small Scale Irrigation in South Africa* booklet. This very successful publication also appeared in a series of articles in the *Farmers Weekly*.

Extensive fieldwork was done during 1994 and computer routines were programmed to facilitate the development of design procedures. An interim report *Towards successful small-scale irrigation* was published to provide additional information to practitioners and was subsequently copied and reprinted in *International Water Irrigation Review* in 1997.

The project now entered a period where opportunities arose for testing the concepts that had been developed by the research team, while at the same time contributing to the rural development process. The insights gained have been incorporated in this report.

Members of the team, notably M de Lange, P L Mohajane, C M Stimie and J P Leeuwner, had became recognised practitioners of the Participatory Rural Appraisal (PRA) methodology and had done pioneering work in linking the institutional and sociological aspects of PRA with the technical realities of small-scale farmer irrigation. This lead to the concept of Participatory Irrigation Planning (PIP) and a full-scale multi-disciplinary exercise was undertaken with the Northern Province Department of Agriculture, Land and Environment in August 1996.

Preliminary activities leading to the new National Water Act (No. 36 of 1998) commenced in 1996 with a series of public consultation workshops throughout the country. Irrigation Policy was discussed in depth at over 50 grassroots workshops held in all the provinces. The task of organising, facilitating and reporting on this process funded by the National Department of Agriculture was entrusted to members of the research team partly on account of their specialised insights into small-scale farmer irrigation. The workshops were well attended by commercial farmers, emerging farmers and participants in community gardens.

Shortly after the completion of the grassroots workshops, the Northern Province Department of Agriculture, Lands and Environment embarked on a project to assess how parastatal-managed small-scale farmer irrigation schemes should be upgraded and transferred to the participants. It was decided to select three schemes from a short list and to develop them as pilot projects. The team assisted with the drafting of the consultants brief and acted as advisors to the Department and the consultants, in return for access to the information generated in the course of these participatory developments.

A new initiative of the National Department of Agriculture, the Land Care Programme, is being implemented in several provinces. Late in 1998, a study of the conservation status of the Sabi-Sand catchment was funded and included two major small-scale farmer irrigation schemes. This was an opportunity to assess the practical application of the new approaches to feasibility studies and irrigation development. A multi-disciplinary team from the Agricultural Research Council (ARC), under the guidance of members of the research team, completed the irrigation feasibility studies in accordance with the approaches developed in this project. The programme has now been considerably extended and is being undertaken by a team from the ARC in partnership with a consultant.

The National Water Act is presently being implemented on several fronts, including the registration of water use, the establishment of CMAs and WUAs and the pilot assessment of the water demand management strategy. Here again members of the team are actively involved, particularly from the point of view of the needs of small-scale irrigation farmers and how these can be met.

4. REVIEW OF CHAPTERS IN THE REPORT

CHAPTER 1: INTRODUCTION

Chapter 1 is an edited reproduction of a popular illustrated booklet by M de Lange, project research leader, *Small Scale Irrigation in South Africa* that was published after the initial evaluation. This publication provides an excellent background to the circumstances of small-scale farmer irrigation in South Africa and places this final report in context. The booklet is unfortunately no longer available but the text is reproduced in the report in its entirety. In this executive summary it is only possible to touch on the main issues.

CHAPTER 2: PRE-FEASIBILITY AND FEASIBILITY STUDIES

It is important, to appreciate the present position in respect of small-scale farmer irrigation projects in South Africa. The record of the past is one of failure. The infrastructure of the state and parastatal schemes is in a state of collapse and budgets for rehabilitation are restricted. Policy is therefore that the 'farmers' take over the schemes and accept full responsibility. It is a prerequisite for any degree of state support that schemes are sustainable. A paradigm shift in approach is unavoidable and the suggestions for modified approaches to feasibility studies must be seen against this background.

Clear, proven procedures have still to be established. The experiences in other parts of Africa can provide useful guidelines but circumstances are different and, in the years to come, South Africans will have to find their own answers. What is important is that the new procedures conform to the now-established principles of participatory development.

Pre-feasibility studies

Pre-feasibility studies are the essential, concise, first screenings: the 'go/no-go' phase. In the case of irrigation projects, the findings of the pre-feasibility study are usually reported to the senior management of the organisation that will fund further investigations. The investigation should concentrate on establishing the essential issues that have a major bearing on the decision that has to be made. The pre-feasibility study is not only a technical exercise, but also a crucial instrument in 'selling' the idea to the decision-makers. (No project should be turned down simply because of poor advocacy.) It is therefore important to present the report convincingly and thoroughly, without being verbose: Too much detail may bore and confuse, while too little may cause scepticism.

There will need to be a paradigm shift in the approach to developing small-scale irrigation schemes and this should be reflected in the approach to their feasibility studies. The practice in the past has been to analyse each irrigation project as an entity, with the emphasis on the well-being of the irrigation farmers themselves. This situation has changed and the National Water Act (No. 36 of 1998) leaves no room for doubt that the contribution an irrigation project can make to its socio-economic hinterland must be a main concern of a pre-feasibility study.

Four pre-feasibility study methods have been developed and subjected to limited testing. In order to identify them, temporary names have been coined: the 'National Geographic' method (based on annotated maps), the SAPFACT method, the bussing method and the Adendorff method. In addition, the Sondeo and Participatory Rural Appraisal methods discussed in Chapter 3 can be utilised to support pre-feasibility studies.

There is no reason why these methods should not overlap or be combined with more conventional approaches. It is the approach that is adopted that counts, not the specific method alone.

The National Geographic method is intended to assist management with the initial phases of establishing priorities and action programmes on a number of irrigation schemes.

The SAPFACT method is appropriate where a quick evaluation by one or two people is required, but a wider range of aspects is considered than in the National Geographic method. It is particularly applicable when existing schemes and farmers are being evaluated.

The bussing method is applicable when a pre-feasibility study has to be done on an existing scheme or a proposed scheme, where it is important to obtain the inputs of all stakeholders. This method will generally be used for the somewhat larger schemes or groups of schemes and is most appropriate when sustainability is of particular importance.

The Adendorff method is especially suited to schemes requiring rehabilitation, and to communities where an in-depth appreciation of the people's needs and potential is important.

The choice of pre-feasibility study method therefore depends very considerably on the type of project under review and on the experience of the people undertaking the study. There can be no set rules or procedures and it is frequently advantageous to synthesise, using the relevant elements of good practice, from a number of the pre-feasibility study approaches.

Feasibility studies

There are international guidelines for feasibility studies in developing countries, published by such organisations as the World Bank and the European Commission. Possibly the most appropriate guideline is that published by the Food and Agricultural Organisation of the United Nations. However these international guidelines deal with principles. All procedures and checklists will tend to be situation-specific and, to some extent, subjective. This is inevitable because, while principles can be reduced to generalities, specifics cannot.

However, experience has shown that guidelines are necessary to facilitate the evaluation and reporting on the rehabilitation of small-scale farmer irrigation schemes. This is an unfamiliar field to most planners and consultants and important aspects may be overlooked at the planning phase. The objective of this chapter is to therefore provide guidelines that will ensure that no important questions are left unasked. (Some of these questions will remain unanswered initially but at least there will be an appreciation that answers must be sought.)

The procedure for compiling a feasibility study described in this chapter was developed with the rehabilitation of small-farmer irrigation schemes in the Northern Province of South Africa in mind.

Section 1 of a feasibility study should be a description of the scheme and the writer is led by paragraph headings and suggested approaches. This section should be a simple narrative and can be regarded as a rapid pre-feasibility study to enable preliminary decision-making on the viability of the scheme. Information for this section should be just sufficient to decide whether or not it is warranted to engage the community in a participatory procedure that will inevitably raise expectations. Information for Section 1 can be gathered from literature and Rapid Rural Appraisal-type field investigations (RRAs).

Section 2 of a feasibility study should cover key questions on the present situation. The answers to these questions can be generated with the community through a combination of participatory approaches like Participatory Rural Appraisal (PRA) or Adendorff's pre-development survey (Adendorff, De Lange, Crosby; 1999).

Section 3 should contain detailed multi-disciplinary technical and institutional information required for assessing future development possibilities. This is best generated through a Sondeo-type field investigation, where specialists of different disciplines together assess the resource potential, infrastructure, institutional and social factors, with an emphasis on generating possible scenarios in accordance with opportunities and constraints.

Section 4 should address typical areas that must be covered in the community's development plan, and the subsequent evaluation of progress towards the agreed goals. The development plan is discussed, adapted and accepted in a community mass meeting and forms the basis for the training and development initiatives.

The officials and consultants of the provincial Irrigation Action Committees, joint committees of the departments involved in irrigation development and support, would utilise the procedure in the assessment of projects. It is expected that the detail of the questions in Sections 1 to 4 will be adapted with experience.

CHAPTER 3: PARTICIPATORY IRRIGATION PLANNING (PIP)

The project research team coined the phrase 'Participatory Irrigation Planning'. It is a synthesis of the Sondeo research method, the RRA method and the standard PRA method. This implies that the community is invited to take part in the process of identifying, analysing and solving problems so that all options are considered before recommendations are made

It has been established both internationally and in South Africa that engineers and social scientists and others from widely differing disciplines and interests can harmonise when involved in development. A major change takes place in the planning relationship when an engineer accepts that the social scientist can make valid contributions to the engineering aspects of an investigation, and vice versa, and when they both accept that it is the community that counts and not academic disciplines.

The PIP exercise was undertaken in co-operation with the Northern Province Department of Agriculture, Land and Environment, after the three Strydkraal and Mooiplaats communities that farm some 300 hectares on the Arabies-Olifants irrigation scheme in the Northern Province expressed the wish to become independent managers of their own irrigation affairs. The chapter concludes with an account of the PIP undertaken and examines the lessons learned

All the people involved in the investigation, the facilitators, the farmers and all the other stakeholders are part of the PIP team. However, the 'PIP team' generally includes as co-facilitators any experts from outside the local community, called in to be part of the group.

The task of the team of experts was to find workable solutions for the problems specific to the area, with the full participation of the community – solutions suitable, not only to the soil, climate and resources of the area, but also to the people. The specialists had not had prior exposure to participatory methods so that the exercise doubled as a training course for them in these techniques. The facilitator was faced with the task of orchestrating a multi-disciplinary team initially uneasy about the unfamiliar circumstances.

Participatory planning cannot be done in a hurry. A week to ten days is required. No matter what technique is used, it is essential to ensure that the community becomes thoroughly familiar with the issues at stake; and it takes time to build up the necessary relationships with the various members of the community so that good communication can occur. It takes even more time to guide the community in analysing their own situation and planning for the future.

CHAPTER 4: MANAGING CROP WATER REQUIREMENTS

This project has disclosed that, in South Africa, practitioners have so far not been particularly concerned with the factors that influence the relationship between crop production and crop water requirements in irrigation. This is to the detriment of all irrigation, but is of especial importance in the case of small-scale farmers facing resource, market and management constraints.

Present methods of estimating crop water requirements do not take account of the production strategies of risk-averse small-scale farmers. The project team saw examples of over-irrigation but also found cases where it was hard to credit that the farmer could 'get by' with a very limited water supply. In almost all cases, it was possible, on analysis, to find a satisfactory explanation.

Therefore, when both designer and farmer have the same understanding of crop/irrigation relationships, significant improvements and savings can be achieved through design. There are ways of designing to promote simpler and more efficient management of irrigation for the farmer. This is particularly important when small-scale farmer projects are being planned. These farmers face constraints that make non-standard irrigation management procedures more the rule than the exception and these should be addressed from the outset.

This project has also disclosed that the role of agronomic factors in achieving effective water use has not received the attention they deserve, particularly in the case of emerging farmers. This chapter includes valuable notes on how to select and manage crops in water-short situations, derived from the book *Efficient use of irrigation water* by Professor G H Sankara Reddi and Dr T Yellamanda Reddy of the Andhra Pradesh Agricultural University, India. Their book includes a chapter, "Irrigation efficiencies and water use efficiencies" that provides a well organised and authoritative review.

The chapter also includes details of the program SAPWAT (Crosby *et al;* 1999), which has updated procedures for estimating crop irrigation requirements and caters for non-standard situations and non-standard agronomic factors, which should be considered in modern irrigation design but which have received little attention in the past. They are: maximum canopy cover achieved, area of soil wetted, frequency of irrigation, the influence of varieties and climate on growing season length, and location. By taking these factors into consideration, it is possible to develop crop factors that are applicable to most irrigation methods and irrigation farming practices and are especially important in the case of small-scale irrigation.

SAPWAT provides a convenient way of illustrating the interaction of these factors. (One of the motivations for the development of SAPWAT was to cater for the production methods of risk-aversive small-scale irrigation farmers.) The chapter includes examples of how SAPWAT can be applied to develop practical irrigation strategies.

vary too, anything from a hectare to ten hectares. They are communal in the sense that a number of people share the infrastructure, and there is generally an overall management committee responsible for the maintenance of infrastructure and the orderly management of the garden.

For all practical purposes, the participants are market gardeners. They usually each work their allocated area for their own profit. There are sometimes a number of communal plots on which the participants take turns to provide labour and inputs, and the proceeds are used to provide for fuel, repairs and similar common expenses.

Some community gardens are successful; many are not. The successful gardens were usually developed on the initiative of the community. It is where the infrastructure was provided by an external agency and the community" was presented with a fenced area, irrigation system, water supply, etc, on a plate, that the results are often unsatisfactory.

The availability of water is a major problem. Sinking and equipping a borehole is expensive, and mechanical maintenance of engines and pump can be a difficulty, so some community gardeners carry water by hand over considerable distances to water the crops.

In gardens that are developed with outside funding, there is a tendency to over-elaborate the irrigation equipment. Often, what is required is just a source of water. The actual application can be done by hose, or by bucket, provided that there is sufficient water and it is in the right place.

A number of community garden case studies are included in this chapter and specific information is provided on the following aspects:

- **Review of field investigations**: garden organisation, irrigation methods and management, water supply, fencing, appropriate technology.
- **Planning community gardens**: administrative processes, guidelines for decisions by gardening group, local authorities, support organisations, milestones and responsibilities.
- **Water delivery and application**: short furrow, hose, garden sprinkler, water and soil quality.
- **Administration**: milestones and responsibilities in the development of gardens, planning reports, costs.

5. THE CONTRIBUTION OF THE PROJECT

The objectives of the project have largely been met but it must be recognised that this is an ongoing study. The technical aspects of existing irrigation applications, techniques and equipment, as used by subsistence and emerging farmers, have been evaluated and the ground rules established for design methods and norms applicable to the effective planning and application of irrigation in development.

The circle of people and organisations concerned with the subject of small-farmer irrigation is relatively specialised and limited and this report will facilitate technology transfer. However, there has already been considerable communication through participation with key organisations in the process of evaluating in practice information generated through the project.

Key organisations involved are the Department of Water Affairs and Forestry, National Department of Agriculture, Agricultural Research Council, Provincial Governments, Consultants, International Water Management Institute, Universities, NGOs and irrigation communities.

Possibly the most important contribution of the project has been the role the research team has played in the development of a 'new' participatory approach to planning small-scale farmer irrigation, which has received official recognition and is in the process of implementation. There are indications that a paradigm shift is taking place in the approach to irrigation development and the way forward is becoming clearer with each passing month. This participatory approach goes beyond engineering planning and design and is epitomised by the following steps (de Lange, 2000):

- Interdisciplinary assessment of development potential;
- Pre-development survey, vision building and participatory formulation of the community Development Strategy;

- Institutional development: Establishment of voluntary farmer groups with elected management committees;
- Developing and conducting needs-based training courses for farmers and their committees, in accordance with their Development Strategy and realistic access to inputs, support services and markets;
- Networking with role-players to establish services, input provision and markets; and
- Labour-intensive construction and community project management of gradual and on-going infrastructure improvement.

Success is, however, by no means assured. The participatory approach to irrigation development must be seen in the context of the economic development of the deep rural areas as a whole. Development in the era following the Tomlinson Commission was backed by massive government financial and management support. This continued in a modified form in the homeland era when the DBSA Farmer Support Programme (FSP) was the mainspring. Now the policy is one of irrigation management transfer (IMT) to the farmers on existing schemes. In the case of new enterprises, participants themselves will have to accept full responsibility from the outset. This policy is largely being implemented without the massive official support of earlier periods, in an atmosphere of uncertainty.

In the past, irrigation projects were treated as 'islands of development' in the communal land tenure areas, and they failed. Now, there must be a co-ordinated approach to land tenure, resettlement, rehabilitation, civil and traditional governance, Water User Associations, finance, infrastructure development, and marketing before IMT can become a reality. Such a wide range of co-ordination will be hard to achieve.

6. RECOMMENDATIONS

Research will be required in the future and content and priority will certainly become evident as the process of rehabilitation and land settlement proceeds. At this stage, however, projects should possibly be limited to monitoring, recording and analysing initiatives such as the Northern Province Pilot and Land Care projects.

There is a need, however, for incisive analysis of the institutional, economic and administrative factors that must be identified and co-ordinated in order to develop policies and procedures that will make small-scale irrigation development possible. A series of 'think tanks' such as the recent *National Policy Workshop on Irrigation Management Transfer and Rehabilitation of Small Holder Irrigation Schemes* (Svendsen and Merrey, 2000) would seem to be a starting point.

CHAPTER 5: WATER SUPPLY AND MANAGEMENT

The chapter on water supply and management is one of the most important chapters in the report. Throughout this investigation, a major objective has been to identify the reasons for the general failure of irrigation in the context of development. The hope was that, once these reasons had been identified, viable recommendations for remedial action could be devised. It now appears that the management of water delivery to small-scale farmers could be a key to the failures of the past and that, in many cases, there may be no obvious short-term solution. Innovative thinking is therefore essential if the assets of infrastructure, natural resources and experience are to be gainfully exploited. Restoring the *status quo* does not seem to be enough.

The chapter consists of seven sections, each contributing to an understanding of the problem.

Observations derived from the fieldwork. These were largely developed by Ms Marna de Lange and derived from the interim report to the steering committee in 1996.

The concept of indigenous irrigation schemes. This is taken from a paper presented by Slabber (1992).

Water supply and irrigation schedules. The emphasis is on small schemes and draws on the procedures developed by the Department of Agriculture, Republic of Kenya (1990).

Developing a water supply schedule in practice. It is difficult to appreciate just what is entailed in organising water delivery amongst a group of farmers served by one lateral. In order to quantify the situation, C P Crosby (1998) developed a computer simulation routine that can be applied in design and planning.

Water delivery control, flexibility and reliability. This is from a chapter on international aspects, which was published in 1990 in an American Society of Agricultural Engineers monograph on irrigation management and which has valuable comments on development (Burt and Plusquellec).

Irrigation efficiency. FAO No 24 clarifies the impact of various factors on scheme efficiency and design (Doorenbos and Pruitt, 1977).

Pumping. Pumping is important, both on schemes and on individual farms. Serious problems were disclosed in the course of the investigation. These were largely centred on cost and the difficulties of maintaining equipment in the deep rural areas. The limited size typical of independent farms and community garden projects where water is taken from rivers and boreholes, coupled to their isolation and lack of suitable backup facilities, results in very specific problems.

These problems relate to the basic truth that must be clearly understood for every irrigation project: Water is the economic lifeblood of the farmers. If it is provided in an uncertain and unreliable fashion, anarchy quickly develops as individual farmers try to prevent their personal destruction.

CHAPTER 6: PRESSURISED SYSTEMS FOR SMALL-SCALE FARMER IRRIGATION

There was a general swing to pressurised irrigation systems on small-scale farmer irrigation schemes in the 1980s, due to the problems experienced with flood irrigation at that time. The systems installed were conventional sprinkler systems with portable laterals, although there were exceptions, including a limited number of centre pivot installations. In later years, dragline systems became popular.

On the negative side, there have been problems, including over-regimentation of management, poor maintenance, vandalism and theft, the inherent difficulties associated with operating pumping installations in the deep rural areas, and malpractice in the field. In addition, the cost of electricity and fuel is no longer being subsidised and this has imposed a heavy load on many communities.

There is a positive side, however, in that at least reasonable water distribution is achieved, and there is no reason to believe that present problems are insurmountable in the longer term. Analysis has shown that sprinkler irrigation can be surprisingly tolerant, but that design for the specific circumstances encountered in small-scale farmer irrigation requires refinement and the application of basic principles. In time, a new set of 'standards' may emerge but designers need to be made aware of how to approach the present situation.

The importance of sprinkler distribution characteristics has come to the fore. This is far more involved than simply achieving a satisfactory coefficient of uniformity. Little attention has been given in the past to analysing the operation of sprinklers in isolation (dragline), along a lateral (conventional hand move), and when a segment of a field is irrigated at one time (permanent set). The impact on application rates and losses can be significant and, while analytical approaches are useful, more field testing is required.

Greater flexibility will be possible if the areas irrigated can be broken down into smaller management units. The possibilities of pumping units based on tractors or the new generation of small Asian diesel engines should also be considered.

The filling of soil profiles prior to planting, using single non-overlapping laterals and the application of skip-a-position lateral spacing, depends on the selection of sprinklers with a flat, rectangular distribution characteristic. The development of a new generation of relatively low-cost, plastic sprinklers is a plus factor, while the full potential of the floppy sprinkler has not been fully exploited. There is room for both micro and drip irrigation in specific circumstances.

CHAPTER 7: SHORT-FURROW IRRIGATION

In the past, the majority of small-scale farmer irrigation schemes were based on flood irrigation. Far from being a crude, primitive system, applied by relatively untrained and inexperienced people, conventional field scale flood irrigation requires great experience and skill. There are just too many 'degrees of freedom' for the uninitiated. The soil surface must be uniform and well-graded and water flow rate must be adequate and consistent. However, there are few small-scale farmer schemes where the flow rate is sufficient for even conventional furrow irrigation.

There are, though, two irrigation methods that are not nearly as sensitive to these factors as the more conventional flood irrigation methods and so they deserve particular attention. Small-basin and short-furrow irrigation have proved their suitability for small-scale irrigation schemes in Africa, the former in Kenya (where it has been well-documented in official publications), and the latter in South Africa.

Short-furrow flood irrigation has been practised in South Africa for many years, but there has been a complete lack of theory to support rational design. The development of theories was one of the original main objectives of the project. The project team has extensively investigated short-furrow irrigation, with the lead being taken by the Institute for Agricultural Engineering of the Agricultural Research Council, under the guidance of research team member, C M Stimie.

The work done included field evaluations and computer simulations of the efficiency of distribution in the short furrows and losses in the earth supply furrows. Full-scale field tests at the Silverton terrain of the Institute, backed by in-field applications by I van der Stoep, confirmed the simulation results. A practical method for determining dynamic infiltration rates in earth furrows was assessed.

This chapter contains the necessary information for short-furrow systems to be designed according to a rational procedure. Guidelines for on-scheme water distribution design, including the layout of plots and secondary canals, have also been compiled. Aspects discussed are:

Laying out short-furrow schemes: on-farm layout, farm shape and orientation, dividing schemes into blocks, proportional water distribution.

Design of infrastructure: flood flows, sediment exclusion, water control, reservoir storage, field water management, design for operations.

Supply furrow losses: determining losses, simulation of losses, supply furrow characteristics.

Distribution uniformity in short furrows: gradient, flow rate, soil type.

Recommendations for design: supply furrow flow rate, length and layout, gradient, the furrow width, erosion prevention, general design norms.

CHAPTER 8: COMMUNITY GARDENS

Community gardens can be found in any area where people are living. These areas may be small villages in the rural areas, or fairly large rural towns, or peri-urban areas. The size of the gardens can

VAN DER HOVEN, J (1998). Personal communication. Department of Agriculture, Northwest Province.

VANASSCHE, F M G and LAKER, M C (1989). Studies on irrigation management, based on PAWC and soil water monitoring. (WRC Report No 166/1/89) Pretoria: Water Research Commission.

REDDI, G H S and REDDY, T Y (1995). Efficient use of irrigation water. Ludhiana: Kalyani Publishers.

REINDERS, F B (1995). Personal communication.

ROUSE, W B (1991). Design for success. New York: Wiley Interscience Publications.

KENYA-REPUBLIC OF. Scheme design: manual for senior staff on gravity schemes with basin irrigation operated by farmers (1990). (Smallholder Irrigation Series), Ministry of Agriculture, Irrigation and Drainage Branch.

Schulze, R E editor (1989). ACRU: Background, concepts and theory (WRC Report No 154/1/89) Pretoria: Water Research Commission.

Schulze, R E; George, W J; Angus, G R and Lynch, S D editors (1989). ACRU:2 user manual (WRC Report No 154/2/89) Pretoria: Water Research Commission

SCHULZE, R E; SMITHERS, J C and LYNCH, S D (1994). "Agrohydrological modelling with PC-ACRU: Where from? What's new? Where to?" Paper presented at SAILI Symposium '94. Pretoria: South African Institute of Agricultural Engineers.

SCHULZE, R E (1997). South African atlas of agrohydrology and -climatology. (WRC Report No TT82/96; ACRU Report No 46, 1997). Pretoria: Water Research Commission.

SLABBER, P J (1992). Western and Indigenous principles of irrigation water distribution. Paper presented at Conference on Small-scale Farmer Irrigation. Southampton, 1992.

SMALING, A (1990). "Munchhausen-objectivity: A bootstrap conception of objectivity as a methodological norm" in Baker W J, Hyland M J, Van Hezewijk R and Terwee S editors. Recent trends in theoretical psychology – Vol III. New York: Springer-Verlag.

SMALING, A (1992). "Varieties of methodological intersubjectivity – the relations with qualitative and quantitative research, and with objectivity" Quality and quantity; 26. 169-180.

SMITH, M. 1992. CROPWAT: a computer program for irrigation planning and management. (FAO Irrigation and Drainage Paper No 46). Rome: Food and Agriculture Organization of the United Nations.

SMITH, M; ALLEN, R and PEREIRA, L (1997) "Revised FAO methodology for crop water requirements".

SUBHADIRA, S; SIMARAKS, S and LOVELACE, G (1988). "Introduction" in Lovelace, G W; Subhadira, S and Simaraks, S editors. Rapid rural appraisal in Northeast Thailand: Case studies. Khon-Kaen: Khon-Kaen University.

SVENDSEN, M and MERREY, D. (2000). Bridging the gap between large and small-scale irrigated agriculture: issues and opportunities. International Water Management Institute. Unpublished report.

VAN AVERBEKE, W and MARAIS, J N (1991) "Increasing grain yield by optimising plant density in maize" in Proceedings of the South African Irrigation Symposium, Durban, 1991.

VAN AVERBEKE, W; M'MARETE, C K; IGODAN, C O and BELETE, A (1998). An investigation into food plot production at irrigation schemes in Central Eastern Cape. (WRC Report No 719/1/98). Fort Hare: Report by the Faculty of Agriculture and Agricultural and Rural Development Research Institute (ARDRI)., University of Fort Hare for Water Research Commission.

VAN DER BAN, A W and HAWKINS, H S (1988). Agricultural extension. Harlow: Longman Scientific and Technical.

CLEMMENS, A J (1987). "Delivery system schedules and required capacities" in Planning, operation, rehabilitation and automation of irrigation water delivery systems, Proceedings of a Symposium sponsored by the Irrigation and Drainage Division of ASCE; edited by D. Zimmelman. New York: American Society of Civil Engineers.

CORNISH, G A (1997). Modern irrigation technologies for smallholders in developing countries. (TDR Project R6659, Report OD/TN 87). Oxford: HR Wallingford.

CROSBY, C P (1997). "Rapid determination of the sensitivity of sprinkler irrigation distribution uniformity to various operational discrepancies." S A Irrigation/S A Besproeiing; October/November 1997; 3-6.

CROSBY, C T (1992a). The development of decision making procedures for the estimation of crop water requirements for application in irrigation system design. (Interim Report; January 1992). Pretoria: Murray, Biesenbach and Badenhorst, Inc for Water Research Commission.

CROSBY, C T (1992b). "A procedure for assessing mechanisation contractors in developing areas." Agricultural Engineering in South Africa; 24, 1.

CROSBY, C T (1994). SAPMECH 1.0 – A computer program to assess the viability of mechanisation contractors. Midrand: Farmer Support Programme, Development Bank of South Africa.

CROSBY, C T (1994). SAPWAT 1.0 – A computer program for estimating irrigation requirements in Southern Africa. Pretoria: Murray, Biesenbach and Badenhorst, Inc for Water Research Commission.

CROSBY, C T and CROSBY, C P (1999). SAPWAT – A computer program for establishing irrigation requirements and scheduling strategies in South Africa. (WRC Report No 624/1/99). Report by MBB Consulting Engineers to WRC.

DE LANGE, M (1994). Small scale irrigation in South Africa. (WRC Report No 578/1/94). Report by MBB Consulting Engineers to WRC

DE LANGE, M (2000). Personal communication

DE LANGE, M and CROSBY, C T (1995). "Towards successful small-farmer irrigation." SA Water Bulletin; September/October 1995.

DE LANGE, M; ADENDORFF, J and CROSBY, C T (2000). Developing Sustainable Small-Scale Farmer Irrigation in Poor Rural Communities-Guidelines and Checklists for Trainers and Development Facilitators. (WRC Report No 774/1/00) Report by MBB Consulting Engineers to WRC.

DE LANGE, M; ADENDORFF, J and CROSBY, C T (2000). Developing Sustainable Small-Scale Farmer Irrigation in Poor Rural Communities-Guidelines and Checklists for Trainers and Development Facilitators. (WRC Report No 774/1/00) Report by MBB Consulting Engineers to WRC.

DOORENBOS, J and KASSAM, A H (1979). Yield response to water. (FAO Irrigation and Drainage Paper No 33). Rome: Food and Agriculture Organization of the United Nations.

DOORENBOS, J and PRUITT, W O (1977). Guidelines for predicting crop water requirements. (FAO Irrigation and Drainage Paper No 24). Rome: Food and Agriculture Organization of the United Nations

DU PLESSIS, F J and VAN DER STOEP, I (2000). Evaluation of the appropriateness and management requirements of micro irrigation systems in small-scale farming. (WRC Report No 768/1/00) Report by MBB Consulting Engineers to WRC.

ECKARD, J H (1990). Personal communication.

ENGLISH, M J; MUSIK, J T and MURTY, V V N (1990) "Deficit irrigation" in Hoffman, G J; Howell, T A and Solomon, K H editors (1990). Management of farm irrigation systems. (ASAE Monograph). St Joseph: American Society of Agricultural Engineers.

FERREIRA, M (1988). "A sociological analysis of medical encounters of aged persons at an outpatient centre: A qualitative approach" in Mouton, J and Marais, H C. Basic concepts in the methodology of the social sciences. Pretoria: Human Sciences Research Council.

FOOD and AGRICULTURAL ORGANISATION, ROME (1986). Guidelines: land evaluation for irrigated agriculture, (FAO Soils Bulletin No 55.)

FOOD and AGRICULTURAL ORGANISATION, ROME (1986). Guidelines: land evaluation for irrigated agriculture, (FAO Soils Bulletin No 55.)

Green, G C editor (1985). Estimated irrigation requirements of crops in South Africa: Parts 1 and 2. (Memoirs on the Agricultural Natural Resources of South Africa; No 2). Pretoria: Department of Agriculture and Water Supply, Soil and Irrigation Research Institute.

HENSLEY, M & DE JAGER, J M. 1982. The determination of the profile available water capacities of soils. (Report to WRC.) Alice: University of Fort Hare.

HILDEBRAND, P E (1981). "Combining disciplines in rapid appraisal: The Sondeo approach." Agricultural administration; 8.

Hoffman, G J; Howell, T A and Solomon, K H editors (1990). Management of farm irrigation systems. (ASAE Monograph). St Joseph: American Society of Agricultural Engineers.

Institute for Agricultural Engineering, Agricultural Research Council (1997) Irrigation design manual.

Institute for Agricultural Engineering, Agricultural Research Council (1999), New Forest and Dingleydale irrigation scheme overview and development potential. Unpublished report to AWARD and Northern Province Department of Agriculture, Lands and Environment.

Keller (1990) in Cornish, G A (1997). Modern irrigation technologies for smallholders in developing countries. (TDR Project R6659, Report OD/TN 87). Oxford: HR Wallingford.

KRUGER, G H J (1998). Die ontwikkeling en rekenaarisering van 'n geskikte vloedbesproeiing-ontwerpprosedure. (WRC Report No. 290/1/98).

Lovelace, G W; Subhadira S and Simaraks S editors (1988). Rapid rural appraisal in Northeast Thailand: Case studies. Khon-Kaen: Khon-Kaen University.

MARTIN, D L; STEGMANN, E C and FERERES, (1990). "Irrigation scheduling principles" in Hoffman, G J; Howell, T A and Solomon, K H editors. Management of farm irrigation systems. (ASAE Monograph). St Joseph: American Society of Agricultural Engineers.

MASCARENHAS, J. (1991). Interviewing in PRA. (PRA-PALM Series IV-B). Bangalore: Myrada.

MEULENBERG-BUSKENS, I (1991). Manual for the free attitude interview technique. Pretoria: Human Sciences Research Council.

Mouton, J and Marais, H C editors (1988). Basic concepts in the methodology of the social sciences. Pretoria: Human Sciences Research Council.

PLUSQUELLEC, H L and WICKHAM, T (1985). Irrigation design and management – Experience in Thailand and its general applicability. (World Bank Technical Paper No 40). Washington, DC: The World Bank.

PRATT, B and LOIZOS, P (1992). Choosing research methods. (Development Guidelines No 7). Oxford: Oxfam.

REDDI, G H S and REDDY, T Y (1995). Efficient use of irrigation water. Ludhiana: Kalyani Publishers.

REINDERS, F B (1995). Personal communication.

ROUSE, W B (1991). Design for success. New York: Wiley Interscience Publications.

KENYA-REPUBLIC OF. Scheme design: manual for senior staff on gravity schemes with basin irrigation operated by farmers (1990). (Smallholder Irrigation Series), Ministry of Agriculture, Irrigation and Drainage Branch.

Schulze, R E editor (1989). ACRU: Background, concepts and theory (WRC Report No 154/1/89) Pretoria: Water Research Commission.

Schulze, R E; George, W J; Angus, G R and Lynch, S D editors (1989). ACRU:2 user manual (WRC Report No 154/2/89) Pretoria: Water Research Commission

SCHULZE, R E; SMITHERS, J C and LYNCH, S D (1994). "Agrohydrological modelling with PC-ACRU: Where from? What's new? Where to?" Paper presented at SAILI Symposium '94. Pretoria: South African Institute of Agricultural Engineers.

SCHULZE, R E (1997). South African atlas of agrohydrology and -climatology. (WRC Report No TT82/96; ACRU Report No 46, 1997). Pretoria: Water Research Commission.

SLABBER, P J (1992). Western and Indigenous principles of irrigation water distribution. Paper presented at Conference on Small-scale Farmer Irrigation. Southampton, 1992.

SMALING, A (1990). "Munchhausen-objectivity: A bootstrap conception of objectivity as a methodological norm" in Baker W J, Hyland M J, Van Hezewijk R and Terwee S editors. Recent trends in theoretical psychology – Vol III. New York: Springer-Verlag.

SMALING, A (1992). "Varieties of methodological intersubjectivity – the relations with qualitative and quantitative research, and with objectivity" Quality and quantity; 26. 169-180.

SMITH, M. 1992. CROPWAT: *a computer program for irrigation planning and management*. (FAO Irrigation and Drainage Paper No 46). Rome: Food and Agriculture Organization of the United Nations.

SMITH, M; ALLEN, R and PEREIRA, L (1997) "Revised FAO methodology for crop water requirements".

SUBHADIRA, S; SIMARAKS, S and LOVELACE, G (1988). "Introduction" in Lovelace, G W; Subhadira, S and Simaraks, S editors. Rapid rural appraisal in Northeast Thailand: Case studies. Khon-Kaen: Khon-Kaen University.

SVENDSEN, M and MERREY, D. (2000). Bridging the gap between large and small-scale irrigated agriculture: issues and opportunities. International Water Management Institute. Unpublished report.

VAN AVERBEKE, W and MARAIS, J N (1991) "Increasing grain yield by optimising plant density in maize" in Proceedings of the South African Irrigation Symposium, Durban, 1991.

VAN AVERBEKE, W; M'MARETE, C K; IGODAN, C O and BELETE, A (1998). An investigation into food plot production at irrigation schemes in Central Eastern Cape. (WRC Report No 719/1/98). Fort Hare: Report by the Faculty of Agriculture and Agricultural and Rural Development Research Institute (ARDRI)., University of Fort Hare for Water Research Commission.

VAN DER BAN, A W and HAWKINS, H S (1988). Agricultural extension. Harlow: Longman Scientific and Technical.

REFERENCES

ADENDORFF, J (1996). Personal communication about presenting material in "parables". Pretoria.

ADENDORFF, J (1997). *Unpublished report.*

ALLEN, G R; PEREIRA, L; RAES, D and SMITH, M (1998). Crop evapotranspiration: guidelines for computing crop water requirements. (FAO Irrigation and Drainage Paper No 56). Rome: Food and Agricultural Organization of the United Nations.

BEMBRIDGE, T J (1991). The practice of agricultural extension: a training manual. Johannesburg: Development Bank of Southern Africa.

BEMBRIDGE, T J (1996) in Backeberg, G R; Bembridge, T J and Bennie, A T P. Policy proposal for irrigated agriculture in South Africa: Discussion paper (WRC Report No KV96/96). Pretoria: Water Research Commission.

BENNIE, A T P (1993). Besproeiingswater bestuursprogram (BEWAB).; hersiene weergawe. [Irrigation water management program; revised version]. Bloemfontein: University of the Orange Free State, Department of Soil Science.

BENNIE, A T P; COETZEE, M J; VAN ANTWERPEN, L D and BURGER, R (1988). 'n Waterbalansmodel vir besproeiing gebaseer op profielwatervoorsieningstempo en gewaswaterbehoeftes. (WRC Report No 144/1/88). Pretoria: Water Research Commission.

BENOR, D; HARRISON, J Q and BAXTER, M (1984). Agricultural extension: the training and visit system. Washington: World Bank.

BERNARD, H R (1988). Research methods in cultural anthropology. London: Sage Publications.

BOEDT, L J J & LAKER, M C (1985). The development of profile available models. W R C. Report No. 98/1/85.

BURT, C M and PLUSQUELLEC, H L (1990). "Water delivery control" in Management of farm irrigation systems (ASAE Monograph). St Joseph: American Society of Agricultural Engineers.

CERNEA, M M; COULTER, J K and RUSSELL, J F A (1985). Research-extension-farmer. Washington: World Bank.

CHAMBERS, R (1980). Shortcut methods in information gathering for rural development projects. Brighton: University of Sussex, Institute of Development Studies.

CHAMBERS, R (1992a). Methods of analysis by farmers: The professional challenge. Brighton: University of Sussex, Institute of Development Studies.

CHAMBERS R (1992b). "Relaxed and participatory rural appraisal: Notes on practical approaches and methods" in Participatory Rural Appraisal Workshop recommended reading. Pietermaritzburg: Midnat, April 1993.

CHANCELLOR, F M and HIDE, J M (1997). Smallholder irrigation: Ways forward – Guidelines for achieving appropriate scheme design; Vol 1: Guidelines (TDR Project R5830, Report OD 136). Oxford: HR Wallingford.

Chapter 1

INTRODUCTION

See also ***Irrigation Design Manual*** (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

1.1 INTRODUCTION 1.1
1.2 OBJECTIVES 1.2
1.3 HISTORY OF PROJECT DEVELOPMENT 1.3
1.4 REVIEW OF CHAPTERS IN THE REPORT 1.4
1.5 SMALL-SCALE IRRIGATION IN SOUTH AFRICA 1.5
1.5.1 Foreword 1.5
1.5.2 Introduction 1.5
1.5.3 Overview of Small-Scale Farmer Irrigation 1.6
1.5.4 Vegetable gardeners 1.7
1.5.5 Independent farmers 1.9
1.6 IRRIGATION TECHNOLOGY IN SMALL-SCALE AGRICULTURE 1.9
1.6.1 Flood beds 1.9
1.6.2 Furrow irrigation 1.10
1.6.3 Sprinkler irrigation 1.11
1.6.4 Centre pivot 1.12
1.6.5 Micro irrigation 1.12
1.6.6 Drip/trickle irrigation 1.13
1.7 ISSUES AROUND SMALL-SCALE IRRIGATION 1.13
1.7.1 Limited irrigation and crop water requirements 1.14
1.7.2 Sharing of infrastructure and equipment - need for organisation of farmers 1.15
1.7.3 Management of irrigation schemes and empowerment of farmers 1.16
1.7.4 Training needs 1.16
1.8 S A STATE OF THE ART: IRRIGATION DESIGN MANUAL 1.16
1.8.1 Preface to the *Irrigation Design Manual* 1.16
1.8.2 Contents of the *Irrigation Design Manual* 1.17

1.1 INTRODUCTION

There is a perception that irrigation is a first step in promoting development in impoverished rural areas. This is applied in the context not only of large schemes but also to the establishment of landless people as emergent farmers and the creation of food plots and community gardens to promote food security both in deep rural areas and adjacent to major population centres. This is not new; the origins go back some 50 years.

Van Averbeke *et al* (1998) have reviewed the origin of the irrigation schemes in the communal land tenure areas.

In the former 'Bantustans' or 'Native Areas', minor irrigation developments occurred before 1950, but *most irrigation schemes were started after the publication in 1955 of the Report of the Commission for* the Socio-economic Development of the Bantustans, the so-called Tomlinson Commission. The Commission estimated the total area under irrigation in the 'Bantustans' at 11 400 ha farmed by 7 538 plot-holders, resulting in an average irrigated land holding of about 1.5 ha per farmer.

Based on information collected at existing schemes, the Commission suggested that irrigated holdings of 1,3 to 1,7 ha were adequate to **'provide a family with a living that would satisfy them, whereby the whole family would work on the holding'**. Preliminary surveys suggested that the irrigable potential of the Bantustans was about 54 000 ha, sufficient to settle 36 000 farming families, a very attractive rural development strategy.

The Commission recommended that action be taken to improve and replan all existing schemes, so that each holding could provide a **full-time living to a Bantu family**; and that new schemes, which could be operated by simple diversion weirs and furrows, be developed during the next 10 years. In the early years the schemes under the management of dedicated Department of Bantu Affairs officials were largely efficient and productive. Unfortunately this 'top down' approach was not sustainable.

During the 1970s political and administrative independence of the Bantustans was encouraged. Before the advent of the homelands the emphasis was on concrete-lined canals and flood irrigation. When capital became freely available and the emphasis was on homeland development at any cost an attempt was made to 'facilitate' the process by automating the technical and management aspects by introducing centralised pumping facilities and sprinkler and micro irrigation. This approach to *facilitating community adaptation to technology and its use has failed, one of the reasons being that it* is difficult to maintain sophisticated equipment in the deep rural areas where maintenance infrastructure is not readily available.

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

Small-scale irrigation farmers in South Africa can be categorised in terms of their water supply as farmers on irrigation schemes, vegetable gardeners (served by communal water supply infrastructures); and independent farmers, each with a 'private' water supply. There are examples of very successful independent farmers and community garden operations despite the problems that must be overcome but they are in the minority. Access to appropriate equipment and technical support is a major problem.

The initial objective of this project was essentially technical and the intention was to evaluate existing irrigation techniques and equipment used by small-scale farmers with a view to establishing design methods and norms that would facilitate the future planning and development of small-scale farmer irrigation projects.

Field visits paid to small-farmer irrigation schemes and farms across South Africa afforded the research team an invaluable opportunity for observation and discussion. Evaluations of irrigation systems were carried out in-field during normal operation and the team came to realise that the purely technical evaluation of irrigation systems as a basis for design norms is not enough. It is essential to adopt a participatory 'bottom-up' approach to irrigation planning. However, technical aspects remain important. The successful development of small-scale farmer irrigation requires exceptionally high technical and organisational proficiency on the part of planners, designers and implementing agencies.

1.2 OBJECTIVES

The origins of the project can be traced back to the South African Institute for Agricultural Engineers initiatives for promoting Mechanisation and Irrigation in Developing Areas (MIDA). The first MIDA symposium took place in 1986 and became an annual event. By 1992 it had become clear that adequately funded in-depth investigations were essential if progress was to be achieved.

The Water Research Commission's Co-ordinating Committee for Irrigation Research confirmed that a thorough investigation of the irrigation practices and problems of subsistence and emergent small-scale farmers was a high priority research need. An appropriate research proposal was subsequently submitted and approved.

The objectives of the project were:

- To evaluate existing irrigation applications, techniques and equipment as used by subsistence and emerging farmers; and
- To establish design methods and norms that would promote the effective planning and application of irrigation in development.

The original proposal and initial work focused on short-furrow and sprinkler irrigation, because of their general application in the small-scale irrigation sector.

One year into the project, the team reported their findings and preliminary recommendations to a workshop in which developers, academics, government officials, NGOs, policy advisors and small-scale farmers participated. The general consensus at the workshop was that the team was following an appropriate approach and that the original objectives could all be met. It was considered that the research team was positioned to add a further dimension to the research. It was consequently recommended that the duration of the project be extended in order to attend to the following additional aspects.

- The development of guidelines for the rehabilitation and/or transformation of existing irrigation schemes, i.e., investigation of the need for innovative approaches to the transformation of schemes from a 'top-down' to a 'farmer-managed' situation for small-scale irrigation, and for successful subdivision and management of existing single-owner farms.
- The compilation of a code of practice for the development of community garden projects. The initial project had clearly identified the importance of community gardens from a food supply point of view, and there was a need for clear-cut guidelines regarding the development, sustainability and management of these gardens.

In retrospect the assumption that it would be possible to reduce the complexities of small-scale farmer irrigation development to a series of tidy engineering norms, guidelines and codes of practice was naïve. The project was initiated in 1992 and it was impossible, at that time, to foresee all the changes in policy and circumstances that have taken place over a very short period.

However, the project gave the research team the opportunity to become, and remain, participants in the process of change. Project funding and time made it possible for the team to gain the knowledge and experience between 1993 and 1995 that subsequently placed them in a position to play a proactive role in the development of small-scale farmer irrigation. This included the public consultation and legal drafting processes that preceded the National Water Act (No. 36 of 1998) and the development of irrigation policy, the establishment of Catchment Management Agencies and Water User Associations and the much-needed links between Government Departments and agencies actively involved in rural development. Throughout concentration has been on the little understood situation and needs of small-scale farmers.

There is a close relationship with the Department of Water Affairs and Forestry and the Department of National Agriculture, the Agricultural Research Council and the Provincial Departments of Agriculture, particularly the Northern Province Department of Agriculture and Environment. There is close liaison with consultants and NGOs concerned with planning and implementing small-scale farmer irrigation. International liaison is expanding rapidly with increased recognition being given to the South African initiatives.

It will be appreciated that there has been a paradigm shift in water management policy; the position of the previously disadvantaged and the role of government in financing development and this has necessitated a similar shift in policy and implementation in respect of small-scale farmer irrigation. *This is still in process but the research team have been privileged to play a part in configuring the 'new'* approach. This report deals with the information that the team has acquired over the years and includes case studies derived from practice. Where possible and in line with the original objectives of the project the report has been confined to technical aspects but it is recognised that institutional and land settlement and tenure issues are of key importance.

The project has since its inception contributed to providing the inputs originally identified by the South African Institute of Agricultural Engineers. Papers and poster presentations by team members have become a regular feature at the annual symposiums of the Institute

This report should be read in conjunction with the following parallel Water Research Commission reports developed by MBB Consulting Engineers:

> **Developing Sustainable Small-Scale Farmer Irrigation in Poor Rural Communities- *Guidelines and Checklists for Trainers and Development Facilitators* M de Lange, J Adendorff and CT Crosby (2000).**
>
> **Evaluation of the appropriateness and management requirements of micro irrigation systems in small-scale farming. FJ du Plessis and I van der Stoep (2000)**
>
> **SAPWAT- A computer program for establishing irrigation requirements and scheduling strategies in South Africa. C T Crosby and C P Crosby. (1999)**

1.3 HISTORY OF PROJECT DEVELOPMENT

The project was approved in 1992 and the work programme for 1993 was aimed at:

- Establishing appropriate evaluation techniques and identifying suitable circumstances and locations for detailed evaluations in the second year and;
- Establishing an overview of irrigation as practised by small farmers
- Initial physical evaluations of flood and sprinkler irrigation systems
- Initial rapid rural evaluations to gain insight into the technical needs of small farmers and to learn from their experience.

A work session was organised under the auspices of the Water Research Commission and held on 28 January 1994 at the Directorate Irrigation Engineering, Silverton, to share preliminary findings and elicit recommendations for further research. More than 40 people representing a wide range of interests attended the session.

On recommendation of the March 1994 WRC Steering Committee meeting, the content of the 1993 interim report was adapted for use by students in land use planning at the University of Pretoria and further refined for publication by the WRC as the ***Small Scale Irrigation in South Africa*** booklet (De Lange, 1994). This very successful publication also appeared in a series of articles in the Farmers Weekly.

Extensive fieldwork was done during 1994 and computer routines programmed to facilitate the development of design procedures. An interim report ***Towards successful small scale irrigation*** (De Lange, 1997) was published to provide additional information to practitioners and was subsequently copied and reprinted in ***International Water Irrigation Review*** in 1997.

The project now entered a period where opportunities arose for testing the concepts that had been developed by the research team while at the same time contributing to the rural development process. The insights gained have been incorporated in this report.

- Members of the team, notably M de Lange, PL Mohajane, CM Stimie and JP Leeuwner had became recognised practitioners of the Participatory Rural Appraisal (PRA) methodology and had done pioneering work in linking the institutional and sociological aspects of PRA with the technical realities of small-scale farmer irrigation. This lead to the concept of Participatory Irrigation Planning (PIP) and a full-scale multi-disciplinary exercise was undertaken with the Northern Province Department of Agriculture, Land and Environment in August 1996.
- Preliminary activities leading to the new National Water Act (No. 36 of 1998) commenced in 1996 with a series of public consultation workshops throughout the country. Irrigation Policy was discussed in depth at over 50 'grassroots' workshops held in all the provinces. The task of organising, facilitating and reporting on this process funded by the National Department of Agriculture was entrusted to members of the research team partly on account of their specialised insights into small-scale farmer irrigation. The workshops were well attended by commercial farmers, emerging farmers and participants in community gardens.
- Shortly after the completion of the 'grassroots' workshops the Northern Province Department of Agriculture, Lands and Environment embarked on a project to assess how parastatal managed small-scale farmer irrigation schemes should be upgraded and transferred to the participants. It was decided to select three schemes from a short list and to develop them as pilot projects. The team assisted with the drafting of the consultants brief and acted as advisors to the Department and the consultants in return for access to the information generated in the course of these participatory developments.
- A new initiative of the National Department of Agriculture, the Land Care Programme, is being implemented in several provinces. Late in 1998 a study of the conservation status of the Sabi-Sand catchment was funded and included two major small-scale farmer irrigation schemes. This was an opportunity to assess the practical application of the new approaches to feasibility studies and irrigation development. A multi-disciplinary team from the Agricultural Research Council (ARC) under the guidance of members of the research team completed the irrigation feasibility studies in accordance with the approaches developed in this project. The programme has now been considerably extended and is being undertaken by a team from the ARC in partnership with a consultant.
- The National Water Act is presently being implemented on several fronts including the registration of water use, the establishment of CMAs and WUAs and the pilot assessment of the water demand management strategy. Here again members of the team are actively involved, particularly from the point of view of the needs of small-scale irrigation farmers and how these can be met.

1.4 CHAPTERS IN THE REPORT

Chapter 1: *Introduction* is a general introduction and provides a broad picture of the status of small-scale farmer irrigation activities, standard irrigation design approaches and an overview of the content of the report.

Chapter 2: *Feasibility studies* introduces innovative approaches to pre-feasibility and feasibility studies developed in Kenya and South Africa.

Chapter 3: *Participatory irrigation planning* follows with a discussion of the place of interdisciplinary qualitative research in planning, and introduces the concept of Participatory Irrigation Planning (PIP).

Chapter 4: *Managing crop water requirements* deals with crop water requirements and irrigation management and completes the general part of the report.

Chapter 5: *Water supply and management* outlines the unexpected importance of water supply management on small-scale farmer irrigation projects;

Chapter 6: *Pressurised irrigation systems* analyses the appropriateness of irrigation methods utilising piped water under pressure.

Chapter 7: *Short furrow irrigation* deals with flood irrigation and particularly the design of short furrow systems.

Chapter 8: *Community gardens* integrates the information contained in earlier chapters in the form of guidelines for the planning and design of community gardens.

(For a more detailed review of the contents of the chapters, see the *Executive Summary*.)

1.5 SMALL-SCALE IRRIGATION IN SOUTH AFRICA

This introductory chapter continues with a general introduction to small-scale farmer irrigation in South Africa. This is taken from the popular illustrated booklet ***Small-scale irrigation in South Africa*** by M de Lange (1994), project research leader, summarising the preliminary findings of the research at the conclusion of the first year of the programme. The booklet was based on the interim report and emphasised the relationships between technical, management, institutional and farmer aspects. The booklet is unfortunately no longer available and the text is reproduced here in its entirety.

1.5.1 FOREWORD

This information document is based almost exclusively on a progress report to the Water Research Commission (WRC) on the first phase of the project: *Evaluation of the irrigation techniques used by small farmers*. It has been reworked somewhat to transform it into an information document rather than simply a research progress report.

Of particular importance is that politicians, planners and technicians realise the contribution that small- and micro-scale irrigation makes to household food security in South Africa. Especially the vegetables grown on community garden plots often provide an important additional income to housewives and pensioners who are otherwise fully dependent on outside sources of income, yet responsible for the nourishment of large families. In contrast, a large impressive modern irrigation scheme often burdens its participants with high overhead costs and restrictive management.

It is hoped that this document will help towards a better understanding of the realities of small-farmer irrigation in South Africa and bringing it into line with international trends of the 1990s.

1.5.2 INTRODUCTION

The objective of the first phase of this Water Research Commission funded project is to evaluate existing irrigation techniques and equipment used by small farmers and to establish design methods and norms that will facilitate the effective planning and application of small-scale farmer irrigation projects. Implementation of the research results should enable irrigation planners and designers to develop irrigation projects that are technically sound, cost-effective, and promote small-farmer development.

The project programme strove to establish an insight into the realities of small-scale irrigation farming by drawing on the experience of organisations and individuals over a wide spectrum. Individuals in government departments, parastatal development corporations, non-government organisations (NGOs), community based organisations (CBOs), as well as consultants, researchers and, above all, farmers, were consulted. A literature study provided the background and insights into world-wide experience.

Field visits were paid to small-farmer irrigation schemes and farms across South Africa. Spending days with farmers in their fields while physically evaluating their irrigation system, afforded the research team an invaluable opportunity for observation and discussion.

Evaluations of irrigation systems were carried out in field during normal operation. Farmers were specifically asked not to change their normal practice for the sake of the evaluation. Farmers appreciated that they could carry on normally and not waste their time.

Participatory analysis of farmers' experiences and constraints with their irrigation convinced the research team that it is essential to approach irrigation planning on a participatory basis. The practical techniques are available in South Africa and are within reach of irrigation planners and designers.

The purely technical evaluation of irrigation systems to establish design norms is not adequate. It is essential to look at all the components of the farming system in each case. The successful development of design criteria for small-scale farmer irrigation requires exceptionally high technical and organisational proficiency on the part of planners.

1.5.3 OVERVIEW OF SMALL-SCALE FARMER IRRIGATION

Small-scale irrigation farmers in South Africa can be categorised in terms of their water supply as follows:

- farmers on irrigation schemes;
- vegetable gardeners (served by communal water supply infrastructures); and
- independent farmers, each with 'private' water supply.

A further distinction should be made between full-time and part-time farmers in order to understand the technology requirements. Irrigated agriculture is almost invariably aimed at generating a cash income or at least replacing expenditure on food through own production. Even individuals growing vegetables in community gardens normally only use a small portion of their produce for home consumption: The bulk is sold to augment the family income.

Statistics on the number of irrigation schemes in South Africa, the irrigation technology used, and the number and gender of participants are not readily available. There is no central database containing this information and the degree of record keeping varies greatly in the different regions. A rough estimate obtained from the Development Bank of Southern African indicates that there are at least 150 000 farmers on irrigation schemes, but later work records approximately 40 000 small-scale farmers on about 50 000 ha. (Bembridge, 1996)

Irrigation methods. The full range of irrigation systems is found on schemes, viz. flood, sprinkler, centre pivot, micro and drip irrigation. Sprinkler irrigation is most commonly found. An indigenous flood irrigation system of short furrows is widely used and very popular because of its manageability and maintainability without sophisticated equipment. Similar systems are used widely in other African countries. In Kenya, a related system is known as 'basin irrigation'. A form of small-basin irrigation is used in South Africa for trellised row crops, such as tomatoes.

Management systems. The management systems of small-farmer irrigation schemes can be divided into two broad categories, viz:

- Schemes which are totally, or largely, centrally (externally) managed and where farmers have no or very little decision-making powers;
- Schemes on which the farmers themselves are the decision-makers, especially at individual farm level.

The success and acceptability of irrigation schemes to participants seems to be closely related to the management system of the scheme. There is growing dissatisfaction amongst participants on irrigation schemes which are centrally (ie, externally) managed, however noble the intentions of the developers and/or managers. Farmers have expressed very negative views on being deprived of decision-making powers, especially when they have no control over crop choice and production and marketing decisions. On one scheme, farmers complained that they were forced to grow cotton, while their families went hungry for most of the year. The worst scenario is where central management not only takes all decisions unilaterally on a 'top-down' basis, but also conducts all on-farm operations.

Transparency in financial matters and bookkeeping of centrally 'top-down' managed irrigation schemes is often lacking.

On some schemes, farmers are provided with financial statements in the form of computer printouts but most find these incomprehensible. Many farmers believe they are being 'cheated' and that the managing company is 'getting rich out of the farmers', especially where the farmers have no decision-making power about cultivation practices, where ploughing, planting, spraying and marketing is done or arranged by the managing institution.

Paradoxically, the companies managing the irrigation schemes believe that they are acting in the best interests of the farmers, as advantage is being taken of the economy of scale by farming the consolidated area, so that the farming enterprise should be more profitable. The position of the scheme manager is probably just as unsatisfactory as that of the farmers, as company management expects scheme managers 'to meet budgets'. Scheme managers prefer to do this by controlling the cultivation on the scheme. Ironically, the net farm incomes of farmers on sophisticated centrally managed schemes are often very low due to high overhead and management costs incurred (outside the control of the farmers) on such schemes.

It is clear that 'ownership' of the project and responsibility for its success or failure under these circumstances do not lie with the farmer.

A World Bank study into successful irrigation projects in the Sahel (West Africa) concluded that there are two models that are sometimes successful, namely, (i) small privately-owned enterprises and (ii) large irrigation estates, employing paid labour. Problems are encountered where these two concepts are mixed, namely, when so-called 'farmers' are settled on centrally-managed estates, where the 'farmer' has no decision-making power, yet carries the risks of failure.

Management of water supplies. The sharing of a common water source by a group of farmers limits members' flexibility in terms of irrigation, but the choice of suitable technology is important to ensure as much flexibility for each individual farmer as possible. The irrigation technology on some centrally managed schemes in South Africa has been adapted and/or expanded to increase flexibility and manageability by farmers.

A crucial element in the successful sharing of a water source is that the group of farmers be well organised and equipped (trained) to control, operate and maintain their infrastructure and manage their finances.

Financial sustainability. Irrigation schemes were generally intended to supply individuals with a full income. In practice this does not always realise, especially where expensive infrastructure (ie, irrigation systems) was implemented and repayment and/or running costs are crippling. Many scheme farmers are seriously indebted and depend almost entirely on production loans and/or off-farm employment to keep them going.

There is a view that farmers should not be artificially kept in business too long and should be 'allowed to fail'. Some people feel that, by not allowing farmers to fail, the independence of the community is undermined. These arguments could only be valid for those cases where the farmer has decision-making powers and has had access to adequate training and support services, because only then can they be blamed for failure.

1.5.4 VEGETABLE GARDENERS

Small- and micro-scale vegetable farming present a significant and important sector of irrigation farming in rural and urban areas. It is estimated that at least 150 000 growers participate on community gardening projects in South Africa and an unknown number grow food in home gardens. Community gardens are the 'Portuguese market gardens' of rural and sometimes urban areas, so that millions of people benefit from the availability of locally produced fresh vegetables at reasonable prices, while growers augment the family budget.

Community gardens are similar to irrigation schemes in that a group of farmers shares infrastructure for water supply. These 'irrigated foodplots' constitute one of the biggest success stories in agricultural development in South Africa. Their success is in sharp contrast to the problems of many of the sophisticated top-down managed larger irrigation schemes.

Community gardening provides individuals with the opportunity to develop virtually a full range of entrepreneurial and farming skills on a small enterprise, as growers have autonomy in decision-making on cultivation and marketing, yet have to co-operate in an organisational structure around shared water supply, infrastructure and equipment. Community gardening is unique in the opportunity it can provide the poorest of poor people to improve their standard of living. Community garden participants are mostly women.

External support. Participants are empowered in the sense that they manage their own garden, but they are often still dependent on the Department of Agriculture for maintenance of pumping equipment. This often leads to delays and frustration, for instance, where a garden has to cope without its diesel engine (and thus water supply) for a period of three months during the growing season.

The extension official often plays a major role in the success of a garden project. Her role is that of technical adviser, motivator, runner of errands, provider of transport and even mediator.

Garden irrigation technology. A variety of irrigation technologies is currently being employed on community gardens. Many gardens are being irrigated by bucket directly from rivers and springs, or from earth furrows. Some gardens have pumping equipment and water is pumped either into a reservoir or directly into a distribution network of pipes and tapstands. Hosepipes are sometimes used with a tapstand system. One community garden was even equipped with a solar pump system, although it was not operational due to sabotage.

Furrow irrigation is used widely on community gardens in Northern Province. This system works well, although methods need to be developed to limit water loss from supply furrows in low-clay soils. The irrigation cycle in one garden could be reduced from sixteen days to less than eight days by eliminating infiltration losses in the supply furrows, thereby increasing yield and profitability significantly.

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Wrong siting of reservoirs is a common technical mistake in community gardens, resulting in inadequate pressure and long-term frustration of users. The reason is normally one of the following:

- The reservoir is built inside the garden, because 'it belongs to the garden';
- The reservoir position is planned for furrow irrigation, but pressure becomes inadequate when the participants decide to 'upgrade' to a piped distribution system with tap stands;
- Sometimes the topography is not suitable for a better reservoir position.

'Ownership' of community gardening projects usually rests entirely with the participants. The participants through their management committee handle common garden management matters, while each participant retains full authority over the cultivation and marketing of produce on her own garden plot.

1.5.5 INDEPENDENT FARMERS

Independent irrigation farmers are those not participating in an irrigation scheme or in a gardening group. Independent farmers have a 'private' water supply, such as pumping directly from a river, or an own borehole. Independent farmers are often *bona fide* farmers aiming to make a living out of farming. Others consider farming an additional income. Many are shopkeepers or other entrepreneurs and develop the irrigation as an added dimension. An independent farmer typically started his irrigation enterprise using own or family capital and built it up over a period. These enterprises range from the very small vegetable or fruit tree plot, to fairly large commercial units, eg, 100 ha intensive tomato cultivation under sophisticated drip irrigation.

There are virtually no statistics on independent farmers, as they are seldom being financed or managed by formal institutions. Yet, the 'independent farmer' sector probably forms a significant component of small irrigation farming in South Africa.

Irrigation technology. Independent farmers are probably in a better position than other small-scale farmers to adapt technology to their requirements and circumstances. Many 'learned their trade' working for large commercial farmers. However, some of these independent farmers have made serious and expensive mistakes with irrigation and water supply technology.

Independent farmers survive because they are successful at farming, as they have only themselves to rely on. There is no question of anybody being kept solvent artificially, except where the irrigation farming is subsidised from a farmer's other businesses and then the decision is his, he will only continue as long as he considers it worth his while.

The responsibility for success lies entirely with the farmer.

Lack of support services. In most areas there is a serious lack of support services for independent irrigation farmers. The most serious of these is a lack of specialised irrigation extension technicians who can advise them in regard to cropping aspects, as well as lack of technical advice on engineering aspects. Maintenance support services are often poor or non-existent. Problems are encountered regarding the availability of inputs such as seed, fertilisers and pesticides.

Quite apart from the physical problem of procuring seed, fertilisers and pesticides, maintenance services and spare parts are seldom locally available. Specialised technical advice on cropping, irrigation management and equipment installation and operation is usually conspicuous by its absence.

Lack of specialised irrigation advisory (extension) and support services are major drawbacks to independent Irrigation farmers.

Development of irrigation technologies for small-scale farmers. Appropriate irrigation technologies need to be developed for small farmers. For example, the small pumps currently available on the market are not very efficient. Investigation into the suitability of different power supplies is also needed as electricity is seldom available in the rural areas. There is also need for the improvement of indigenous irrigation techniques.

1.6 IRRIGATION TECHNOLOGY IN SMALL-SCALE AGRICULTURE

A wide variety of irrigation technology is currently used by small-scale irrigators. Sprinkler irrigation is used most commonly on 'modern' irrigation schemes, while an 'indigenous' system of short furrows is very popular and used widely on older schemes and in community vegetable gardens.

1.6.1 FLOOD BEDS

Irrigation schemes designed for 'wild flooding' have mostly been converted to either sprinkler or short-furrow irrigation. Flood irrigation in beds needs specialised management, without which over-irrigation and soil erosion often occur. Rice is irrigated in level basins, which differs from flood beds because water is retained in the basins; whereas bed irrigation requires an exact balance between slope, stream size and cut-off time to be efficient. Mastering the skill of conventional flood bed irrigation may well be too tall an order for an individual new to irrigation farming, who has still to master the other aspects of cultivation and the farming business.

1.6.2 FURROW IRRIGATION

Long-furrow irrigation. Furrow irrigation is used in many forms and is generally somewhat easier to manage than flood beds. If long furrows are properly designed and laid out and the correct flow rates are available, they are irrigated in much the same way as flood beds, with the correct cut-off time being important to ensure efficiency. This often requires that the inflow be cut off when the water has advanced two-thirds of the distance to the end of the furrow. Shorter furrows, however, are filled relatively rapidly from a supply furrow and do not require similar skill and experience. In some cases it may be possible for a farmer to start off with short furrows and to increase the length of the furrows as his skill improves or as the flow rate becomes more stable or predictable.

Achieving an accurate layout with the right furrow gradient is more difficult with long furrows than with shorter furrows. One independent farmer had difficulty constructing his long furrow layout on an uneven slope. In order to improve distribution uniformity, he retarded the water by damming at intervals in each furrow. This was an improvement, but it is unlikely that a high degree of accuracy can be attained. An alternative layout of shorter furrows may well be a better solution.

Short-furrow irrigation. Short-furrow irrigation systems were evaluated at irrigation schemes at Tukhela Ferry and Tshiombo. The furrow system of an independent farmer at Sterkspruit and that of a community garden near Giyani were also evaluated.

The short-furrow irrigation system is an indigenous modification to the original 'wild flooding' beds. It is highly manageable and requires comparatively little in terms of permanent infrastructure and maintenance. The water source will determine running costs and may be insignificant.

Irrigation and weeding are done simultaneously. Completing an irrigation of a field of 0.1 ha (1 000 m^2) may take one to three hours, depending on the soil characteristics and the stream size (flow rate) and this allows adequate time for simultaneous weeding and manual insect control.

According to computer simulation, at flow rates of between 5 and 15 m^3/h, the slope does not have a significant influence on the time needed for irrigation. However, from a distribution uniformity point of view, the slope in the short furrows should be perfectly horizontal for best results (ignoring losses in the supply furrow, 95% CU in the short furrows is achievable).

Overall distribution uniformity is very dependent on the losses in the supply furrow of a short-furrow irrigation system. On suitable soils, with the correct layout and adequate flow rate, losses may be as low as 5%, but in the extreme it is possible to have 100% loss, ie, the water does not reach the irrigation furrows, but infiltrates completely in the supply furrow.

Experience in Kenya and Zimbabwe has confirmed that, correctly designed and applied, short-furrow irrigation can be more efficient in water use than the more conventional (modern) irrigation methods, and is particularly effective where water is a limiting factor.

As part of the research project, a design procedure was developed to predict the field situation for different soil characteristics, layouts and flow rates, by adapting an existing computer simulation program for conventional flood irrigation simulation.

When asked whether they would prefer to change to a different irrigation system, farmers using short-furrow systems indicated that they considered short-furrow irrigation preferable for their circumstances. An exception to this view was voiced by a tomato farmer whose enterprise had expanded to such an extent that he was converting to drip irrigation to facilitate efficient management.

Community garden furrow plots. A system of furrow irrigation is used on many community gardens. Participants irrigate on a schedule that depends on how long it takes to complete the cycle for the *entire garden. Unutilised plots pose no problem to the water supply schedule, as they are simply* bypassed. Preventing water loss in the supply furrows can often reduce irrigation cycles significantly.

Small-basin tomato irrigation. A system of small basins is used in different versions to irrigate trellised row crops, such as tomatoes. In one version, the irrigation procedure is the following:

Starting at the top of a row, every alternate basin in the row is filled, moving down the row. The remaining basins are then filled, moving back up the row and ending at the top of the row again. In this manner, the need to cross over rows, as with the short-furrow system, is eliminated.

This system has not yet been evaluated for distribution efficiency. It is expected that it should perform almost as efficiently as the short-furrow system. The problem with losses in the normal supply furrows as experienced with the short-furrow system, probably also applies in this instance. There could be some additional losses associated with the 'secondary supply furrows' to each row of basins.

One youngster employed by an independent farmer to perform the basin irrigation on his tomatoes, complained bitterly about the "back-breaking work, with not a moment to rest." The flow rate was very high, possibly because the young man was in a hurry to finish the task!

1.6.3 SPRINKLER IRRIGATION

Sprinkler irrigation is the system most frequently used on irrigation schemes developed by development agencies. However, maintenance of sprinkler irrigation systems is often neglected in isolated rural areas. Ignorance of the implications for power consumption and possible yield loss due to poor distribution efficiency often leads to neglect of this aspect. The consequences of poor maintenance including yield loss and increased power consumption are not appreciated.

One system was evaluated where nozzles were worn to such an extent that an average of 9 mm/h was being applied instead of the design rate of 5 mm/h. Scheduling requirements were still based on the design application rate, with the consequence that the farmer was over-irrigating by 80%.

Because of too-high standards in design criteria, pumping installations are often too expensive, making irrigation unaffordable for small farmers.

Conventional moveable pipe. The conventional moveable pipe system has widespread application on irrigation schemes and is also used by some independent farmers. Sprinkler irrigation is not recommended on vegetables and is rarely found in community gardens.

Dragline. Dragline systems are often used for sugar irrigation and seem to be particularly suited to this application, mainly because draglines are easier than conventional pipe systems to move when the cane is high.

A peculiar situation exists where draglines are shared among farmers on a scheme because the irrigation layout does not coincide with the farm boundaries. This situation came about because a decision was made (to prevent land disputes) not to interfere with existing land allocations when the sugar scheme was introduced.

The approach was a breakthrough, as land disputes have indeed been prevented but, after a few production seasons, farmers are now determined to increase the number of draglines available on the scheme so that each farmer may control his own equipment. This would, however, require farmers to co-operate closely to avoid overexploitation of the water supply system capacity.

Field measurements showed that draglines are not always positioned correctly and distribution uniformity suffers as a result. One measurement showed a distance of approximately 30 m between two adjacent positions, where this distance ought to have been 18 m. The difference was clearly visible on the cane growth. One may add that this was only the second season of production and that farmers, having concentrated on mastering the other farming skills until then, were probably ready to receive training to improve their irrigation practices. This embodies one of the advantages of a manageable irrigation system. A farmer can 'get by' on rudimentary knowledge of irrigation in the first few seasons while learning about cultivation practices, get used to the irrigation and then receive training to upgrade the irrigation skills – if the training can be made available.

Evaluation. A sprinkler irrigation system was evaluated on the Middle-Letaba irrigation scheme and on the Makhatini scheme. The team concentrated first on the practical application of sprinkler irrigation and the faults that occur. Subsequently, standard sprinkler irrigation design approaches were evaluated in terms of small-farmer applications.

The research team recommends that designers put their sprinkler irrigation designs for small farmers to a test of 'what-ifs' and explain the influence of deviations to their farmer clients. Very commonly, sprinkler lines are extended beyond the design length; 12-hour stand times change to longer night and shorter day cycles; sprinkler nozzles are not replaced when worn or are replaced with nozzles of a different size; spacings between layouts are wrong, varying or inconsistent, etc.

1.6.4 CENTRE PIVOT

Centre pivots were used in the small farming sector in different ways.

- **One pivot – one farmer**: There are examples of farmers who operate centre pivots successfully. Usually the units have been bought or taken over from agencies that previously managed the farm or scheme. As can be expected, the relatively large area under irrigation can strain the farmer's financial and management resources and it is doubted that pivots are suited to small-farm applications. There are, of course, black commercial farmers who are operating large modern irrigation systems successfully.
- **One moveable pivot – used on a number of circles**: Generally speaking this type of pivot installation has not been successful in South Africa. Mechanical deterioration is accelerated as a consequence of the unit having to be towed from one locality to another, while management is more difficult.
- **Circle subdivided - four farmers**: A centre pivot circle is sometimes subdivided and shared by four farmers. On one scheme, it was mentioned that there is difficulty in controlling the start and stop positions of the pivot at the point where farmers are planting crops with different irrigation requirements. We did not visit the scheme and it is not clear to what extent the scheme is managed (if at all) by the farmers themselves. Sharing of irrigation equipment is only possible with good co-operation between farmers. Farmers need to be well organised to manage and maintain their shared equipment. External management is not conducive to farmers' taking responsibility for their farming enterprises. The farmers neglect maintenance of equipment if they do not see it as their responsibility. Mechanical failure of a pivot at the height of the season can have serious consequences for all the participants.

  On one scheme where groups of four farmers share centre pivots, the Agricultural Bank mentioned the problem of financing a group of four farmers. According to the rules of the bank, if one member of the group defaults, this holds direct consequences for the availability of finance to the remaining three farmers in the group.
- **Circle subdivided – sixty farmers**: On one scheme, centre pivots used to be shared by forty to sixty farmers, depending on the size of the circle. Each farmer had access to approximately one hectare. The scheme was centrally controlled at the time and most of the cultivation done by the resource centre. Cotton was grown under contract to a ginnery. The pivots are presently not used because participants rebelled against the regimentation imposed by the system.
- One scheme has a centre pivot that is shared by about twenty elite members of the area. The 'shareholders' regularly attend meetings where, advised by the scheme managers, they decide on crop and cultivation levels. The centre pivot circle is then cultivated as a unit by the scheme management. Successful production is taking place. However, there is no human resource development gained from this exercise.
- Pivots are sometimes used for irrigation of extension demonstration plots.

1.6.5 MICRO IRRIGATION

It is mainly independent farmers cultivating fruit trees who use micro irrigation. We visited a farmer on a scheme where water was supplied under pressure who used micro irrigation on mango trees and intercropped by using spaghetti tubing of 5 m lengths. The excessive pressure loss in the spaghetti tubing was justified on the grounds that surplus pressure was available as a consequence of the scheme's operating pressures and the topography.

1.6.6 DRIP/TRICKLE IRRIGATION

Drip irrigation was not found on any irrigation scheme. Independent tomato farmers, who made the change for management reasons, use this system. When their enterprises became too large to manage a flood irrigation system, they converted to drip systems.

Vegetable growers in Malawi and increasingly in South Africa use an interesting application of drip irrigation. A dripper line is connected to the bottom of a bucket, which is hung in a tree to provide the necessary pressure to irrigate the row of crops. The bucket is then filled at intervals during the day and the line moved from row to row. This system saves the farmer the trouble of having to water the crops separately by bucket. [The Wagon Wheel system, fed from a standard '40-gallon' drum, is a South African adaptation that has caught international attention.]

1.7 ISSUES AROUND SMALL-SCALE IRRIGATION

The suitability of an irrigation system is particularly related to the manageability of the system for a specific set of circumstances. The distance from the fields, the priority the irrigation farming enjoys in the life of the farmer, and the size of the enterprise should all influence the recommendations.

For example, a housewife irrigating crops to supplement family income, but whose fields are 3 km away from home, will not find a sprinkler irrigation system with a 12 hour stand time practical. This system would require her to be away from home very early in the morning and again in the late afternoon to move the irrigation pipes, which coincides with the times of her day when her household duties and family need her full attention. In her case, a short-furrow system, requiring one visit to the fields for a period of three to four hours to complete the irrigation, weeding and other cultivation would probably be more suitable.

Conversely, a full-time farmer with larger fields may find furrow irrigation too time-consuming or may find it difficult to find labourers willing and experienced enough to flood irrigate. Such a farmer may want a system that leaves him adequate time to pay attention to other activities, such as marketing, financial and labour management, maintenance, etc.

> In all cases, the farmers and the irrigation technologist, working as a team with each contributing from his experience, should investigate the most suitable choice of equipment. The final decision on irrigation technology should be made by the farmers themselves, once enough information exchange has taken place to enable them to make an informed decision.

In Kenya, a rule applies that at least 70% of the farmers aspiring to participate in an irrigation scheme must attend all planning meetings. During these meetings, irrigation technologists share their knowledge on alternatives for irrigation technology with farmers. Farmers then take decisions on layout, technology, etc, and the technologists design the scheme accordingly.

It is critically important that, in the identification, adaptation or development of appropriate technologies for specific situations, all relevant factors are taken into account. Apart from the labour aspects already mentioned, and especially keeping in mind that women often have their labour burden increased by irrigation, which can seriously affect scheme productivity, these *inter alia* include:

- **availability of the necessary infrastructure and support services** ensuring sustainable maintenance of sophisticated equipment such as overhead irrigation systems, pumps, etc. Although the situation in South Africa is probably better than in most other African countries in this regard, its importance in the more remote rural areas of South Africa is possibly underestimated;
- **affordability.** Net farming income per hectare on the Coetzeedraai scheme, based on flood irrigation, was found to be more than double that on the Grootfontein scheme, based on a centre pivot (Bembridge & Sebotja, 1992);

- **selection and adaptation of irrigation systems according to soil condition.** With the increased shift from flood irrigation to overhead systems, it has become clear that Southern Africa has large areas of soils that are extremely prone to very severe soil crusting under overhead systems, and even under drip and micro-sprinkler irrigation. On the other hand, waterlogging is found under flood irrigation on sandy soils with high infiltration capacities; and
- **looking at indigenous systems with great potential**, such as the short-furrow systems, identifying flaws that may occur in these systems (eg, water loss through seepage from supply furrows) and developing appropriate measures to eliminate these flaws.

World-wide there is great disillusionment with the failures of large mechanised soil and water conservation projects and mega-irrigation projects in developing countries, especially in Africa. The 1990s is now characterised by the concept of 'building on tradition', whereby there is an approach of looking at traditional indigenous systems as the basis from which to develop improved soil and water conservation and irrigation systems for small farmer situations.

1.7.1 LIMITED IRRIGATION AND CROP WATER REQUIREMENTS

One of the most significant observations with regard to small-scale irrigation farming in South Africa, is that some small farmers seem to apply much less irrigation water than is recommended for conventional full irrigation. Consequently the need arises to investigate actual crop water use to enable recommendations to be made for lower planting densities and low-input cultivation methods (see "Limited Irrigation" below). Lower irrigation recommendations may bring irrigation within financial reach of farmers who cannot afford a full capacity system. On the other hand, a full capacity system may be under-utilised in a low-input, limited irrigation farming approach, or may lead to over-irrigation.

It is important that the technologist consult the farmer on current and expected future requirements. In this way it will be possible to know when to attempt building flexibility and adaptability into the original design to provide for future expansion or adaptation.

During field evaluations, the team had the opportunity to speak to farmers about their irrigation methods and scheduling. Although continuous monitoring was not possible within the scope of this project, the results of field evaluations, combined with information from farmers, suggest that less irrigation water is applied than is generally recommended for full irrigation. One farmer indicated that she irrigated her vegetables weekly and at times once in two weeks. The evaluation of her short-furrow irrigation system showed that she applied 10 mm per irrigation. It is an inherent characteristic of furrow irrigation systems that the first application (at planting) is considerably higher, as the soil is freshly tilled and the infiltration rate high. Possibly this farmer was giving a 'large' irrigation application, effectively filling the soil profile at planting, which probably explains how she could get by on reduced irrigation during the growing season.

Under these low-cost, low-input regimes, irrigation is employed to reduce risk, in contrast to intensive high-input irrigation farming, which is high-risk farming.

An implication of a low-input regime is that design crop water requirements and consequently irrigation scheme costs could be reduced. This could make a scheme affordable to both farmers and funders. Procedures for estimating the reduced water requirements are being assessed.

The value of simple flood irrigation approaches to fill up a soil profile to field capacity and then exploiting the stored water, with or without additional irrigation during the cropping season, is well known in South Africa and other parts of the world. The best known in South Africa is probably the 'sowing dam' system ('saaidamstelsel') used by farmers along the Sak River in the extremely hot, arid North-western Cape. The Sak 'River' is normally just a dry, flat river bed, flowing only during rare occasional floods. Farmers construct earth bunds across the area, creating shallow, relatively flat basins that are filled during the floods. After the water has infiltrated, wheat is planted at a low planting density. The crop is grown and matured on the water stored in the soil profile. A similar system has been used by farmers in the Graaf-Reinet district in the Eastern Karoo.

At the University of Fort Hare, Van Averbeke and Marais (1991) demonstrated the value of planting a maize crop on a deep, medium-textured soil filled to field capacity before planting during a low-rainfall season. On the plots filled to field capacity by flood irrigation, and thereafter receiving no further irrigation, they harvested more than 8 t maize per hectare. The normal dryland plots, starting with an empty profile and thereafter receiving the same rainfall as the pre-plant irrigated plots, had a complete crop failure – the plants did not even survive until the end of the season.

An important aspect in regard to the approach of utilising the water stored in a soil filled to field capacity, is to know the amount of plant-available water that can be stored in a specific soil profile. For this purpose Hensley and de Jagerl (1982) developed the Profile Available Water Capacity (PAWC) concept at the University of Fort Hare. Laker and his co-workers at Fort Hare (Boedt and Laker, 1985, and Vanassche and Laker, 1989) further developed PAWC models and combined the concept with Miller's 'deficit irrigation' (limited irrigation) concept to improve irrigation water use efficiency (ie, increase yield per unit water applied).

PAWC and deficit irrigation form two of the main components in the BEWAB computerised irrigation scheduling programme developed by Bennie *et al* (1998) at the University of the Orange Free State. BEWAB is an extremely simple, easy to manage program by means of which the soil profile is steadily filled to field capacity under any type of sprinkler irrigation system (including centre pivots) before the peak crop water demand period. During the peak period, deficit irrigation is practised and the PAWC of the soil is exploited. The simplicity of irrigation scheduling under this approach should make it highly suitable for small-farmer irrigation. Apart from optimising irrigation water use, the BEWAB approach also reduces the size of the system that is required, thus reducing the cost of the system.

The WRC project team believes that there is a great need to look urgently at real crop water requirements under the following two conditions prevailing in some small-farmer irrigation areas:

- the limited irrigation, low planting density situation described at the beginning of this section. It is highly unlikely that crop water requirements under these conditions will be the same as under intensive full irrigation. Over-estimation of the crop water requirements will lead to waterlogging, low irrigation water use efficiency and unnecessarily large and expensive irrigation systems.
- the very hot, dry conditions with high evaporative demands found during summer in some areas. Various researchers, including Vanassche and Laker (1989) in South Africa, have shown how differently plants react under these conditions than under normal conditions. There is a striking example in the FAO's CROPWAT publication (Smith, 1992) of how much lower the crop coefficient for citrus is under hot and dry conditions than under normal conditions. Failure to take this into account will also lead to waterlogging, poor water use efficiencies and excessive system costs. Severe waterlogging of citrus under drip irrigation during a hot, dry period was observed at an estate in Swaziland as a result of failure to do a downward adjustment of the crop factor (Laker, 1994).

1.7.2 SHARING OF INFRASTRUCTURE AND EQUIPMENT - NEED FOR ORGANISATION OF FARMERS

The sharing of water supply infrastructure, such as reservoirs, weirs and canals, but also water supply equipment such as pumps and pipelines, is often inevitable for a project to be practical and feasible. Such sharing requires that the group of farmers be organised to manage and maintain their infrastructure and equipment. A conventional irrigation board is a formalised structure set up to fulfil this function. *[Note: The Irrigation Board structure will soon become available to small-scale farmers as Water User Associations under the new National Water Act. MdL, May 1998]*

> Note that the emphasis is on the farmers themselves being well enough organised to be able to manage their own affairs – experience world-wide and in South Africa has shown that management and control by 'outsiders' should be avoided at all cost. Farmers are resentful and negative and the failure of the scheme is inevitable.

The sharing of irrigation equipment, however, is much harder to manage satisfactorily and is often a cause of dispute between farmers. Experience suggests that farmers should be as independent as possible in terms of their irrigation equipment. Examples of the sharing of equipment have already been mentioned with regard to draglines and centre pivots.

1.7.3 MANAGEMENT OF IRRIGATION SCHEMES AND EMPOWERMENT OF FARMERS

It has been indicated that the management system of an irrigation scheme (project) is critically important. 'Top-down', centrally (externally) managed systems are unacceptable. Farmers have made this very clear. Experience in the rest of Africa confirms this. Bembridge & Sebotja (1992) give clear comparisons in this regard and even state: "High political and social costs are involved when farmers play only a passive role on irrigation projects."

Unfortunately development agencies and institutions, consultants and managers, and especially politicians and government officials have rosy perceptions of schemes – oblivious to the perceptions of the farmers involved. Because it is not the farmers who take decisions, it is very difficult to correct matters.

In contrast, where farmers on schemes have been empowered with decision-making powers and freedom of choice in regard to crop selection, irrigation and production practices and marketing, there is a high degree of personal satisfaction and a sense of belonging. Bembridge & Sebotja (1992) also show that a much larger number of male farmers are found full-time on such schemes, with a much smaller percentage engaged in additional off-farm employment. These schemes have much higher positive ratings in regard to socio-economic parameters and socio-psychological variables than top-down managed schemes. They do not rate as well in regard to technical aspects due to lack of adequate support and advisory services, something that should be corrected by the state.

It is acknowledged that there are certain types of projects, eg, plantation projects such as tea, which should rather be centrally managed. In such cases, people should be employed as labourers instead of creating false impressions that they are farmers.

1.7.4 TRAINING NEEDS

At a workshop during January 1994 in Pretoria, organised by the research team, and attended by participants from various institutions and organisations in South Africa, it became clear that a lack of advisors with specialised training in irrigation poses a serious problem in South Africa. This lack seriously impairs the technical efficiency of independent small-scale irrigation farmers, both individual farmers and empowered farmers on irrigation schemes. South Africa has never had a program for the training of specialist irrigation extensionists, especially not at diploma level. It is imperative that such training programme should be started as soon as possible.

During the field visits, extension workers expressed their desire to receive further training in irrigation theory and practice.

There is a great need for hands-on, on-farm practical training of small-scale irrigation farmers. This should meet the localised day-to-day training needs of farmers. Bembridge & Sebotja (1992) point out that farmers and their organisations should be involved in developing training content and strategies for these programmes. Farmers stressed the need for technical advisors "trained right here, under our conditions."

1.8 S A STATE OF THE ART: IRRIGATION DESIGN MANUAL

The preface and table of contents of the ***Irrigation Design Manual*** (Institute for Agricultural Engineering, 1997) are reproduced here to illustrate the purpose and scope of what is now the accepted basis for irrigation design in South Africa. It should be consulted in conjunction with this review, which concentrates on non-standard situations typical of small-scale farmer irrigation.

1.8.1 PREFACE TO THE *IRRIGATION DESIGN MANUAL*

Irrigation plays an important role in the context of agricultural production in South Africa. This is underlined by the fact that 30% of the total agricultural produce in the country is supplied by irrigated agriculture on 10% of the total area under cultivation. To reach this level, irrigated agriculture requires more than 50% of total water consumption in South Africa.

It has been said in the past that local irrigation was in a privileged position as far as the allocation of water was concerned, and that it therefore occasionally received preferential treatment. It has also been said that irrigation was more an art than a science. However, population growth, urbanisation and industrialisation will unavoidably make greater demands on the availability and allocation of water. This requires a strict, scientific approach to all facets regarding irrigation, as well as the proper application of all research results and new technologies. Only then can present production levels be maintained, or even increased, with less water.

Against this background and from several directions, the need for a manual on irrigation design was identified. Many organisations indeed initiated efforts to address the various aspects of the problem. For example, the South African Irrigation Institute (SAII) took certain steps to ensure satisfactory irrigation design standards. Then followed the publication of this *Irrigation Design Manual*, the combined effort of experts from the Provincial Departments of Agriculture and the Institute of Agricultural Engineering of the Agricultural Research Council (ARC), as well as the Water Research Commission (WRC). These organisations are all directly or indirectly members of the South African National Committee for Irrigation and Drainage (SANCID), the local branch of the International Commission on Irrigation and Drainage (ICID). Furthermore, this publication is endorsed by SANCID.

The basic point of departure during the development of this publication was that it should be user-oriented and presented at a level easily understood by technicians involved in irrigation design. Its main purpose is to contribute to the more effective application of a limited resource, namely water. I believe that this manual succeeds in combining the know-how and experience of several experts in a single publication, which covers the subject from natural resources (water and soil), to the various irrigation methods and designs, and their related equipment. The manual should therefore be of great value to technicians involved in irrigation, and will promote effective communication and co-operation between these technicians and engineers, soil experts and crop experts.

The South African National Committee for Irrigation and Drainage would like to express its appreciation for and acknowledgement of the inputs of the authors, editors and other individuals who contributed to the development of this manual. Its impact will not only be felt on local soil, but will also be observed by other countries on this sub-continent.

December 1997
David S van der Merwe
Chairman: SANCID

1.8.2 CONTENTS OF THE *IRRIGATION DESIGN MANUAL*

Introduction.

Irrigation terminology: Symbols and abbreviations, definitions and concepts, units, conversion of units.

Soil: What is soil, classification, physical characteristics, chemical soil characteristics, organic characteristics, factors that may influence the irrigation of soil, soil samples, a typical soil analysis report, soil conservation, drainage, leaching requirements.

Crop water ratios and climate: Climate, crops, evapotranspiration.

Water: The irrigation farmer and the Water Act of 1954, hydrology, dams, water quality, groundwater.

Pipe hydraulics: The SI system, general definitions, hydrostatics, hydrodynamics, pipe classes, air and anti-vacuum valves, water hammers.

Canals: *Flow classification, laminar and turbulent flow, design of canals.*

Flow measurement: Measurement notches, flow over measuring structures, partial gutter, crump measuring structure, maintenance of measuring notches and gutters, small openings for establishing flow in canals, floats for establishing flow measurements.

Irrigation accessories: Types of pipes available, valves, water meters.

Irrigation systems: Classification of systems, flood irrigation, moving systems, static systems, selection of irrigation system, comparisons between systems, guidelines for the design of irrigation systems.

Planning: Soil survey and analysis, climate, crop study, water source survey and hydrological study, management aspects, selection of type of irrigation system, surveying, irrigation requirement, water balance, scheduling planning, theoretical sizes of irrigation groups.

Micro irrigation: Emitters, laterals, filtration, planning, distribution uniformity, design, automation.

Sprinkler irrigation systems: Types of sprinkler irrigation, components of sprinkler irrigation, design norms for sprinkler irrigation, design for sprinkler irrigation systems, hydraulic calculation, side-roll systems.

Moving irrigation systems: System types.

Flood irrigation: Factors that may influence flood irrigation, water sources, control mechanisms, conveyance systems, planning of flood irrigation systems, basin irrigation, bed irrigation, furrow irrigation.

Pumps: Function of a pump, classification of pumps, pump performance, selection of pumps, accessories.

Driving systems: Electrical motors, combustion engines, coupling, energy costs.

Chemical irrigation: Classification of chemical irrigation, factors that may influence chemical irrigation, advantages and disadvantages of chemical irrigation, application methods, application equipment, legal aspects and protection.

Economy: Costs of an irrigation system, advantages of an irrigation system, cost-benefit ratio, economical pipe diameters.

Chapter 2

PRE-FEASIBILITY AND FEASIBILITY STUDIES

See also *Irrigation Design Manual* (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

2.1 INTRODUCTION 2-1

2.1 PRE-FEASIBILITY STUDIES 2-2

2.1.1 The characteristics of pre-feasibility studies 2-2

2.1.2 Pre-feasibility study procedures 2-4

2.2 FEASIBILITY STUDIES 2-10

2.2.1 Introduction 2-10

2.2.2 The FAO approach to land evaluation for irrigation 2-12

2.2.3 Appropriate feasibility study concepts for small-scale farmer irrigation projects 2-14

2.3 QUESTIONS FEASIBILITY STUDIES SHOULD ANSWER 2-16

2.3.1 Introduction 2-16

2.3.2 Description of the Scheme 2-17

2.3.3 Key Questions on the Present Situation 2-21

2.3.4 Key Questions on Future Development 2-27

2.3.5 Key Questions on the Development Plan 2-32

2.4 GENERAL CONCLUSIONS AND RECOMMENDATIONS 2-36

APPENDIX 2-A. EXECUTIVE SUMMARY OF A 'NEW APPROACH' FEASIBILITY STUDY 2-37

2.1 INTRODUCTION

In common with all projects involving capital investment in infrastructure development, pre-feasibility studies and feasibility studies have preceded irrigation projects in the communal land tenure areas of South Africa. The approach to these studies was determined by the prevailing circumstances, where:

- The projects were usually fairly large and there was a bias towards central management.
- The emphasis was on socio-economic issues and the need to promote development.
- Funding was available from official sources via the Development Bank of Southern Africa (DBSA). The projects were required to pass the test of being economically viable with a satisfactory cost benefit ratio.

The current situation of these projects is detailed in Chapter 1: *Introduction.*

The approach to these studies is under review in the light of the new circumstances, where the development of irrigation projects is largely an agricultural matter and agriculture is the responsibility of the provincial governments. Each of the provinces is unique in the role that irrigation now plays, and can play in the future. Irrigation pre-feasibility and feasibility studies will be essential to inform and guide provincial policy-makers and developers concerned with small-scale irrigation farmers and should therefore be accorded high priority

Feasibility study procedures will have to be modified to incorporate another change in circumstances, which is that, in future, irrigation projects for small-scale farmers will be operated and maintained by the farmers themselves. The old system where Departments of Agriculture or parastatals managed the schemes is no longer acceptable because top-down management has proved ineffective. In addition, the State is no longer in a position to carry the full financial burden of operation, maintenance and development. Unfortunately the infrastructure of these schemes has deteriorated and the current financial position of the farmers makes it impossible for them to take over operation and maintenance unless the infrastructure is operational and suitable. It is a prerequisite that feasibility studies assess what is required to achieve this and whether schemes will be sustainable with limited state support.

The planning and development of small-scale farmer irrigation projects on a similar scale to that which is envisaged in the future in South Africa has received attention in other parts of Africa. A report, Smallholder irrigation: ways forward - guidelines for achieving appropriate scheme design (Chancellor and Hide, 1997), is based on research undertaken in a number of African countries and draws heavily on experience gained in Kenya. The authors explain the differences and relationships between pre-feasibility studies, feasibility studies and development planning.

> Development proposals are assumed to include both a pre-feasibility stage, at which proposals are screened for suitability and compared on the basis of outline estimates of economic and technical viability; and a feasibility stage, where estimates are refined on the basis of semi-detailed planning. In practice, though, small-scale developments are not likely to justify studies of the type and scale of those hitherto conventionally carried out by consultants for large irrigation projects.
>
> However, much greater emphasis needs to be placed on socio-economic aspects of proposed developments, making it essential to have the active participation of the intended beneficiaries in the studies.

Pre-feasibility and feasibility investigations may well be combined in one stage of the work. However, the distinction between the two stages is maintained here in order to emphasise the need to proceed logically through a series of steps, during each of which the extent and detail of the information sought should be related to the consequent decisions to be made.

Many of the basic decisions involved in scheme development are affected, not only by the physical and socio-economic parameters characteristic of the area, but also by other design/development choices. Planners need to identify linkages so that appropriate choices that take account of all the various factors are made at each stage of development.

The relevant categories of small-scale farmers are defined and explained in Chapter 1, *Introduction*, Section 1.2.3. Currently, the rehabilitation of existing schemes and resettlement projects are a priority. Commercial farmers in the communal land tenure areas would not normally be the objects of feasibility studies, as they make decisions and negotiate independently. However, if they are seeking a loan, it is probable that some kind of feasibility study would be required by the financing concern.

The small-scale irrigation projects considered in this review will include both the emerging farmer and the household food security situations because, in many cases, irrigation scheme infrastructure can be expected to have to cater for the full gamut of small-scale farmers. Since there is some debate as to whether the food security aspects should be the responsibility of local government rather than the Department of Agriculture, there would probably have to be close co-ordination between the various authorities with regard to the farmers on irrigation schemes, each authority catering for a different category of farmer. Considerable progress has been made in Africa, particularly Kenya, in developing sound guidelines for feasibility studies and this chapter is indebted to Chancellor and Hide (1997) for a revised approach based on their participation in these activities.

It is important, however, to appreciate the present position in respect of small-scale farmer irrigation projects in South Africa. The record of the past is one of failure. The infrastructure of the state and parastatal schemes is in a state of collapse and budgets for rehabilitation are restricted. Policy is that the 'farmers' take over the schemes and accept full responsibility. It is a prerequisite for any degree of state support that schemes are sustainable. Under these circumstances, evaluating and implementing new schemes or rebuilding existing schemes is more than just a challenge.

A paradigm shift in approach is unavoidable and the suggestions for modified approaches to feasibility studies must be seen against this background. Clear, proven procedures have still to be established. The experiences in other parts of Africa can provide useful guidelines but circumstances are different, and in the years to come South Africans will have to find their own answers. What is important is that the new procedures conform to the now established principles of participatory development.

2.2 PRE-FEASIBILITY STUDIES

2.2.1 THE CHARACTERISTICS OF PRE-FEASIBILITY STUDIES

Pre-feasibility studies are the essential, concise, first screening, the 'go/no-go' phase, while technical and economic detail is more at home in the feasibility study phase. In the case of irrigation projects, the findings of the pre-feasibility study are usually reported to the senior management of the organisation that will fund further investigations. The investigation should concentrate on establishing the essential issues that have a major bearing on the decision that has to be made. Therefore, although there is always a temptation to gather as much information as possible, in the belief that this will enable senior management to reach a decision, this should be avoided. Decision-makers will ask for more information if they want it.

It is up to the practitioner in the field, even if relatively junior, to assess the situation and present it to seniors fairly, without hiding information. This is because senior management is too far removed from day-to-day practice and has no time to undertake the chore of interpreting information and synthesising an evaluation of the position. Management want to know what is going on, what is behind it, and whether to go ahead or not. It should therefore always be quite clear whether the data that practitioner in the field presents is true and reliable beyond all shadow of doubt, or is an intelligent assumption based on experience, or whether it is not possible to come up with valid recommendations.

The pre-feasibility study is not only a technical exercise, but also a crucial instrument in 'selling' the idea to the decision-makers. No project should be turned down simply because of poor advocacy. It is therefore important to present the report convincingly and thoroughly, without being verbose. Too much detail may bore and confuse, while too little may cause scepticism.

The purpose of the pre-feasibility study is to:

- make a first-hand assessment of irrigation potential,
- identify farmers' objectives, requirements and capabilities,

- provide background for informed decisions
- identify stakeholders, determine their roles and interests, highlight potential conflicts and strengths and,
- use existing data and findings to indicate preliminary feasibility.

A good pre-feasibility study report therefore amounts to good journalism, including a critical analysis, and good briefing. Unfortunately, engineers and natural and social scientists, by their very nature and training, are oriented towards presenting unvarnished facts. They are not journalists, and this is can be a problem in practice.

2.2.1.1 The impact of the scheme

There will need to be a paradigm shift in the approach to developing small-scale irrigation schemes and this should be reflected in the approach to their feasibility studies. The practice in the past has been to analyse each irrigation project as an entity, with the emphasis on the well-being of the irrigation farmers themselves.

This situation has changed and the National Water Act (No. 36 of 1998) leaves no room for doubt that the contribution an irrigation project can make to its socio-economic hinterland must be a main concern of a pre-feasibility study.

The objective of managing the quantities, quality and reliability of the nation's water resource is to achieve optimum, long-term, environmentally sustainable, social and economic benefit for society from their use.

There are three obvious ways in which irrigation can help achieve optimum, long-term, environmentally sustainable, social and economic benefit for society.

- The first is by being a source of products for which there is a demand in the immediate surroundings, particularly if this means that foodstuffs can be made available at a reasonable, affordable price, where they would otherwise be unobtainable. This could raise the local nutritional levels by providing a more satisfactory and varied diet, while promoting an informal and semi-formal marketing chain.

- Another contribution could be in the production of specialist, high-value crops, possibly requiring packaging and processing, which would, in effect, be a new industry for the area. An example of this is sultana raisin production in Turkey, which is almost totally concentrated in the hands of small farmers and their co-operatives that undertake the necessary processing. Alternatively, if large commercial packhouses or processing plants are close by, serving existing commercial farmers, an outgrow programme, similar to those developed by the South African sugar industry, can be advantageous.

- Last, but by no means least, is the issue of food security. This can be provided in many forms, ranging from home gardens, community gardens and food plots through to full- and part-time farming on one- to two-hectare plots, or even on larger holdings. It is particularly in this area of food security that the role of women is important, although they play a role in all the categories of farmers.

Circumstances may dictate extensive and expensive redevelopment, aimed at a new commodity enterprise, or the low-cost conversion to a community garden of a scheme with water limitations. Conventional engineering design norms and specifications should not be accepted without detailed consideration of what is appropriate for the circumstances. The community, and particularly the women, should be in the picture throughout and should be involved, from design, through construction, to implementation.

It is not only the rehabilitation of existing schemes that requires new and innovative approaches. The opening up of irrigation farming to communities and individuals that were previously deprived of access to water requires a new look at pre-feasibility studies. Projects can vary from land settlement schemes involving people with little knowledge of crop production and irrigation, to farmer communities that purchase irrigation farms as a going concern, through to community gardens.

2.2.2 PRE-FEASIBILITY STUDY PROCEDURES

2.2.2.1 Introduction

The Manual for Irrigation Planning in Developing Areas was published by the Secretariat of the Economic Community of Southern Africa (SECOSAF) in 1993 and was the first to concentrate on small-scale farmer irrigation schemes. This manual concerns itself with relatively large and formalised irrigation schemes built by government or parastatal bodies and intended for small-farmer occupation. It reflects the then requirements of the Development Bank of Southern Africa (DBSA) for an acceptable and effective evaluation procedure.

However, sound as they are, these procedures are no longer appropriate in the changed circumstances, where future irrigation schemes for small farmers will be operated and maintained by the farmers themselves. The pre-feasibility phase must now be related particularly to community projects.

In the course of this research project, developments in other parts of the world, and particularly Africa, were assessed, including developments in participatory irrigation planning and management. The concepts of participatory irrigation planning and management are relatively new and it was only recently that applicable reports on procedures became available. However, these reports can, with suitable adaptation and refinement, contribute to the development of appropriate guidelines for the circumstances in South Africa. Particular attention has been paid to the developments in Kenya, which are summarised by Chancellor and Hide (1997).

In addition to assessing progress elsewhere in Africa, it was possible to develop and apply four 'prototype' techniques in the Northern Province. This is an on-going process that is far from finality but has moved out of research into the experimental phase as outlined below.

Four pre-feasibility study methods have been developed by the research team and subjected to limited testing. In order to identify them, temporary names have been coined: the National Geographic method, the SAPFACT method, the bussing method and the Adendorff method. In addition they have applied Sondeo (3.2.3) and Participatory Rural Appraisal (3.2.5) methods in support of pre-feasibility studies.

There is no reason why these methods should not overlap or be combined with more conventional approaches. It is the approach that is adopted that counts, not the specific method alone.

- The 'National Geographic' method is intended to assist management with the initial phases of establishing priorities and action programmes on a number of irrigation schemes.

- The SAPFACT method is appropriate where a quick evaluation by one or two people is required, but a wider range of aspects is considered than in the National Geographic method. It is particularly applicable when existing schemes and farmers are being evaluated.

- The bussing method is applicable when a pre-feasibility study has to be done on an existing scheme or a proposed scheme, where it is important to obtain the inputs of all stakeholders. This method will generally be used for the somewhat larger schemes or groups of schemes and is most appropriate when sustainability is of particular importance.

- The Adendorff method is especially suited to schemes requiring rehabilitation and communities where an in-depth appreciation of the people's needs and potential is important.

The choice of pre-feasibility study method therefore depends very considerably on the type of project under review and on the experience of the people undertaking the briefing. There can be no set rules or procedures and it is frequently advantageous to synthesise, using the relevant elements of good practice from a number of pre-feasibility study methods.

2.2.2.2 The Kenyan approach

Chancellor and Hide (1997) endorse the pre-feasibility study system that has been adopted in Kenya and regard it as an example of good working practice. According to the Kenyan system, the priorities of project proposals are initially assessed on the basis of twelve factors. These factors rate the 'character' of the community and the quality of the 'environment' rather than the more conventional technicalities. Experience in South Africa endorses this approach. The factors are weighted according to their likely impact on project performance and sustainability, and guided subjective judgements still have to be made. However, the potential for variability between individuals is reduced and decisions either in favour of, or rejecting, a given development can be justified on a rational basis.

The ranking of the factors is in itself of significance and deserves close attention. Assessment factors are rated in groups:

The first:

- strength of farmer's organisation;
- land tenure;
- farmer's initiative; and
- access to market.

The second:

- potential for increasing gross margins;
- cost; and
- chances of equitable water distribution.

The third:

- availability of inputs;
- farmer's technical knowledge; and
- cost of maintenance.

The fourth:

- benefit to region; and
- national development.

Since an assured supply of water is essential to the proper functioning of a scheme, water supply is determined separately:

- water shortage expected once in five years only or less frequently;
- serious water shortage expected more frequently than once in five years; and
- reliability of supply not known: further investigation required.

We may not agree with all the Kenyan priorities, but this is a major step towards planning for sustainability. There are, however, significant differences in circumstances between South Africa and Kenya. Our experience in the field in South Africa endorses the importance of organisation, increased gross margins, land-use arrangements, farmers' initiative and markets. If these aspects are satisfactory, the project has a fighting chance. The item 'chances of equitable water distribution' illustrates the importance of recognising the practical realities of development. However, we would not rate 'benefit to the region' at the bottom of the list; on the contrary, we regard this as a most important factor.

2.2.2.3 The National Geographic Method

This method is called the 'National Geographic' method because it is based on annotated maps and aerial photographs, with sketches or photographs of detail, the very effective reporting technique frequently employed by the prestigious publication after which it is named. It was remarked earlier that a pre-feasibility report should have an element of good journalism. Applying this method can assist engineers and scientists in their report development and production.

Essentially, the method consists of answering five questions and, while community issues are addressed, the emphasis is on physical aspects:

- Where is it and what is it?
- What is the present situation of the scheme or, if no irrigation has as yet been developed, what is the situation of the community and the area?
- What can be expected to happen if no new actions are taken in respect of the scheme?
- What could be done to promote improvement?
- What would be the long-term implications of the alternative actions that are suggested?
- Presentation can range from rough overheads to sophisticated GIS graphics.

The file on each scheme would consist essentially of two or three annotated maps, some illustrations, and tabulated data on the facts that have a bearing on the assessment of the situation. The degree of detail to be included in the tables and comments would depend on the circumstances and the availability of information but, in any event, the information filed should be appropriate and usable.

The first map should establish where the proposed or existing scheme is situated. This may be a small-scale map, say 1:250 000, or a larger scale, showing where the scheme lies in relationship to other schemes, rivers, dams, the centres of population, towns and villages, and the extent of rainfed arable land, etc. Explanatory notes should be added in boxes, in order to clarify the present situation.

The second map should be to the largest scale available – orthophotos are the most suitable because they provide detail as well as contours. If it is an existing scheme, most of the detail can be sketched onto the orthophoto or map, with notes on the condition of elements of the scheme, the area irrigated or to be irrigated, notes on the soils, and present cropping, etc. Where appropriate, photographs or sketches of such things as the extraction works, canals, pump stations, and irrigation equipment can be included.

The third map would be similar to the second but the proposed improvements would be indicated, possibly with more than one alternative.

The necessary text and tables to augment the notes on the visual material would back it up with a good description of the scheme, notes on water supply and key engineering and irrigation aspects, and an indication of factors like the cropping pattern and the marketing situation, etc

The National Geographic method can be used to prioritise development of a number of schemes; for example, in the Northern Province, where there are a large number of schemes that require attention. The first necessity is to identity these schemes, to know where they are, and to have a good indication of their condition and requirements. Detail is probably not necessary for evaluations of this kind because management initially requires a broad briefing on the current state of affairs.

2.2.2.4 The SAPFACT Method

SAPFACT is a computer routine for interpreting the information gained from unstructured personal inspections and interviews (Crosby, 1996). It was developed because, in the course of discussions and inspections on an irrigation scheme, a great deal of preliminary information can be gained in a very short time about the scheme, the farms, the people themselves, and their irrigation practices. However, it is not easy to organise or interpret the information because an extremely complex range of inter-related factors must be taken into consideration.

Human aspects play an important part, and so much is dependent on the local circumstances, institutions, committee systems, background, and education and training of the participants. It is also difficult to quantify such factors because they are unique to the scheme and to individuals. It is no simple matter to sift through the information obtained and to classify it and interpret it. SAPFACT facilitates this process.

It is based on a relatively simple qualitative research method developed to assess the success potential of a new product in industry by integrating the contributions of human and technical factors (Rouse, 1992). The SAPFACT program is used to organise the impressions that have been gathered during field interviews and was originally developed for use with commercial farmers. However, it was relatively simple to develop additional modules to evaluate mechanisation services, individual small farmers, and small-farmer schemes. It can therefore easily be further tailored for the requirements of individual schemes and can be personalised by the interviewer.

The SAPFACT method integrates the separate aspects and their factors that all contribute to the overall probabilities for success of an irrigation scheme. By focusing on specific factors, one can develop recommendations for improvements or new developments.

In the case of small-scale farmer irrigation schemes, six broad aspects are considered:

- water supply;
- crop profit potential;
- irrigation management situation;
- support services availability;
- the general situation of the community; and
- financial aspects of the scheme.

Each of these broad aspects is broken down into eight contributing factors.

WATER SUPPLY		IRRIGATION MANAGEMENT	
1.	Total Water Amount	1.	System Suitability – Soils
2.	Transmission Losses	2.	System Suitability – Crops
3.	Reliability of Supply	3.	Plot Sizes
4.	Frequency of Supply	4.	Tenure Arrangements
5.	Fairness of Distribution	5.	Local Management Structures
6.	Integrity of Farmers	6.	Intensity of Utilisation
7.	Farmer Costs	7.	Contribution to Income
8.	Supplier Costs	8.	Development Status
CROP PROFIT POTENTIAL		SUPPORT SERVICES	
1.	Suitability of Climate	1.	Irrigation and Cropping
2.	Suitability of Soils	2.	Mechanical Equipment/Repairs
3.	Alternative Crop Possibilities	3.	Mechanisation Support
4.	Crop Yields	4.	Water Supply Maintenance
5.	Importance of Food Security	5.	Availability: Spares
6.	Potential Hinterland Market	6.	Availability: Electricity
7.	Outgrow Potential	7.	Availability: Inputs/Fuel
8.	Access to Commercial Farms	8.	Access Roads

COMMUNITY SITUATION SCHEME/AREA		FINANCIAL ASPECTS OF THE SCHEME	
1.	Houses	1.	Institutional Strength
2.	Gardens	2.	Access to Credit
3.	Domestic Water Supply	3.	Debt Load
4.	Communications/Electricity	4.	Contribution to Community Income
5.	Schools/Clinics	5.	Control of Plot Allocations
6.	Community Centres	6.	Participation in Management
7.	Mechanical Repair Facilities	7.	Potential Marketing Channels
8.	Shops/Coops	8.	General Support by Communities

The particular version of SAPFACT being discussed here is SAPFACT-SCHEME (Crosby, 1994) and forty-eight factors are taken into account for small-scale farmer irrigation.

SAPFACT relies on qualitative research techniques and does not record data and statistics. Instead, it provides a multi-faceted evaluation of the strengths and weaknesses of the scheme and the inter-relationships between the various aspects.

The strengths, weaknesses and inter-relationships of a project that are input into the SAPFACT program are obtained during a visit to a project to discuss the situation with management, participants and any other individuals who can contribute. No formal questionnaire is used, but the person undertaking the pre-feasibility study is fully aware of the headings in SAPFACT and will bear these in mind when conducting interviews. At each interview, people are asked to talk about the scheme but, in order to promote the free flow of discussion, no notes other than the bare essentials are taken. Naturally, leading questions will be used from time to time to stimulate the process. The intention, however, is to allow people to talk about those matters which are important to them. It is therefore a great advantage if these interviews can take place in the fields.

At the end of the discussions, which may take one or two hours, and a field visit the investigator has two options. He can use SAPFACT on a laptop computer to go through the various factors with the interviewees so that consensus is reached. Alternatively, he can wait until he has left the scheme and then run through the SAPFACT routine on the laptop to organise his thoughts.

2.2.2.5 The Bussing Method

In projects where there are large numbers of stakeholders and the inputs of several disciplines and organisations are required this is a useful technique.

A representative and knowledgeable team covering the key role-players concerned with the scheme or schemes is brought together for two days (which need not be consecutive). The team travels through the area for a day in a bus or kombi, stopping at key points in the field, pre-arranged with the team members. To get the discussion going, the team member who arranged the stopping point explains the situation and introduces other people from communities or organisations who rendezvous with the touring group at this point and state their case.

It is essential for two reasons that people travel together: Firstly, the discussions normally continue amongst the team members while driving through the scheme to the next stopping point, and *experience has shown that these discussions can be very animated and valuable.*

The second reason for travelling together is that, by the end of the field trip, the participants are literally speaking the same language; there is a sharing of knowledge and experiences in an atmosphere of goodwill that greatly facilitates the workshop discussions that follow. This provides an opportunity to understand the viewpoints of the other stakeholders: Vague concepts become reality, people become individuals, and foundations are laid for future co-operation, so that the discussion at the workshop has a new depth and significance.

It is desirable, if possible, to have an informal review of impressions and conclusions at an evening event to end the day.

The person responsible for the pre-feasibility study is expected to take the lead in identifying the stakeholder groups in the area in which the scheme or schemes are located. He then puts together a team by inviting the stakeholder groups to send a representative and by selecting and inviting specialists in disciplines relevant to the area under study. The points of visit where the team can interview a representative cross-section of interested and affected people are then arranged. Finally, a workshop is organised for a subsequent day, where impressions can be discussed in depth and a report developed. The objective of the workshop is to provide all participants with a common viewpoint of the realities of irrigation and conditions in the area.

The team members, who made the trip, plus other interested people, attend the workshop. *Participants are asked to let the facilitator know beforehand what important issues should be* discussed. These issues are then grouped into four or five policy categories and participants are divided to discuss these in smaller groups. Each group should, of course, have adequate representation from the main stakeholder groups. The groups are requested to report back to the plenary session in a semi-structured format to assist with the development of co-ordinated workshop documentation and recommendations, which can guide management and policy-makers.

2.2.2.6 The Adendorff Method

The Adendorff pre-development survey method (Adendorff, 1996) is the first phase of the 'development through training' process developed by Johann Adendorff at Phokoane in the Northern Province some ten years ago. Johann Adendorff succeeded, with the help of one other Lebowa Agricultural Corporation (LAC) official and two seconded extension technicians, in revolutionising the lives of 7 000 small farmers over a period of some four years. The transformation, from producing the normal four to five bags of maize per hectare, to producing 11 000 tons of surplus maize for sale to the co-op, was achieved by women and old men farming independently under dryland conditions.

The method has since been introduced in other provinces and is presently the basis for evaluating irrigation projects under consideration for transfer to the farmers in the Northern Province. The summary that follows is adapted from an unpublished report (Adendorff, 1997).

The steps in the process are:

- Compilation of an appropriate pre-development survey form and interview schedule;
- Meeting with community leadership to obtain permission to interact with the community and enter the villages (opening the door);
- Mass meetings with the community, and group and individual interviews, ensuring that land holders and landless people's views are captured, the dominant as well as the dominated;
- Participatory analysis of poverty levels and expectations;
- Initial review of existing and possible future infrastructure;
- Assessment and analysis of current agricultural practice;
- Analysis of the Needs, Problems, Fears and Expectations (NPFE), community and agricultural profiles and a Development Strategy (DS);
- Meetings with leadership and arrange a report-back meeting with the community (closing the door);
- Reporting back to the community and other role-players; and
- Community adoption of the results of the survey (NPFE, profiles and DS) as a true reflection of the current situation and a basis for development intervention.

Compilation and use of a survey form and interview schedule

The interviewers use the interview schedule as a reminder of aspects to discuss during their meetings and interviews with community members – it is not used as a questionnaire requiring mechanistic completion. Interviews are informal and aimed at creating trust and improving the interviewer's real understanding of what is seen and heard. Questions are open-ended; the interviewer is careful not to create expectations and should be very clear on the purpose of the visit.

The survey form is used during the interview to capture each interview and would normally capture needs, problems, fears and expectations (NPFE), other remarks and the interviewer's observations. The interviewers work together to consolidate and prioritise the results of all their interviews onto one form and develop a profile of the community. The NPFE are captured in a document for presentation to the community and, if appropriate at this stage, the first components of a development strategy are captured.

Meetings and interviews

Meetings with the community are an important part of the procedure. These should be structured in accordance with requirements and so will vary from one community to another, depending on institutional and other factors. The current study of irrigation scheme rehabilitation can serve as an example of a useful approach.

Rural communities are often reluctant to divide into groups for discussions, but this is a valuable way to increase participation and achieve triangulation (that is, confirmation or contradiction between the findings of the various groups).

Facilitators should ask one question at a time and let the groups discuss it amongst themselves. Individual interviews during the group discussions are also valuable, especially with leaders who might otherwise dominate the group discussions. In some cases, it might be desirable to undertake a series of individual interviews after the group discussion meeting.

Groups then report back to each other and debate their findings. Before the meeting is closed, the facilitator and participants agree on the next steps, and undertake to have a special separate report-back meeting at the end of the survey.

The questions debated by the participants in the Northern Province survey were:

- What are your needs?
- What are your problems?
- What are your fears?
- Why did the scheme fail?
- What went wrong?
- Who should upgrade the scheme?
- Who should provide the money?
- How are the farmers prepared to help?
- Are farmers prepared to pay for water?

The answers reveal significant differences between communities.

The Adendorff method is particularly valuable in that it provides in-depth information about the key factors in development projects, the community and its situation. It could well be that the key factor pattern that emerges reveals that there is no point in going further with the project. If, on the other hand, the verdict is positive, it is necessary to go forward to assessing the technical and economic situation and the study can be augmented by, for example, the National Geographic method.

2.3 FEASIBILITY STUDIES

2.3.1 INTRODUCTION

The purpose of the feasibility study is to:

- Ensure that there are adequate resources to meet farmers' objectives;

- Ensure that these resources are available for the proposed development;
- Determine farm budgets, organisation and needs for assistance;
- Provide a basis for discussion with farmers;
- Provide opportunities to modify design or withdraw the proposal;
- Initiate structures that will provide a basis for loans, management and O & M; and
- Enable comparison of projects competing for funding.

There are international guidelines for feasibility studies in the developing countries, published by such organisations as the World Bank and the OECD (Organization for Economic Cooperation and Development). Possibly the most interesting and useful guideline is that published by the Food and Agricultural Organisation (FAO) of the United Nations (UN).

There are also South African guidelines. The South African government departments dealing with agriculture and water affairs have, for many years, undertaken or commissioned feasibility studies before proposed irrigation schemes could be approved or become eligible for financial support. The departments work closely together as members of the Irrigation Investigation Committee and developed an interim document, Guidelines for irrigation project investigations, targeted at state and irrigation board schemes. The guidelines suggest that no fewer than twenty chapters that should be covered in a report submitted to decision-makers. The twenty chapters suggested are:

1. Overall summary
2. Background information
3. Consultant's brief
4. Area description
5. Natural resources
6. Crops and livestock which are suitable for the area
7. Land preparation, drainage, mechanisation packages, and irrigation systems
8. Suitability of the land for irrigation development
9. Water distribution and pricing
10. Existing farming structures
11. People resources
12. Infrastructure
13. Market for agriculture products
14. Enterprise budgets
15. Representative farms for planning purposes
16. Scenarios for development
17. Cost benefit analysis
18. Conclusions and recommendations
19. References
20. Appendices

It is stressed that the attention should be on the broad feasibility of the project as a whole, not on technical details. The guidelines are comprehensive but not rigid or prescriptive and provide a useful list of aspects that should be assessed when preparing feasibility studies. Some of the aspects could be omitted in certain proposals because they would not have a significant impact on the decisions that need to be made. However, the omission of one of what are generally acknowledged as key factors would normally require motivation.

A multitude of factors must also be considered when assessing small-scale irrigation projects but it is important to achieve a realistic perspective. There is not sufficient funding or time to make an in-depth study of the type that is warranted for major schemes. At the same time, the planner must not lose sight of the broad picture while concentrating on the critical aspects that can determine success or failure.

Experience has shown that, when extensive procedures are available, there is a tendency on the part of planners to concentrate on following the procedure to the letter and, consequently, to fail to see the wood for the trees. It is important that they concentrate on the critical aspects, and the principle of 'need to know' should be extended to 'need to include'.

The comprehensive procedure manual, FAO Soil Bulletin No 55, *Guidelines – Land evaluation for irrigated agriculture* (1986) concludes an introductory summary with the following paragraph, which endorses this requirement:

> The reader should use these guidelines selectively, as not all the factors listed will be relevant in a given evaluation. The procedure provides for a sifting out of considerations deserving special emphasis, in order to avoid needless investigations and unnecessary expense. The evaluation procedure is an essential preliminary to project planning and should be conducted in a manner that will minimise costs, but at a level that is consistent with achieving practicable recommendations.

2.3.2 THE FAO APPROACH TO LAND EVALUATION FOR IRRIGATION

The introductory chapters of FAO Soil Bulletin No 55, *Guidelines – Land evaluation for irrigated agriculture*, provide a valuable introduction to how irrigation planning should be approached. This section is based on this publication and is largely in the form of extracts. It should be noted that the FAO Soil Bulletin No 55 uses the word 'evaluation' where this report would use the term 'feasibility study'.

> Land evaluation provides information and recommendations for deciding 'which crops to grow where' and related questions. Land evaluation is the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable.

Irrigation planning is an iterative process

> In the early stages of land resources investigations, land evaluation studies indicate in a preliminary way, the suitability of land for alternative crops and irrigation methods and the land improvements that may be worthwhile. With further field studies, projects are identified and a plan of irrigation development is worked out. Individual projects are ranked in order of priority. The priority projects are planned in more detail and each project plan is progressively refined.

The proposed crops, methods of irrigation, inputs and land improvements are progressively adjusted until a satisfactory project plan is produced.

Circumstances dictate the criteria that are established

> Various criteria are used to decide whether a project plan is satisfactory. Apart from social and political objectives, which in practice are often paramount, a satisfactory plan is one that leaves the farmers, the community and the national economy better off. In other words, it results in the largest practicable increment in nett benefits in an economic comparison of 'without project' and 'with project' situations. Such a plan will generally utilise limited resources of land, water or inputs for the most productive use.

A satisfactory plan is one that is practicable and likely to work out under actual field conditions, not necessarily the most economically attractive on paper.

The stages of irrigation development tend to merge and are not entities in themselves

> Land evaluation reports, maps and data continue to be useful after the planning stage, during design and implementation and for monitoring the project. The detailed design of engineering

works may depend on information collected earlier during the evaluation study. During the implementation and later management of the irrigation project, the land evaluation study provides a basis for monitoring changes in physical, social and economic conditions. In. response to such changes, the recommendations may need modification and updating from time to time.

Currently, the rehabilitation of irrigation projects is an important aspect of land evaluation work. This highlights the need for thorough evaluation of land and water resources in the preparation of irrigation projects from the start, obviating the need for later rehabilitation.

All relevant land characteristics must be considered

The FAO Framework indicates that it is necessary to evaluate land and not just soils. The suitability of soils for irrigated crops is useful information but it is inadequate for making decisions about land use development. Therefore all relevant land characteristics, including soils, climate, topography, water resources, vegetation, etc and also socio-economic conditions and infrastructure need to be considered.

The main objective of land evaluation for irrigated agriculture is to predict future conditions after development has taken place. It is necessary to forecast the benefits to farmers and the national economy, and whether these will be sustained without damage to the environment. Essentially, a classification of potential suitability is required which takes account of future interactions between soils, water, crops and economic, social and political conditions.

Land has permanent features but there are characteristics that can change

Some factors that affect land suitability are permanent and others are changeable at a cost. The costs of necessary improvements may be determined, so that economic and environmental consequences of development can be predicted. Typical examples of permanent features are temperature, soil texture, depth to bedrock, and macro topography. Changeable characteristics that may be altered deliberately or inadvertently, typically may include vegetation, salinity, depth to groundwater, micro relief, and some social and economic conditions (eg, land tenure, accessibility).

Land suitability must therefore be assessed and classified with respect to specified kinds of land use, ie, cropping, irrigation and management systems. It is obvious that the requirements of crops and irrigation and management methods differ, so the suitability of any land unit may be classed differently for various uses. It can be useless or misleading to indicate suitability for irrigated agriculture in general if the land developer needs to know about its potential for a specific irrigated crop or irrigation method.

Land suitability evaluation is essentially an economic concept

Land evaluation requires a comparison of the outputs obtained with the inputs needed to generate these outputs, on different kinds of land. In other words, land suitability evaluation is essentially an economic concept, although formal economic analysis may not be necessary for simple surveys. Assessment of physical factors alone does not permit prediction of the results of irrigation; they must be translated into economic terms. It is most important to achieve a land classification that reflects differences in the long-term productivity and profitability of the land under irrigation, rather than one that focuses only on physical differences without regard to their economic implications.

The evaluation must take account of the local physical, political, economic and social conditions. The success of irrigation when it is introduced may depend as much on factors such as pricing policies for crops, labour supply, markets, accessibility, land tenure, etc, as on climate and soils. To avoid any misunderstanding, all the factors that are relevant in the local situation should be explicitly stated rather than assumed. However, not all conditions need to be considered: only those that can usefully be taken into account.

Land suitability must be for sustained use and planning is interdisciplinary

The land suitability must be for sustained use, that is, permanently productive under the anticipated irrigation regime. Either there should be no land degradation anticipated, or the cost of prevention or remedial action to control erosion, waterlogging, salinisation should be included in the comparison of inputs and outputs.

It is evident that an interdisciplinary approach is required, because no one discipline can cover all aspects of land suitability evaluation. Land evaluation can be carried out using general economic considerations to establish a context for selecting appropriate crops and management, and to establish the criteria for boundaries between suitable and unsuitable land. To make a quantitative evaluation at project or farm level, however, requires formal analysis in financial and economic terms.

Finally, land evaluation is an iterative process leading to successive refinements, and the need for surveys and investigations that are appropriate in scale and intensity during the different stages, from reconnaissance to detailed project planning, and thereafter in successive phases of project implementation.

2.3.3 APPROPRIATE FEASIBILITY STUDY CONCEPTS FOR SMALL-SCALE FARMER IRRIGATION PROJECTS

2.3.3.1 Introduction

Small-scale farmer irrigation projects have diverse and distinctive characteristics that necessitate modifications to the conventional approach to feasibility studies. Chancellor and Hide (1997) have developed detailed guidelines based on their researches in Africa (including South Africa)

It is probably as a consequence of this in-depth research that this publication is the only one that has come to the attention of the team that can be unreservedly accepted for application in South Africa. The emphasis is on surface-irrigated, medium-sized schemes but the principles are applicable to small-scale farmer irrigation projects as a whole.

The key considerations of each section are summarised here but do not do justice to the in-depth discussions contained in the publication. It is therefore recommended that practitioners undertaking feasibility studies refer to the full publication as a working guide.

The publication concentrates on principles and practices. It is noteworthy that it avoids falling into the trap of being top-down and prescriptive. The relationship between pre-feasibility studies, feasibility studies and the design process is well set out and it is an excellent introduction to small-scale irrigation project development.

The guidelines are based on a collaborative development process between government, designers and farmers, which is already practised in the implementation of new farmer-managed schemes in Kenya and, to some extent, in Zimbabwe.

Governments can no longer provide extensive support to small schemes so commitment from farmers is needed to ensure that developments are sustained. It is therefore the responsibility of the Kenyan (and Zimbabwean) government to ensure that farmers are given a realistic understanding of the potential difficulties and drawbacks, as well as the benefits to be derived from a proposed development.

Farmers are expected to produce proposals for the operation and maintenance of the scheme. The preferred development process starts with a proposal by farmers to the government irrigation agency for assistance in developing or improving a scheme. The government functions in the role of a technical enabling agency, providing the necessary skills and know-how to ensure those feasible proposals become well-functioning schemes.

Farmers are expected to take out credit under easy-repayment terms and to contribute to the work in kind during implementation. In reality, it will take time for such a way of working to become established. Inexperienced farmers, or those who are not native to the area, may not have the necessary knowledge or understanding to formulate workable proposals so government staff will probably have to adopt a promoting role in the initial stages of a programme, with the intention of later reducing their commitment. (It will be noted that this is a very different milieu to the one in South Africa at the present time but that it is in line with what is proposed for the future.)

2.3.3.2 Smallholder Irrigation: Ways Forward (Chancellor and Hide, 1997)

The approach is practical and related to the field conditions encountered in Africa. Particular attention is given to discussing the depth of investigation appropriate to the circumstances.

The following list provides valuable insights into the role of feasibility studies in small-scale farmer irrigation project development.

Identifying resources

Once there is a basis for believing that a development is possible, it is necessary to make a systematic assessment of available resources to establish that the most basic elements for success are in place.

The following sections are considered in turn:

- Water
- Land and soil
- Labour and skills
- Capital and equipment
- Infrastructure

Emphasis needs to be placed on each aspect before deciding whether the proposal warrants further investigation.

Labour and skills

It is important for designers to investigate, and roughly quantify, issues of labour, including those related to gender, when reviewing the feasibility of proposals. Who will do cultivation, management and maintenance tasks and how they are motivated to find time for their jobs must be constant concerns?

Capital and equipment

Capital clearly encourages innovators to build on existing strengths. A farmer who has money in the bank or a large herd of cows can afford to take limited risks, whereas small farmers operate on very narrow margins that can mean the difference between success and failure.

Loans must be used to cultivate high-earning crops. Once a scheme is developed, farmers will also need funds to cover seasonal production costs

Confirming development potential

The focus is on the activities and support services associated with irrigated farming. It is aimed to summarise for planners the processes farmers must successfully master, so that they are in a position to make informed judgements about whether they are ready and able to take up irrigated farming.

Achieving sustainability

Conditions that support long-term success can be identified. Broadly speaking, issues that affect sustainability in smallholder schemes fall into one or more of the following categories.

- Water source/intake
- Design of the layout and delivery system
- Institutions, organisations and participation in management

- Agricultural and financial support
- Marketing

Summing up

a) Governments aiming to reduce their financial involvement in the irrigated agriculture sector in response to budget shortfall need to frame policies to encourage sustained smallholder development.

b) The success and long-term sustainability of new irrigation schemes can be improved if farming communities are involved in their identification, design and implementation. Farmers must invest resources and effort in the development.

c) The designer must identify and resolve social, economic and agronomic constraints to help ensure that a scheme which is technically sound will perform as intended. Conventional economic analyses aimed at establishing the viability of a project assume overall benefits will be sustained at a certain level over the lifetime of the project. However, to be successful, a scheme must return long-term financial benefits to individuals.

d) It is essential to ensure that land and water are available for more intensive development. Possible adverse environmental effects need to be identified and minimised by appropriate design.

e) Realistic judgements must be made about the way in which the scheme is to be operated and maintained. Small schemes are increasingly required to operate with very limited financial and technical help from governments. The design must therefore be suited to management by relatively untrained farmers.

f) Appropriate designs: Aspects of design that are apparently primarily technical in nature may be strongly influenced by socio-economic considerations. Farmers must be assisted to appreciate the implications in trade-offs between what they want and what is technically possible.

2.4 QUESTIONS FEASIBILITY STUDIES SHOULD ANSWER

All procedures and checklists targeted at specific situations will tend to be subjective and possibly incomplete. This is inevitable because, while principles can be reduced to generalities, specifics cannot. This section is based on the experience gained by the team in the course of participating in the rehabilitation of small-farmer irrigation schemes in the Northern Province of South Africa. (See also Appendix 2.A: Executive Summary Of A 'New Approach' Feasibility Study for a practical example of the application of the procedure.)

2.4.1 INTRODUCTION

Experience has shown that guidelines are necessary to facilitate the evaluation and reporting on the rehabilitation of small-scale farmer irrigation schemes. This is an unfamiliar field to most planners and consultants and many important aspects are overlooked at the planning phase. A checklist is therefore provided here to ensure that no important questions are left unasked. Many of these questions will remain unanswered initially but at least there will be an appreciation that answers must be sought. The writing of the evaluation reports is time-consuming and a computer platform has been developed as an easy to use but comprehensive pro-forma to enable quick capture and reporting where possible.

Section 2.4.2 below explains how to describe the scheme and the writer of the feasibility study plan is led by paragraph headings and suggested approaches. This section should be a simple narrative and can be regarded as a rapid pre-feasibility study to enable preliminary decision-making on the likely viability of the scheme. Information for this section should be just sufficient to decide whether or not it is warranted to engage the community in a participatory procedure that will inevitably raise expectations. Information for Section 2.4.2 can be gathered from literature and Rapid Rural Appraisal-type field investigations.

Sections 2.4.3 to 2.4.5 explain how to progressively cover the later planning and reporting phases and comprise a series of explanatory notes followed by questions. These sections have been incorporated in a computer program as discussed above. This is public domain and will be available free of charge from the Water Research Commission. Answers can be typed in immediately below each heading and will be classified by the author as positive, neutral, negative, 'don't know' or not applicable. These classifications are automatically transferred to summary tables at the end of the report for quick initial evaluation.

Section 2.4.3 explains how to cover key questions on the present situation that can be generated by the community through a combination of participatory approaches like Participatory Rural Appraisal (PRA) or Adendorff's pre-development survey (Adendorff, De Lange, Crosby, 1999).

Section 2.4.4 explains how to obtain detailed multi-disciplinary technical and institutional information required for assessing future development possibilities. This is best generated through a 'Sondeo'-type field investigation, where specialists of different disciplines together assess the resource potential, infrastructure, institutional and social factors, with an emphasis on generating possible scenarios in accordance with opportunities and constraints.

Section 2.4.5 explains how to address typical questions in the community's development plan and subsequent evaluation of progress towards the agreed goals. In the Adendorff procedure, the development plan is drafted based on the community information generated in the pre-development survey (see Section 2.4.3). This should be augmented by information generated in Section 2.4.4. The development plan is discussed, adapted and accepted in a community mass meeting within a month after the pre-development survey and forms the basis for the training and development initiatives.

This checklist is intended to be used for the assessment of potential projects by the officials and consultants of the provincial Irrigation Action Committees, which are joint committees of the departments involved in irrigation development and support. It is expected that the detail of the questions in Sections 2.4.2 to 2.4.5 below will be adapted with experience.

2.4.2 DESCRIPTION OF THE SCHEME

Note: *This applies to the pre-feasibility study. This is the document that would be required in the first instance by the Irrigation Action Committee. What is needed is a simple narrative, not a report or plan, but it should cover all the points that have been found to be important.*

If some information called for is not available, an indication should be given as to how this information can be obtained. If it is not possible to recreate historic data, state this. Data and information should not be included simply because it is available. The purpose of this scheme description is to give the reader an overall picture of the scheme and its situation. Detail is dealt with in later sections.

Method and approach: The information in this section stems from available literature and a scoping or Rapid Rural Appraisal-type field investigation. This approach avoids unnecessarily raising expectations before the preliminary indications of feasibility have been established.

2.4.2.1 Where is the scheme?

The way to find the scheme is best indicated by marking the route on a photocopy of a road plan.

2.4.2.2 Locality

It should normally be possible to locate the scheme with some degree of accuracy and to provide detail of the surroundings and the topography on a photocopy of a section of a 1:50 000 topographic map. The scheme should be outlined on this map.

2.4.2.3 Layout of the scheme

It is essential that there be some kind of plan of the scheme if the description is to be meaningful. If orthophotos are available, the scheme can be marked on these and explanatory notes can be either pasted or written on the photograph. This annotation method is very effective in presenting the basic principles to the reader. If orthophotos are not available, a sketch plan should be developed.

NOTES

Notes should augment the layout plan of the scheme as follows:

Water source

In addition to identifying the nature of the water source, river, canal, borehole, dam – give an indication as to whether there is an allocation from the Department of Water Affairs and Forestry etc, as well as the reliability of the supply in the various seasons.

Water supply

Provide an overall picture of the way in which the water is supplied. Whether it is pumped into a rising main and distributed by pipeline, or diverted into a canal, etc, at this stage, it is not necessary to go into details of design dimensions, etc.

Irrigation plots and methods

The size and arrangement of the irrigation plots and method of irrigation should briefly be described as well as an indication of the total area irrigated.

Residential areas

The size and location of residential areas are important in that the village may be directly associated with the irrigation development. If the farmers live on residential plots located at a considerable distance from the scheme itself management and control can become difficult. On the other hand the irrigation scheme may be adjacent to a large town that could have an influence on the scheme. This influence can be positive in that there could be a ready market for fresh produce as well as the availability of basic amenities but could be negative in that security may be a problem.

2.4.2.4 History and development

It is valuable to have an understanding as to how the scheme originated and was managed and the role that it played in the early years of its development and subsequently. The past shaped the present and can influence the future.

Date and circumstances of the founding of the scheme

Try and obtain information on when the scheme was established and the responsible organisations concerned. The land acquisition procedures and agreements reached with traditional authorities and participants may be important if the scheme is to be handed over to participants in the near future.

Development history

Outline the developments that have taken place up until the present time. This should include improvements in infrastructure and irrigation methods and extensions to the scheme. Unfortunately many schemes have deteriorated and the pattern of this decline should be documented.

Crop production history

Down the years major changes will have taken place. The changes should be identified and explained as they provide insights into the possibilities for future development.

Scheme 'ownership' and management

Virtually all schemes are located on communal land, in many cases the land was purchased specifically for the purposes of creating the scheme for a group or a tribe.

In some cases the land was trust land and management was undertaken by the Department of Bantu affairs with 'ownership' and responsibility for infrastructure and the provision of services. With the introduction of the homelands the responsibility was largely concentrated in the agricultural development parastatals. Later when the provincial departments of agriculture were established there was another shift in responsibility.

With the impending transfer of schemes to participants it is important that the past and present legal agreements and arrangements are established.

2.4.2.5 Present situation

In this initial description of the scheme it is not expected that the situation on the scheme be dealt with in detail. This will be a major part of the exercise if it is decided to progress further. What is required is a general impression of the situation and identification of those areas that require more detailed investigation.

General level of prosperity/poverty

Give an assessment as to whether or not the community is managing to keep head above water or if poverty prevails. Are there funds for farming inputs?

Sources of income

There are very few schemes where agriculture is the main source of income. It is quite usual for the community to be dependent on pensions, government salaries or wages earned by migrant labour. It is never easy to obtain hard statistics, but it is important to establish the relevant financial importance of farming and food security to the communities on the schemes.

Support services

These can range from mechanisation inputs and the supply of seed and fertiliser to the operation and maintenance of the scheme as a whole. What is the position?

Agricultural production levels

Most schemes are characterised by extremely low production levels and this is one of the reasons why sustainability has not been achieved. Provide estimates of present yields both for field crops and vegetables grown for own consumption and sale. The reasons for low yields should be discussed.

Land utilisation levels

The permission to occupy an irrigation plot provides a family with a degree of security and there is naturally reluctance to any changes that may lead to them losing this privilege. Unfortunately in many cases the plot occupiers either do not have the means or the will to utilise the land other than on a hobby-basis. Give an indication of who are farming and the intensity of land use.

Farmer attitudes, skills and experience

Farmer knowledge and ability in respect of crop production and irrigation can differ widely from one scheme to another and within schemes. What are the general strengths and weaknesses of scheme participants?

2.4.2.6 Infrastructure

The major concern when handing over the management and ownership of the scheme is infrastructure and its condition. Communities are reluctant to accept infrastructure that has deteriorated and needs considerable repair and upgrading to be effective.

Physical condition

Generally the infrastructure on the schemes will have been well constructed originally, but is in most cases in need of considerable repair. Give a summary of the present physical condition and what rehabilitation could entail

Management

The management of pump stations and supply canals is of great importance if the scheme is to be fully effective. In many cases this is deficient. What has not always been appreciated is that the design and layout of infrastructure may be such that it is practically unmanageable. Is this the case on this scheme?

2.4.2.7 *Potential for development*

As a general rule it can be accepted that irrigation farming can only be sustainable if good yields of crops are achieved. There may be circumstances when from the point of view of food security where water is readily and cheaply available that subsistence farming under irrigation can be tolerated. This implies that the potential for significant production must be there and this is dependent on the climate, soil, water and the general circumstances of the irrigation scheme. In the initial stages of evaluation this must be a matter for overall judgement using available clues. Ultimately in-depth investigations will be required.

Climate, soils and water

These factors will determine what is possible and what is not possible. Outline what appears to be possible. There is no point in quoting statistics and data that are not capable of simple interpretation and evaluation. Indicate sources of information.

Commercial farmer precedents

It is of value to identify commercial farmers in the area that farm under similar circumstances and to learn from their successes and failures. It is a plus factor if the scheme is located in an area where there is a successful pattern of farming and sufficient evidence to show that the results achieved there are transferable to the scheme itself.

Markets and potential markets

Marketing is a major hurdle for small farmers. Their products can lack quality and they may have difficulty in ensuring supply. Review the present status of marketing and realistic possibilities for the future.

2.4.2.8 *Future utilisation and development alternatives*

In the case of the rehabilitation of existing schemes there would appear to be four options.

1. Restore present infrastructure and layout;
2. Improve and/or modify the existing infrastructure and possible the layout;
3. Down-size the scheme possible to food plot level; and
4. Abandon all irrigation attempts on the scheme.

Restore present infrastructure

This has tended to be the approach in the past, but is must be recognised that as virtually none of the schemes were successful and it is unlikely that this will be enough. Should this, however, be the way to go explain why.

Improve and/or modify infrastructure

Modifications can vary from being relatively minor to major changes in the whole layout and design of the irrigation system. The dominant factor is likely to be management both of the main canal and of water at farmer-level. In addition the elimination of large pumping units requires serious consideration. Outline the suggested changes.

'Downsize' scheme

There can be many reasons for this being a viable option. One is that there is just no longer adequate water available but there may still be a case for concentration on food plots.

2.4.2.9 *Time frame of development*

Development needs to be evolutionary and should be in-step with the provision of other services and the overall development of the farmers and their markets. The desirable stages of development of the scheme over time should be discussed.

2.4.2.10 Role of the scheme in region and province

The scheme should not be seen in isolation and nor should the assumption be made that it is only the people who presently have the right to occupy the irrigation plots, that should be concerned in the future. The community as a whole should be directly involved in the project in order to obtain general support for development. If the scheme is seen to be an island of prosperity in a sea of poverty, the implications are obvious. Explain how the community as a whole can benefit from the re-development of the project.

2.4.3 KEY QUESTIONS ON THE PRESENT SITUATION

Note: This is the second phase, the feasibility study, once clearance has been given to continue to the next stage.

2.4.3.1 Plan of scheme and contact addresses

Indicate the origin(s) of the plan, eg, original design drawings, aerial photographs, mosaic, orthophoto, GPS, physical survey, etc:

Schedule 2-1: Information Incorporated in the Scheme Plan

(Tick the applicable blocks)

ITEM	Reliable	Estimated	Approximate	N/A
Scheme boundaries			o	
Scheme area			o	
Plot/Farm layouts		o		
Plot/Farm areas		o		
Location of residences			o	
Water source	o			
Canal head works	o			
Pump houses	o			
Supply canals/pipelines		o		
Balancing dams				o
Farm supply systems			o	
Measuring weirs/meters				o
Roads			o	
Cropped areas		o		
Areas requiring drainage				o
Contours/spot heights			o	

Are there plans to achieve greater accuracy or more detail? Yes No

If yes, what is planned?

The plan must be supported by a list of the names, positions, organisations and addresses of the people that have provided information for the report. It is assumed that these will include some or all of the following:

- Provincial DOA representatives at Head Offices, Regional and sub-regional offices.
- Representatives of DWAF located at the provincial office.
- The chief or chiefs with jurisdiction in the area.
- The chairman of the appropriate civil authorities in the area.
- DOA extension officers serving the area.

- Chairpersons of farmer committees and organisations etc
- NGOs
- Commercial organisations
- Concerned individuals

2.4.3.2 *Present ownership and management*

- Who 'owns' and finances the scheme?
- Who manages the scheme?
- Who grants permission to occupy?
- Are there specific and follow-up requirements?
- What charges and levies do the farmers pay?
- Who decides how much and to whom?
- Number, rank and duties of employees.
- What services do they provide?
- What part do farmers play in scheme management?
- What committees are there?
- Are they effective?
- What percentage of the area is actively cultivated?
- What is the general status of service?
- Are the farmers assisted with credit?
- Are farmers assisted with acquiring inputs?

Production – field crops

- Is their concentration on specific crops?
- What are the main crops and the area of each cultivated?
- What is the size of the average land and how many farmers are producing field crops?
- Are plots farmed as a unit or in sub-plots?
- Is there evidence of accepted, crop rotations?
- Is there evidence of fertilisers/manure use?
- Is there evidence of herbicide/insecticide use?
- Are seeds and seedlings purchased?
- Who decides on crops to be produced?
- Who advises on production techniques?
- How are surpluses marketed?
- How do yields compare with commercial practice in the area?
- If poorly, what are obvious constraints?
- Is there evidence that production was better (or worse) in the past?
- Do the farmers have knowledge and experience of crop farming?

Production – horticultural crops

- Are there farmers that concentrate on vegetable crops?
- What area is typical for an average farmer?

- Main winter crops
- Main summer crops
- What proportion is for household use?
- What proportion is for local sale?
- What proportion is for market sale?
- How do yields and quality compare with commercial practice in the area?
- Is there interaction with field crop production?
- Do the farmers practice some form of rotation?
- Are there obvious constraints to production?

2.4.3.3 *Agricultural potential*

- Is the scheme located in an area of established climatic potential or an area with well-known climatic constraints?
- If not, how does it compare with areas that could be similar?
- What are the rainfall characteristics?
- What are the temperature and frost characteristics and are they significant?
- Have the soils been identified and production potential established?
- Do the soils have physical and fertility characteristics that require correction?
- Are there indicators that there are factors that could have restricted production potential in the past?
- Have you established where you can obtain information on managing the soils and crops?

2.4.3.4 *Water requirements and supply- (flood irrigation)*

- What method/methods of irrigation are being used? (Furrow, beds, short furrow etc)
- Have you been able to establish present practices and how much water is being applied to the crops?
- If yes, please complete the following schedule:

Schedule 2-2: Water Applied to Crops

CROP	WINTER		SUMMER		FLOW RATE TO FIELD (m^3/h)
	Planned	Actual	Planned	Actual	

- If the water is being supplied from a canal sketch the layout and explain the operating system.
  - Operating hours weekly and daily.
  - Role of balancing and night dams.
  - Do block receive water on a continuous or rotational basis.
- How many farmers are served by each secondary canal at one time?
- Are there water bailiffs and how do they ensure equitable distribution?

- What measures are there for fair distribution in times of low flows?

2.4.3.5 *Water requirements and supply- (pressure irrigation)*

- What irrigation systems are being used? (Portable pipe, sprinklers, dragline, hop-a-long, micro, drip etc)
- Have you been able to establish present practices and how much water is being applied to the crops?
- If yes, please complete the schedule below.

Schedule 2-3: Estimated weekly irrigation application mm

CROP	WINTER		SUMMER		FLOW RATE TO FIELD (m^3/h)
	Planned	Actual	Planned	Actual	

- Sketch the layout of water source-pumps mains, farm supply laterals, etc, with flow rates and pipe sizes where possible and explain the operating system.
  - Operating hours weekly and daily.
  - 'Ownership' of equipment.
  - Pump station operation and management.
  - Equity in supply volumes and pressures.
  - Scheduling/programming.

2.4.3.6 *Scheme water resources*

- Outline the history of the water resources – origin, catchment development, works, etc, deterioration/improvement.
- Has the status of water supply been checked out with DWAF via the IAC?
- What was the original status of water rights?
- Were these amended?
- What are the implications of the new Act?
- How will the scheme figure in the establishment of WUAs in the area?
- Will the scheme have a legal right to water and what are the possibilities for allocations or licences?
- Is this a water-short catchment?
- Have realistic crop water requirements been estimated?
- Will water shortages have an adverse impact on potential production?
- Is water quality, both above and below the scheme, satisfactory?
- Are there signs of poor drainage, seepage, high water tables, and salinisation on and below the scheme?
- Is the scheme protected against floods?

2.4.3.7 *Condition of infrastructure*

- Are the intake works to canals and pumping stations effective or are they silted up or damaged? What are the main problems?

- What is the general condition of canals both lined and unlined?
- Are there obvious signs of leakage and seepage?
- Are the take-offs to secondary canals (long weirs/sluices) undamaged and effective?
- Are the balancing/night dam take-off and discharge valves satisfactory?
- What is the condition of the dams?
- Are canals regularly cleaned and verge vegetation controlled? Who does this?
- What is the condition of contour drains, berms, overpasses and roads?
- Are pump houses operational – what is the condition of pumps, motors and engines?

2.4.3.8 Irrigation practices – (flood irrigation)

- What irrigation methods and procedures are followed by the farmers? Annotated sketches would be helpful.
- What system is used – beds, long furrows, basins, short-furrows, etc?
- Is the land reasonably level and uniform?
- Is the water turned into one furrow only or several furrows? What flow-rate is used?
- Do the farmers guide or dam the stream to get reasonable distribution?
- Are short furrows managed effectively?
- Are the farmers aware of irrigation techniques – quantities, uniform distribution etc?
- Information on flow rates, losses, distribution uniformity, stream strengths etc is useful.
- How do the farmers make furrows, beds etc and what difficulties do they experience?

2.4.3.9 Irrigation practices –(pressure irrigation)

- What irrigation system(s) and procedures are used? Annotated sketches would be helpful.
- Is information available on stand times, application rates, working hours, pressures and sprinkler spacings?
- Who decides on when and how much to irrigate?
- Do the farmers understand the irrigation method they are using and how to manage it?
- Is the system maintained and are leaks and sprinkler malfunctions repaired?
- Are the systems communal or farmer owned and/or operated?
- How many farmers are served by each pump station and how is water allocated to farmers?
- Are there indications of crusting, run-off or over-irrigation?

2.4.3.10 Support services

- Shortages of funds have lead to severe cutbacks in support services. In analysing schemes it is important to assess the position both before and after recent cutbacks. Is this true of this scheme?
- Who manages and who funds Operation and Maintenance on the scheme?
- Are there Water Bailiffs and who pays them?
- Are circumstances such that it is possible for them to organise equitable distribution of adequate water supplies?
- Are there adequate mechanisation services ensuring timely operations (particularly planting) and who provides these services?
- Where can seed, fertiliser and chemicals be purchased at fair prices and who advises the farmer on selection and use?

- Are farmers aware of credit sources and procedures? Do they make use of credit?

2.4.3.11 Marketing

It is appreciated that marketing is a complex subject. The produce used for home consumption is a substitute for outside purchases and should be priced as such.

- Is production for home consumption important – products and volumes?
- What are the main 'bulk products' sold through agents (eg, maize, wheat and cotton) and are the farmers satisfied with the returns?
- Vegetables such as tomatoes, onions, potatoes and green mealies are widely marketed although transport can be a problem. What is the present situation on the scheme?
- Staple vegetables such as cabbages, beetroot and various spinaches are often important locally. What is the position on the scheme?
- There are specialist products that serve niche markets. Are any being produced on this scheme?
- Fruit, particularly bananas, can be important, are they presently a factor?

2.4.3.12 The scheme in relation to residential areas

- How is the scheme positioned relative to where people are living? There are a number of possibilities.
  - The scheme may fringe on a large residential area with a non-agricultural population.
- There are other possibilities. The scheme cannot be seen in isolation, however, and it is necessary to establish the characteristics of the scheme relative to the residential areas.
- Sketch and explain with annotations the location and characteristics of the residential and urban areas.

2.4.3.13 Poverty and prosperity

- Are there indications that participants and their families are living below the poverty line?
- Alternatively, does the situation appear to be satisfactory?
- Is this due to farming activities?
- Is the population based on old people with a civil pension, families of migrant workers, civil servants 'part timing' or on people dependent on farming?
- Do the scheme participants appear to be better off than non-farming community members?
- How important is production for own use?
- Are participants in a position to risk cash on farming?
- Are there reasonable amenities in the neighbourhood?

2.4.3.14 Tenancy, land utilisation and labour

- Have you clarity on the basis on which scheme recipients have RTO? If yes, describe.
- Is there evidence of sub-letting of plots or parts of plots?
- Is there evidence of sharecropping?
- Does a communal organisation such as church or women's clubs have access to land?
- To what extent is the land being actively farmed?
- Do you gather the impression that some of the plots are being 'hobby' farmed?
- If the scheme is under utilised, why is this the case?
- On what grounds can RTO be withdrawn?

- Is this a conventional 'government' scheme or is it privately owned?
- What is the relationship between the person working the land and the person that holds the RTO: wife or other relation or labourer?
- Is additional labour hired to supplement the family, is this a significant job creator?

2.4.3.15 Security

- Theft a problem?
- Vandalism common?
- Attitude of community members not participating in the scheme?

2.4.3.16 Dependency

- Do the participants have a long list of complaints that indicate dependency on official services?
  - Inadequate tractor and implement availability.
  - Tractor drivers' not coming when requested
  - Delays in equipment maintenance and repair.
  - Water shortages due to broken down pumps and silted canals.
  - Crops destroyed by livestock because fences are not repaired.
  - Difficulty in getting seed, fertiliser and chemicals.
  - No funds or credit to fund production.
  - Lack of technical knowledge.
  - A lack of communication with the technical personnel from the managing organisation.
- If there is dependency how much of this results from not being allowed to interfere with the scheme's operation or maintenance?
- What impact will dependency have on 'privatisation'?
- Are there indications that the participants show initiative and willingness to accept responsibility?

2.4.3.17 Present financial and economic contribution of the scheme

- Does the scheme contribute to the well being of participants?
- Is the scheme a significant factor in the day-to-day activities of the community as a whole?
- Are a significant number of work opportunities dependent on the scheme?

2.4.4 KEY QUESTIONS ON FUTURE DEVELOPMENT

Note: *An evaluation of the present situation justifies the next step, an in-depth assessment of the possibilities for development.*

2.4.4.1 Potential if full 'commercial' production can be attained

It is difficult to predict the pattern of future development. We know the present position and in South Africa usually know what can be achieved by established experienced commercial farmers under similar conditions. It is fair to assume that at some time in the future the rehabilitated and privately managed scheme will be in a position to attain at least the same level of productivity as is presently achieved by commercial farmers. What remain to be answered in a changing world is how long this will take and what the eventual products will be. Irrigation is an intensive form of farming and it costs money. It can only be sustainable if yield levels are such that it is possible to pay for water, equipment and inputs.

- What are the products being produced commercially under similar circumstances?

- What are the crop rotational patterns?
- Yield levels?
- Gross margins and turnovers?
- Total value of production?
- Can you identify additional opportunities?
- Do you regard this possible level of production as being significant in the context of development in the region?

2.4.4.2 *Climatic constraints*

Climate is important in determining the crops that can be grown with acceptable risk. In the frost-free lowveld subtropical fruits thrive and vegetables can be grown 'out of season'. Export table grapes are produced in the arid Northern Cape and the absence of rain is a plus factor. A few degrees can make a major difference to a cotton crop. Wheat yields are enhanced by very cold winters. There are many other examples of the impact of climate on crop production.

- Has the climate, and microclimate, been assessed in order to identify possible crops?
- Are there farming activities in the area that provide precedents?
- Possibly despite there's being water and suitable soils the climate may inhibit sustainable development?
- Is rainfall a significant positive or negative factor under irrigation?
- What about hail?

2.4.4.3 *Soil and fertility constraints*

Soils and their management are vital factors in the success of an irrigation scheme. This is particularly important in the case of rehabilitation projects where the soils have been irrigated for many years because 'soils have a memory'. In many cases, the farmers are crippled at the outset as a result of soil problems and, unless these are corrected, failure will be inevitable.

- Have the soils been sampled, analysed and their physical limitations identified?
- Depth?
- Water holding capacity?
- Tendency to crust?
- Tendency to compact?
- Ease of working?
- Chemical composition
- pH?
- Salinity?
- Calcium and magnesium status?
- Fertiliser requirements?
- Liming?
- Fertility and salinity management?
- Nematodes?
- Soil borne diseases?

2.4.4.4 *Water constraints*

Insufficient or unreliable water supply is the common complaint. This may be due to inadequate attention to hydrology in the past or to changes in the catchments. It goes without saying that the Water Act (1998) that has drastically changed the approach to water management will have a major impact. The source of the problem may be nearer home in the form of broken down pumps and silted up and leaking canal systems.

- Have the crop irrigation requirements, both summer and winter, been realistically estimated?
- Has it been confirmed that sufficient water will be available?
- What is the status of water quality?
- What is the position with regard to the formation of WUAs and how will this influence the scheme in the future?
- Should there be inadequate water to meet apparent needs, what will be the impact on the scheme?
- What conveyance irrigation efficiencies have been assumed?
- What actions to improve water use efficiency have been considered?
- Has allowance been made for the availability of water when identifying potential cropping strategies?

2.4.4.5 Water supply and irrigation management

The blind reinstatement or repair of infrastructure and the unchallenged acceptance of existing irrigation methods should be regarded with suspicion if only because the schemes failed in the past. At the same time if scheme participants have developed workable approaches change for the sake of change should be avoided. It is important to assess if water supply and in-field irrigation systems are 'management friendly'.

- Has the canal or pump station/pipe line sufficient capacity to meet the requirements of the irrigated area?
- Has it been possible to quantify these capacities?
- In the case of canals is the design for continuous or rotational flow?
- Is provision made for the division of water to blocks at times of low flow?
- How many farmers are served by secondary and tertiary canals?
- How will equitable distribution of water be managed?
- Are canals lined, if not, what are the estimated losses?
- In the case of pumping schemes is provision made for varying demand?
- Is the design such that reasonably uniform pressures are attained for all users?
- Will a pump attendant be able to cope with the demands made on him?
- What about maintenance, will it be possible given the circumstances?

2.4.4.6 Selection of irrigation method

The two most commonly used satisfactory methods are short furrow flood irrigation and sprinkler irrigation utilising dragline or portable laterals. It can be anticipated that ultimately, when production has attained profitable levels, the most appropriate irrigation systems available will be preferred. This is, however, an evolutionary process.

- How effective is the present irrigation method used by the farmers?
- Can it be improved and applied for the initial development phase?
- What are the main constraints that will have to be addressed?
- Are some of the farmers utilising other methods that should receive attention?
- What are methods that should be assessed on a pilot basis for the interim development phase?
- Are there particular reasons for these recommendations?

- In the light of present irrigation technology what would be the most suitable methods once full development and production becomes the objective?

2.4.4.7 People/institutional constraints

People/institutional constraints and how they are managed are the keys to future development. There are probably as many approaches and combinations of approaches as there are schemes. Standardisation is not possible. No matter what the final organisation that is envisaged, there will have to be a 'board of directors' who take full responsibility for the operation of the scheme. This committee must be truly representative of all concerned with the scheme and the governance of the community. There need to be checks and balances to prevent the management being taken over by the politically or economically powerful and consequently the structure should develop on an evolutionary basis in phase with scheme development.

There are two groups of issues. Firstly the day-to-day management and physical maintenance and development of the scheme and secondly the effective mobilisation of all the many support services required by the community. Unless effective planning and implementation can be achieved this organisation of people can be an overwhelming constraint to further development. Essentially this has been the major stumbling block in the past.

- Can the present situation be extended/modified to cater for the initial phase of development?
- Are there signs of stress or ineffectiveness?
- Do individuals or groups dominate management?
- What role can still be play by 'official' institutions?
- What role is there for the tribal institutions?
- Are their relationships with commercial farmers and/or private sector concerns that can be extended?

2.4.4.8 Marketing constraints

Marketing is a vital factor to successful development. Small-scale farmer irrigation schemes should be able to serve their own immediate hinterland and local communities should be involved in the distribution and retailing of the produce. The degree of organisation and formal structures that are required to achieve this will vary greatly from one area to another. Another possibility is the co-operative transport and marketing of produce through conventional marketing channels such as regional markets, but this requires a very considerable degree of sophistication not only in production but also in packaging and marketing. Another alternative is formation of a linkage with existing processors, packages or marketers of general commodities. This could be through a citrus pack house, a canned fruit of vegetable installation or a sugar mill. This is an attractive alternative but may impinge on farmer independence. In the past there was major concentration on commodities such as grains or cotton that were marketed through co-operatives. A problem here was standardisation on production across the whole scheme.

- Has the possibility of providing for the fresh produce needs of local communities been assessed?
- If this exists can it be extended?
- What would be the future potential?
- What would be the impact on the 'bakkies' trade and 'spazas'?
- Has the potential for marketing in competition with other producers been assessed?
- Have organisations that can assist/participate been identified?
- Has the potential for co-operation with commodity groups been assessed?
- Are there niche markets or specialised products that have potential?

2.4.4.9 Financial constraints

Money is a paramount factor in every stage of development. This ranges from the capital required to rehabilitate infrastructure, the provision of in-field irrigation facilities, the expenditure on operation and maintenance, financing management and operational personnel, and providing and stocking input materials and last but by no means least, the provision and management of production credit. Unfortunately funding is very often provided on a one-off basis with very definite restrictions on the period in which expenditure must take place. This is counter to the concept of evolutionary development.

- Have sources of finance been identified and evaluated?
- Infrastructure development?
- In-field irrigation development?
- Production credit?
- Support services?
- Management costs?
- Routine O & M?
- Advisory services?

2.4.4.10 Technological constraints

Technology must in all respects be appropriate. It is usually a relatively simple matter to identify the most efficient ways of undertaking any of the tasks involved in an irrigation scheme. What is far more difficult is accessing what method or strategy is likely to be the most appropriate at any point in time. Both internal and external circumstances can have a major impact on the way in which this development takes place. The situation is a dynamic one. It is dependant on the product being produced, the rate of development of technological skills by participants, the relative costs of alternative inputs, and the support of outside organisations and cash flow.

- Has consideration been given to phased applicable appropriate technology?
- Water supply infrastructure?
- Irrigation methods?
- Crop production?
- What training initiatives will be required?
- What technical support facilities will have to be provided?

2.4.4.11 Realistic target level for actual development

Each scheme will have perceived final development levels that can range from intensive all the year round vegetable production to a series of food plots designed to cater for the communities in the immediate vicinity. Alternatively the objective may be the creation of a citrus estate associated with a pack-house system, etc

- Describe what is envisaged for the fully developed scheme.

2.4.4.12 Time frame for realistic phased development

One of the difficulties in irrigation scheme development in the past was that the planning was done on the basis of a number of selected crops or enterprises and the infrastructure was designed accordingly within the limits of donor or other funding. The scheme was then handed over to participants to 'get on with it'. History has shown that this approach does not work. Planning and implementation should take place in achievable 'bite-size' phases with due consideration being given at each stage for the possible next stage of development. It is important that funds be made available in a way that makes staged development feasible.

Outline the envisaged stages of phased development.

- Is a time frame for development available, provide a broad outline?

2.4.5 KEY QUESTIONS ON THE DEVELOPMENT PLAN

Note: *Before final approval can be given for development further checks are required to ensure that key aspects are not overlooked.*

2.4.5.1 Progress towards transfer of 'ownership'

It is policy to transfer schemes from government to the participants or to organisations that promote the requirement of previously disadvantaged farmers. The procedures to be adopted for the hand-over are still in the process of development and this is a complicating factor. The intention is, as far as is known, that the irrigation action committees in each province will co-ordinate the process. It is not always clear as to exactly who owns a particular scheme and obviously the conditions of transfer will depend on this and on any agreements that were reached in the early stages of the establishment of the scheme.

- Has it been possible to ascertain the procedure to be followed in order to transfer the scheme to the participants?
- Has contact been established with the provincial Irrigation Action Committee?
- What are the perceptions of the tribal authorities and the community in respect of the proposed 'hand over'?
- Has attention been given to the legal aspects of the original establishment of the scheme in respect of land and infrastructure?
- Have discussions taken place on the terms of transfer?

2.4.5.2 Progressive upgrading of infrastructure

Where possible the upgrading of infrastructure should be undertaken on an evolutionary basis. It is only in this way that the participants can make a realistic contribution to the pattern of development and so obviating the problem of inappropriate technology. Technology can be inappropriate in both absolute terms and relative terms. Technology that is appropriate after say ten years, will very likely be considerably different to what is appropriate for the rapid development phases of the first two to three years at the outset of the rehabilitation program. It is necessary to give considerable thought to the phasing of infrastructure development.

- Has an evaluation been made of the immediate infrastructure upgrading necessary to stabilise present farming activities and to enable training to be undertaken?
- What are the technological innovations that have been considered in the near future?
- Who will be responsible for design?
- Project management?
- Construction?
- Will labour intensive methods be followed?
- Have scheme participants been exposed to these ideas?
- What has been their reaction?
- Is there a clear picture of the technological progress that appears to be desirable and of the ultimate technology that will be applied?
- Has attention been given to the cost of staged development that may require the replacement of rehabilitated infrastructure in a comparatively short period?
- What would be the consequences if 'final' infrastructure were completed in the next financial year?

2.4.5.3 Training for management and scheme participants

Training is an essential facet of rehabilitation and consequent development. Training at all levels needs to be hands-on and practical. Farmers need to develop the necessary skills to ensure peak production and good water management. Experience has shown that if the training is handled in an appropriate fashion, even illiterate farmers can develop rapidly. The committees responsible for management require training in the same skills as the farmers but in addition in water management, the maintenance and operation of the irrigation systems and the provision of the essential facilities.

Training dare not be stereotyped or 'book-based' and is a major challenge.

- Has a training programme for participants been developed?
- Does it cover both crop production and appropriate irrigation techniques?
- Is it based on interest groups?
- Describe the planned training.
- Who will be responsible for the training?
- Will extension officers be directly involved?
- Will the training include the formation and activities of committees?
- Has a training programme been developed for the 'board of directors' and the scheme manager?
- Describe the planned programme.
- Who will be responsible?

2.4.5.4 *Training groups and management structures*

In any community there will be a limited number of people who have the desire to succeed and immediately grasp the importance of training. These are the people that should be targeted initially and preferable they should form themselves into groups of 20 to 30 individuals. Training should ideally be on request and the group should work together throughout the first season or two, when this training is applied in practice. The group will elect a committee who will facilitate the process and part of the training will be on how such a committee should operate. A number of small enthusiastic groups of this nature should form the nucleus of the governance and management of the scheme in the future. The management committee should be elected from the ranks of these committees so that they are truly representative.

- Have comprehensive plans been made for identifying potential training groups and participants and leaders?
- Have discussions been held to establish the perceived needs of the potential participants?
- Have current production practices been analysed in detail and the reasons for low or above average yields established?
- Is there clarity on training content and methods of presentation?
- Will on-going support and follow-up be possible?
- Who will undertake this task?
- To what extent will the extension and research personnel of the departments of agriculture be involved?
- And the private sector?
- And the ARC?
- The future management will require extensive training and capacity building, is this spelled out?

2.4.5.5 *Management committee (board of directors)*

A management committee truly representative of those with an interest in the scheme is essential. An appointed manager best undertakes day-to-day management. It must go further than this; however, because a typical irrigation scheme sited in a deep rural area can only be successful if all the essentials are in place. The essential functions over and above the strictly irrigation aspects include the preparation of lands and fertilising and planting timeously, the availability of inputs such as fertiliser, seed and chemicals, the availability of production credit and major support of marketing.

- Is there clarity on the composition and functions of the 'board'?

- Will it be possible to elect the members so that they are accepted as being truly representative of the participants and the community as a whole?
- What about abuse of power, and leadership?
- Has thought been given to the process of empowering management?
- Who will act as scheme manager until a permanent appointment can be made?
- Has thought been given to where a suitable manager can be found?

2.4.5.6 Support forum/service providers

The task facing the management committee, the manager and the consultants supporting them is a difficult one. It is virtually impossible for this to be undertaken solely as an in-house operation. External support is essential. In South Africa there are many individuals and organisations that can assist and that want to assist. These range from individual farmers and co-operatives to the Land Bank and commercial organisations providing equipment, input and associated advice. This support forum can play an important role from the very initiation of the rehabilitation process and should be active advisors throughout the planning process. They can give sound technical advice, based on experience built up over many years of operating under the same conditions as exist on the scheme. The actual methods adopted by the participants themselves may differ, but even here the experienced advice can greatly facilitate the process. It is desirable that participants in this group work as a unit and not just as individuals. If at all possible the full group should meet regularly, say three of four times a year in order to assist with the development of policy and to ensure co-ordination in their advisory actions.

- Has a list been compiled of potential forum members and their fields of expertise?
- Have members of the 'board' made contact with these people and organisations?
- Has it been possible to create a support forum that can come together for integrated planning three or four times a year?
- Has the forum played a part in the rehabilitation planning process?
- What about inputs into planning and implementing training?
- Has attention been given to conflict resolution and harmonious water management?

2.4.5.7 Privatised and integrated extension

The role of extension officers on many of the schemes has been that of the manager, with responsibility of the operation and maintenance of the scheme in addition to advising the farmers. It could well happen that when hand-over takes place that some of these extension officers would transfer to the irrigation scheme itself. For a considerable period now in South Africa, a great deal of the technical extension work has been undertaken by the private sector or by commodity groups. Both can be of great value to the developing rehabilitated irrigation schemes, in conjunction with the provision of inputs and other services.

- How will technical support be provided to participants and management on an on-going basis?
- What will be the relationship to the support forum?
- Is it envisaged that the provincial department of agriculture will be actively involved in the future?
- What administrative linkages will be required?
- How will these inputs be financed?
- Who will be responsible for training extension personnel?

2.4.5.8 WUAs and CMAs

It appears that Water User Associations will be an essential element in the subsidisation of infrastructure for the schemes from DWAF and could play an important part in legalising the management structures for a scheme. CMAs will be a body that negotiates water allocations and will co-ordinate the requirements of each of the sectors. It is important that the management committee, and possibly the advisory forum, be well in the picture as to how Water User Associations are formed and the procedures that have to be followed. These are still in the process of being formulated but undoubtedly this will be the way in which development is going to go in the future.

- Is their clarity on the procedures to be followed in establishing a WUA?
- Has this process commenced?
- Are all concerned fully informed?
- How far has the formation of a CMA advanced?
- Has the issue of WUA representation been finalised?
- Have water allocations been finalised?

2.4.5.9 Land use and tenure

There is a natural tendency for scheme participants, (RTOs), to want to 'own the land'. Their right to occupy communal land is reasonably secure but falls short of permanent tenure and does not provide collateral for loans. Numerous options are being explored that can give the farmers 'body corporate' status such as trusts, CPAs and WUAs. There is a case to open up land that is not being fully utilised for development by landless community members. There are a number of approaches possible, ranging from share cropping and leasing to agreements with community groups. This can be a sensitive issue. It is probable that the way in which the land is utilised and occupied will, like the scheme itself, be evolutionary. The more active farmers who want to increase their holdings and their production should be able to extend their activities provided this is not to the detriment of others.

- What measures have been taken to achieve 'body corporate' status for the scheme?
- What are the established 'rules of the game' in respect of land occupancy?
- Has there been co-operation with concerned government departments?
- Have satisfactory arrangements been made for the future?
- Have the local community been fully consulted?

2.4.5.10 Economic and financial issues

To be sustainable a rehabilitated scheme will have to pay for itself. The days of subsidisation are over. DWAF subsidise for the development or redevelopment of infrastructure. There are other funding sources such as Land Care that may facilitate the establishment of the on-farm facilities required and there are Land Bank and commercial bank loans. The normal operational costs of maintenance and operation of the scheme and the running of the farms themselves as well as the provision of inputs and services will have to be self sustaining in the future. Development will have to be evolutionary and cash flows carefully planned. It goes without saying that the scheme should be an economic asset to the community, the region and the province.

- What financial arrangements have been made for the immediate future?
- Are these considered satisfactory?
- Have future requirements been assured?
- Have the costs of operating the scheme been estimated?
- Have cash flow and sensitivity analyses been undertaken to assess scheme sustainability?
- Are all concerned fully informed on the financial implications of proposals?

2.5 GENERAL CONCLUSIONS AND RECOMMENDATIONS

The major changes in the circumstances surrounding the development of small-scale farmer irrigation projects means that drastically modified approaches to both pre-feasibility and feasibility studies be incorporated in planning and evaluation procedures.

The emphasis in extension and development on participatory approaches, and the stated policy of government to progressively reduce the culture of dependency, is two major influences.

Officials and consultants with responsibilities in this field require reorientation and it is recommended that this process be initiated through a symposium that can combine the dissemination of available information and the planning of future training and/or briefing actions.

APPENDIX 2.A. EXECUTIVE SUMMARY OF A 'NEW APPROACH' FEASIBILITY STUDY

Note: The following Executive Summary of the report (ARC-ILI, 1999) on the Dingleydale/New Forest irrigation schemes 1999), provides an example of the suggested feasibility study approach.

OVERVIEW OF THE PRESENT SITUATION

The schemes, Dingleydale and New Forest, proved to be larger and more complex than anticipated. In comparison with other schemes in the communal land tenure areas in the Northern Province they make a favourable impression. There is not the same deterioration and poverty. The participants are less dependent and despite setbacks in recent years, a significant percentage of the plots are being farmed and are productive.

It is probably not fully appreciated that these schemes, larger than 2 000 ha, are amongst the largest in the Northern Province, being similar in area to the Arabie dam irrigated area of the Olifants River and Tshiombo. They are furthermore very close to towns and villages with limited job opportunities and a large component of migrant labour. The area could easily deteriorate into a rural slum with serious consequences to the environment downstream. In addition, the Sabi-sand nature reserve areas are nearby. An overall assessment of the potential of the scheme was formulated by a member of the team:

If the natural resources aspects of the Dingleydale and New Forest irrigated areas are considered from an opportunities and constraints viewpoint, the following are to be noted:

Opportunities:

- A frost free, sub-tropic, sub-humid climate offers the opportunity of out of season crop production if water is available. Areas with similar climate (Crocodile and Komati valleys towards Komatipoort (The Onderberg), Middle and Groot Letaba valleys, Levubu, Blyde River) make extremely important contributions to the supply of fresh produce during the winter months.
- The soils are generally of good quality, particularly as regards their physical properties. The combination of ideal climate and relatively good soils is not at all common. The soils are better than most in the Onderberg, Blyde River and large parts of the Letaba valleys.
- The schemes are free of the salinity and sodicity problems that plague schemes situated in climatically dryer areas.
- A moderate summer rainfall (mean annual rainfall slightly below 700 mm) and above average cloud cover, causes irrigation water applications to be relatively low during the summer months in comparison to schemes located in dryer areas of the lowveld. Water is thus used relatively efficiently.
- A fairly high level of infrastructure is in place. The schemes are well designed.

Constraints:

- Competition between agriculture and the environment for limited water.
- Moderate acidity and relatively low natural fertility of the soils, due to sandy textures.
- Nematode infestations.

This is relatively easily correctable through training and judicious use of fertilisers and lime.

From a natural resources perspective, the opportunities are perceived to clearly outweigh the constraints.

Regarded from a national perspective, the schemes are relatively favourably situated for allocated water to be used sustainably, economically and productively.

The circumstances of the plot holders on the scheme is, however, very different to that of the commercial farmers in the highly developed Nelspruit and Malelane areas. They occupy smallholdings, and have a lack of knowledge, resources, finances and security. The development of a viable sustainable scheme will not be easy, and will take time.

THE SCHEMES - GENERAL OVERVIEW

The Dingleydale/New Forest Irrigation Scheme lies in the Northern Province immediately below and to the east of the Drakensberg range. The Dingleydale Irrigation Scheme was located in the former Lebowa homeland and the New Forest Irrigation Scheme in the former Gazankulu now forming part of the Northern Province.

The scheme is bordered by the Tlulandziteka River on the northern side, the Mutlumuvi River on the southern side and Thulamahashe town on the eastern side.

The area has a warm, frost-free climate with a mean annual rainfall of 690 mm and mean summer and winter temperatures of 24,9° C and 16,5° C respectively.

Road access to the study area is primarily by means of a tar road from the Bushbuckridge / Hoedspruit main route. There are also some dirt roads, in a fair condition, from the main route to the scheme. The scheme is also served by telephone and electricity lines.

The total area of irrigable land is some 2000 ha of which 120 ha are allocated to ARDC for tobacco cropping.

There are about 1 000 farmers on the scheme, most of them being allocated 1,3 ha of land. The fields are mainly irrigated by short furrow irrigation on small strips of contoured land. The main crop in summer is maize and in winter tomatoes.

The Dingleydale/New Forest Irrigation Scheme compares very favourably with similar small-scale farmer irrigation schemes.

ARIAL PHOTOGRAPHY

The Digital Multi-Spectral Video System's (DMSV) capability to acquire high-resolution imagery of terrain, vegetation, etc is used in this investigation. From the aerial photograph, correlated with site observations, aspects such as waterlogging problems, infrastructure, calculations of cultivated and other specific areas are obtainable. The photographic interpretation is still in process and the relevant data will be available shortly.

IRRIGATION

Main canals and dams

The scheme was designed and developed as a flood irrigation scheme. With short furrow irrigation being the system that is predominantly used. A sprinkler irrigation system of 40 hectares is the only other irrigation system on the scheme and it is used by the ARDC on their tobacco fields. The sources are the Tlulandziteka and the Mutlumuvi rivers and the distribution is done through a system of weirs, canals, night storage dams and secondary canals. The scheme can be divided in two main parts namely New Forest and Dingleydale. They are served by two main concrete canals which both end in the Orinoco dam from where the second New Forest canal supplies water to the rest of New Forest. The approximate lengths of the main canals can be summarised as follows:

- New Forest (NF-1) 17 km;
- Dingleydale (DD-1) 23 km;
- New Forest 2 (NF-2) 4 km.

With the estimated total length of the canals of 44 kilometres and the annual evaporation of 2 200 mm the estimated evaporation losses from the canals are 124 000 m3 per annum. This is enough water to irrigate a further 12 hectares on the scheme.

LAYOUT AND MANAGEMENT

Layout

As illustrated in Diagram 1, and stated above, the supply can be divided into three parts namely:

- The canal which runs from the Orinoco abstraction weir on the Mutlumuvi river (New Forest Canal 1, NF-1) which supplies New Forest;
- The canal from the Orinoco dam, which supplies water to New Forest (New Forest Canal 2, NF-2). This canal splits into the NF-2-1 and NF-2-2 canals;
- The weir on the Tlulandziteka river (downstream of the Kasteel dam), which supplies water to Dingleydale (Dingleydale canal, DD-1).

On the diagram, the flow directions of the water in the canals, the canal capacities, the storage volumes of the night storage dams, and a diagrammatic layout of the whole scheme is given.

The water from the NF-1 and DD-1 canal ends in the Orinoco dam from where it is channelled through the New Forest 2 canal (NF-2). Along the main canals there are a number of night storage dams, which assist in the on-farm management of the flood irrigation systems. These storage dams are off canal and their use as canal or buffer storage dams in terms of bulk water storage for canal management is limited. The level of the dams is lower than that of the canal; therefore, water cannot flow back into the canal from which it is supplied. From these storage dams, water is fed into secondary or subsidiary canals that lead to the farmers' fields. Direct abstraction points from the main canals also exist, from where water is fed into secondary canals to the farmers' fields.

The estimated total storage volumes in night storage dams on each canal are as follows:

- NF-1 35 000 cubic meters
- NF-2 nil cubic meters
- NF-2-1 7 500 cubic meters
- NF-2-2 17 500 cubic meters
- DD-1 60 000 cubic meters

Irrigation Water management

The water is managed by water bailiffs who; regulate the flow of the water through the main canals, see that the appropriate farmers get their water at the right time, oversee the filling of the night storage dams and see to the cleaning of the canals. This can be seen as ground level management. Currently there does not seem to be a higher-level management system or plan, for the two schemes as separate units or as combination, in place.

Measurement of water flow

The only measuring structures in the system are currently installed at the inlet to DD-1, NF-2 and at the split to NF-2-1 and NF-2-2. These are Cipoletti measuring notches. As a first step in the measuring of water flow, measuring structures such as Parshall flumes should be installed at the inlets to the DD-1 and NF-1 canals and at the ends before the Orinoco dam. The installation of measuring apparatus in the main canals can serve as a management tool. The installation of metering devices at all the farmers' abstraction points to their irrigated fields will firstly be very expensive and secondly not resistant to tampering. This will also require additional monitoring personnel, whose cost will render it not viable for the current scale of farming operations.

Water infrastructure repair costs

The existing canal network and storage dams represent a very significant investment. Items that need attention are, the clearing of at least one metre on each side of the main canals, repair of storm water drainage works, removal of sediment from the canals, reparation of outlet valves on the major dams, improvement of canal access roads, measuring structures etc

The estimated repair cost to the canals is R1 452 million, of which the bulk (R1 133 million) is allocated to canal replacement and relining of certain sections. The remaining amount is for maintenance works and measuring structures.

Labour intensive projects

The nature of the scheme in terms of infrastructure, ie, canals, dams, roads and fences lends itself to the possible implementation of labour intensive projects for its repair and maintenance. Although soil conservation and veld condition were not part of the scope of this study, they are also areas where labour intensive projects can be initiated.

The purposes of using labour intensive methods to improve and maintain infrastructure in a developing area are:

- to get the local community involved and participating in the improvement of their own area.
- to educate the local community to be able to continue the work without outside assistance.
- to establish a sense of self-reliance and responsibility within the local community.
- to keep any money generated by such methods within the local community.

It is therefore of the utmost importance that any labour intensive projects within a community will be run in such a way that the above purposes are met and fulfilled.

In-field irrigation management

The secondary canals (concrete) each serve a group of farmers, the number in this group vary according to the topography. If there is adequate flow in the main canal, each group usually gets water once a week, sometimes more often if only a few of the lands on the whole scheme are occupied.

Within a group, it is up to the members themselves to decide how the water is divided, ie, how many farmers irrigate at the same time, or how long each farmer has access to the water in the secondary canal. Although the water bailiffs are responsible for preventing water misuse by the farmers, they do not have the authority to enforce any regulations and have been threatened by the farmers when trying to do so.

As far as maintenance is concerned, the farmers themselves are responsible for clearing overgrowth around the secondary canal, and usually do this at the end of the rainy season.

Short furrow irrigation

The irrigation method used at the Dingleydale/New Forest scheme is short-furrow irrigation, which is an indigenous modification to small basin irrigation. The efficiency of well-managed short furrow irrigation systems, are similar to well managed sprinkler irrigation systems. It is highly manageable and requires comparatively little in terms of permanent infrastructure and maintenance. However, this simplicity of operation is only possible by correct system design, requiring a balance between water flow rates, furrow slope and length for the specific soil.

The first phase of the research was to determine the characteristics of the earth supply furrows on the scheme, as significant water losses could possibly occur here.

Three tests were completed on two different soils on the scheme. The data from the tests were used to determine the infiltration parameters of the soils, and this was used in a computer program to simulate the tests that were done. The simulated results compared well with the actual measured data.

In the second phase of the research, the complete irrigation procedure was evaluated. The information from phase one was used to determine the irrigation efficiency in the field. A complete irrigation of a number of field situations was simulated and compared with the actual field data. The simulations provided the data information needed to calculate field efficiencies for different scenarios.

Results showed that a plot with a supply furrow of 100 m could have an efficiency between 59% and 74%, depending on the soil type. Furthermore, a plot with a supply furrow of 61 m could have an efficiency varying between 66% and 77%, depending on the soil type. If supply furrow losses can be curbed, the infield efficiency of this irrigation system could be in the order of 90%.

The short furrow irrigation method used at Dingleydale and New Forest is probably the most suitable and sustainable method of irrigation for the schemes at this stage. It does not require any expensive or moveable equipment, and the farmers are experienced in its implementation.

The project team agreed that the irrigation practices seen on these two schemes were better than most short furrow irrigation schemes in the Northern Province.

However, there are at least two aspects that can be addressed to improve in-field water use efficiency. The first is to change the current layout of the short furrows by constructing the furrows closer together. This means that more plants are grown per hectare, increasing the yield but also increasing the inputs and thus the risk. The second aspect is to match the gradient of the supply furrows with the soil type. On soils with high infiltration rates, the optimum gradient for that topography should be used to reduce the infiltration losses. Care must however be taken to prevent erosion at too steep gradients.

HYDROLOGY

Irrigation water requirement in perspective

Within the limitations and the assumptions that were made, a better understanding could however be developed of the current irrigation water use in the specific schemes as well as the availability of water in general.

Figure 2-A-1 and Figure 2-A-2 show the total annual runoff for the catchment up to the abstraction points and maximum irrigation. The years when shortages occur is when the runoff line drops below the irrigation requirement line. It can be seen that there is surplus water available in most of the years especially for the ACRU model seen in Figure 2-A-2.

Figure 2-A-1: Yearly runoff (VTI) with reserve and irrigation requirements for total catchment

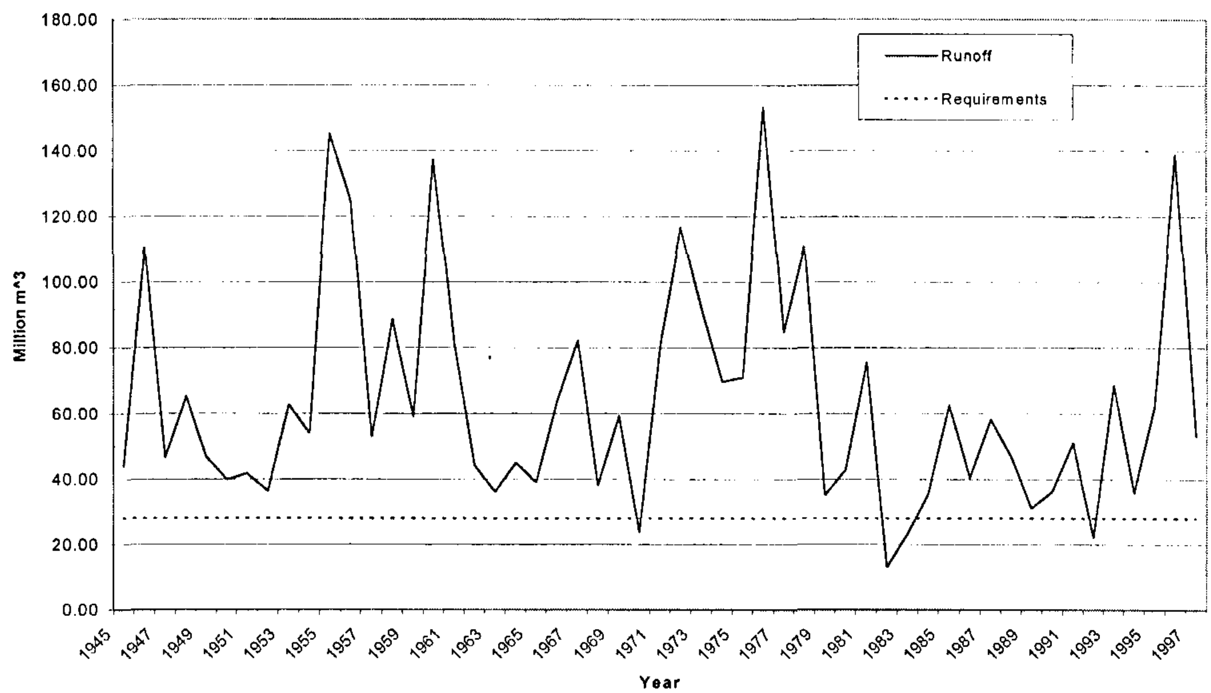
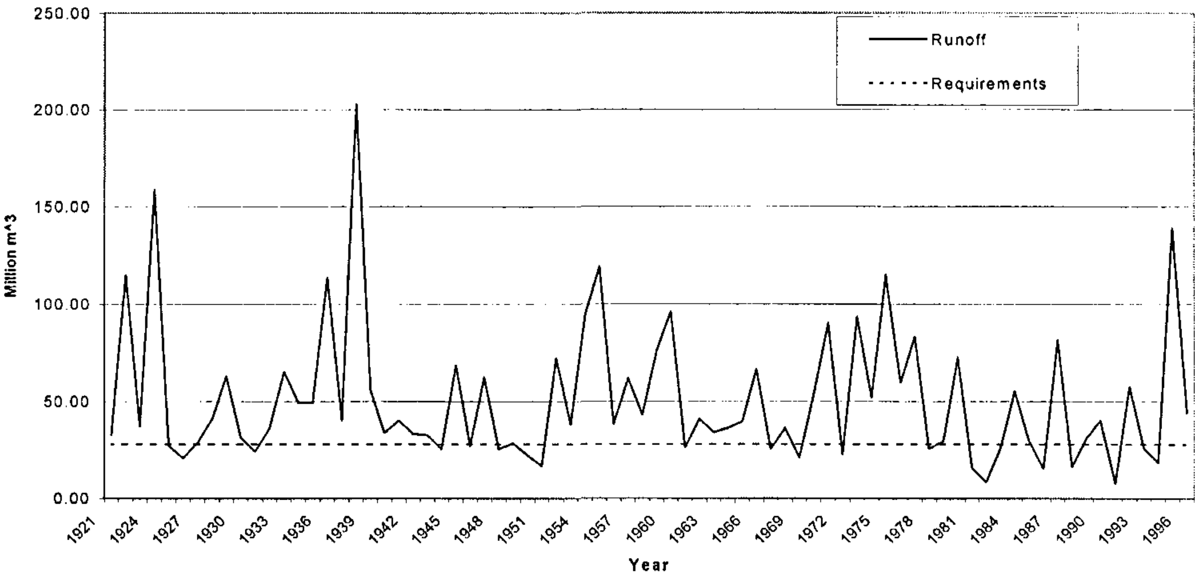


Figure 2-A-2: Yearly runoff (ACRU) with irrigation and reserve requirements for total catchment



Shortfalls in water supply are often experienced in practice due to seasonal and periodical flow fluctuations. The river flows drop substantially from approximately April/May until October resulting in a dry winter period, after which it picks up again.

In practice the irrigation requirement is adapted according to the reality of the available water supply. This is done by adjusting the crop pattern and areas cultivated, especially in winter.

It is, of the utmost importance that a more intensive study of the area is carried out, including the assessment of all the irrigation developments and other water users in the catchment. This information is also necessary for the development of water management models to be used by catchment management authorities (CMAs).

Assumptions

The following assumptions were made as a point of departure for calculating purposes and will have to be refined as soon as more clarity on the final hydrological data and water allocation is made available from the Department of Water Affairs (DWAF):

a) The reserve flow of the rivers at the abstraction was obtained from DWAF, using Management classes B and B/C.

b) An occupancy rate of 25% of the estimated 250 ha irrigable land, at any time, has been allowed for informal irrigation fields. This could not be verified, as those schemes did not form part of the scope of the project.

c) Allowance has been made for irrigation, at Zoeknog and Champagne Irrigation schemes throughout the year at the same rate as at New Forest and Dingleydale respectively.

d) Due to farming practices only a maximum of 75% of the total irrigable area is irrigated at any time of the year, within the schemes.

Water sources

The Dingleydale/New Forest Irrigation Schemes are supplied by two canals from the Tlulandziteka and Mutlumuvi Rivers respectively.

Water available for irrigation

To determine the available water for irrigation at the abstraction points, the water demand for irrigation purposes upstream was deducted from the monthly river flows according to Assumptions (b) and (c). The reserve flows in the river were also deducted using Management class B/C.

Irrigable Area

The losses in the main canals, distribution canals and irrigation efficiency were assumed to be 50%, which is typical for this kind of scheme. The possible area irrigable with a water demand of 40 mm/(week/ha) at the abstraction point was calculated. The possible irrigable areas per season were also calculated for possible water saving measures.

It is clear that the reserve flow has a big influence on the area irrigable. To put the farmers in the same situation as they are now, the efficiency of the system must be addressed. This could be done by replacing the canals with pipelines and using drip irrigation on the irrigation field (Table 2-A-1). This must be implemented in phases and the farmers must be trained in the use of drip irrigation. Everything must be done with the full participation of the farmers.

Table 2-A-1: Infrastructure upgrading

Item	Replacement	Cost R x 1 000	Water Saving mm/week/ha
Main canal	Pipeline	17 000	5
Distribution canals	Pipeline	6 000	6
Short furrow	Drip	26 000	6
TOTAL		49 000	17

SOILS

The soils in the study area have been formed as a result of the interaction between the sub-humid, sub-tropical climate, the easily weatherable Basement complex rock types and the action of the incisive streams.

The irrigable soils are to be found on the rounded landform crests and upper mid-slopes of the landscape. The general quality of the soils appears to be good, particularly as regards their physical properties. The soils may, however, be conducive to compaction and will as such need to be monitored and treated accordingly. The chemical properties of the soils need careful attention so as to rectify present acidic and macronutrient imbalances and prevent further damage due to incorrect production practices. Due to sandy textures, the soils tend to have a low natural fertility and will therefore need to be supplemented by judicial applications of fertilisers and dolomitic lime. The water-holding capacities of the soils appear to be adequate to allow for weekly irrigation applications, provided root development is not restricted.

Taking into account the present constraints posed by the soils, the study area still appears favourable for crop production provided these constraints are correctly addressed.

CROPS

Both annual and, to a lesser degree, perennial crops are produced in the study area. The two most important driving forces behind crop production are the use of the product for home consumption and the selling of the product on the market for an income. These, coupled with the constraints that the farmers face, dictate which crops are grown and in what quantities.

Crops are not only produced on the land set aside for irrigation, but also on areas above the canal and on the plots surrounding the individual households. The annual crops presently grown are: tomatoes, ground nuts, Njuga beans, chillies, sweet potato, beetroot, onions, cabbage, dry beans and spinach. Perennial crops grown are: mango, guava, papaya, banana and to a lesser extent sugarcane and avocado.

Although the climate and soil generally appear to be favourable for crop production, there are certain constraints, which need to be addressed for production to be improved upon. The production constraints presently faced by the farmers can be summarised as follows:

- Soil related constraints
  - Topsoil and subsoil acidity (very important);

  - ♦ Inadequate or unbalanced fertilisation; and
  - ♦ Susceptibility of the soils to compaction.
- Water related constraints
  - ♦ Periodic water shortages.
- Production practice related constraints
  - ♦ Use of low quality seeds and planting material;
  - ♦ Incorrect planting practices;
  - ♦ No deliberate crop rotation plan;
  - ♦ Incorrect use and management of chemicals;
  - ♦ Inadequate weed control;
  - ♦ Inadequate use of disease resistant cultivars; and
  - ♦ Incorrect harvest and post-harvest handling of crops.
- Financial constraints
  - ♦ Farmers do not have the cash flow of inputs.
- Marketing constraints
  - ♦ Can local market handle produce?
  - ♦ Transport to other markets?
- Technical constraints
  - ♦ Farmers do not have access to implements and tractors.

For improved production, farmers need to receive training in the following:

- Soil preparation methods
- Fertilisation
- Pest and disease control
- Plant propagation
- Certain production/cultivation practices
- Crop rotation
- Management (production and financial).

CROP WATER REQUIREMENTS

The average evapotranspiration (ETo), calculated using the Penman-Monteith equation (FAO Irrigation and drainage paper No. 56, 1998), peaks in January and February at just over 5 mm/day. This is a moderate value as a consequence of the incidence of cloud cover during the summer months. Winter values approach 2 mm/day.

Estimates of weekly crop water requirements were derived from the computer program SAPWAT and from experimental work undertaken by Prof Sue Walker. During the winter months, 20 mm/week is adequate for the crop production methods practised and will produce very adequate yields under short-furrow flood irrigation.

Annual rainfall, which falls in summer, is in the order of 700 mm but tends to be erratic. This is adequate for most summer crops and irrigation can be regarded as being supplementary and as an insurance against drought. Crop water requirements can be expected to be in the order of 36 -

40 mm/month in January/February. It is anticipated that 50% of this can be provided by rain and it is assumed that 20 mm/week irrigation would be adequate.

It is felt that 20 mm/week irrigation throughout the year would be a valid estimate for water balance calculations. It is recognised that crop water requirements peak at different dates and that these variations can be expected by a broad average figure.

A number of crop rotations were simulated and land occupation figures of 70 – 80% were achieved. This implies double cropping in most years. Annual water use of between 7 500 and 8 500 m3/ha (field edge) was indicated.

The farmers, supported by the water bailiffs, were well versed in short furrow irrigation. The soils with their moderate infiltration rates, which limit losses in supply furrows, enable reasonable land efficiencies to be achieved.

SUPPORT SERVICES AND SCHEME MANAGEMENT

The schemes have always permitted freedom of decision-making to participants. There never was the degeneration found on many other schemes. The Department of Agriculture (DOA) did, however, provide support services. The extension officers undertook water management and assisted the farmers to the best of their abilities and resources. The Department maintained the canals and other infrastructure and provided tractors for ploughing services. Both financing and the availability of production inputs seem to have been fringe activities that received limited attention. The same can be said for marketing.

The DOA's mechanisation services have, for all practical purposes ceased, such that the farmers are now virtually on their own. Unfortunately there have, as yet, been little constructive 'privatisation' actions. The future institutional arrangements are a matter for conjecture at this stage.

It will be appreciated that meaningful development is only possible if all the elements are in place. This is typified by ploughing and related services. It is virtually impossible for contractors to break-even financially because of the short seasons on the schemes. Existing contractors supplement income by working off the scheme in times of low demand. The need to lime fields periodically should provide additional opportunities for tractor owners.

An example of a project management structure that has already been developed and could be used on the scheme is in Figure 2-A-3 on the next page.

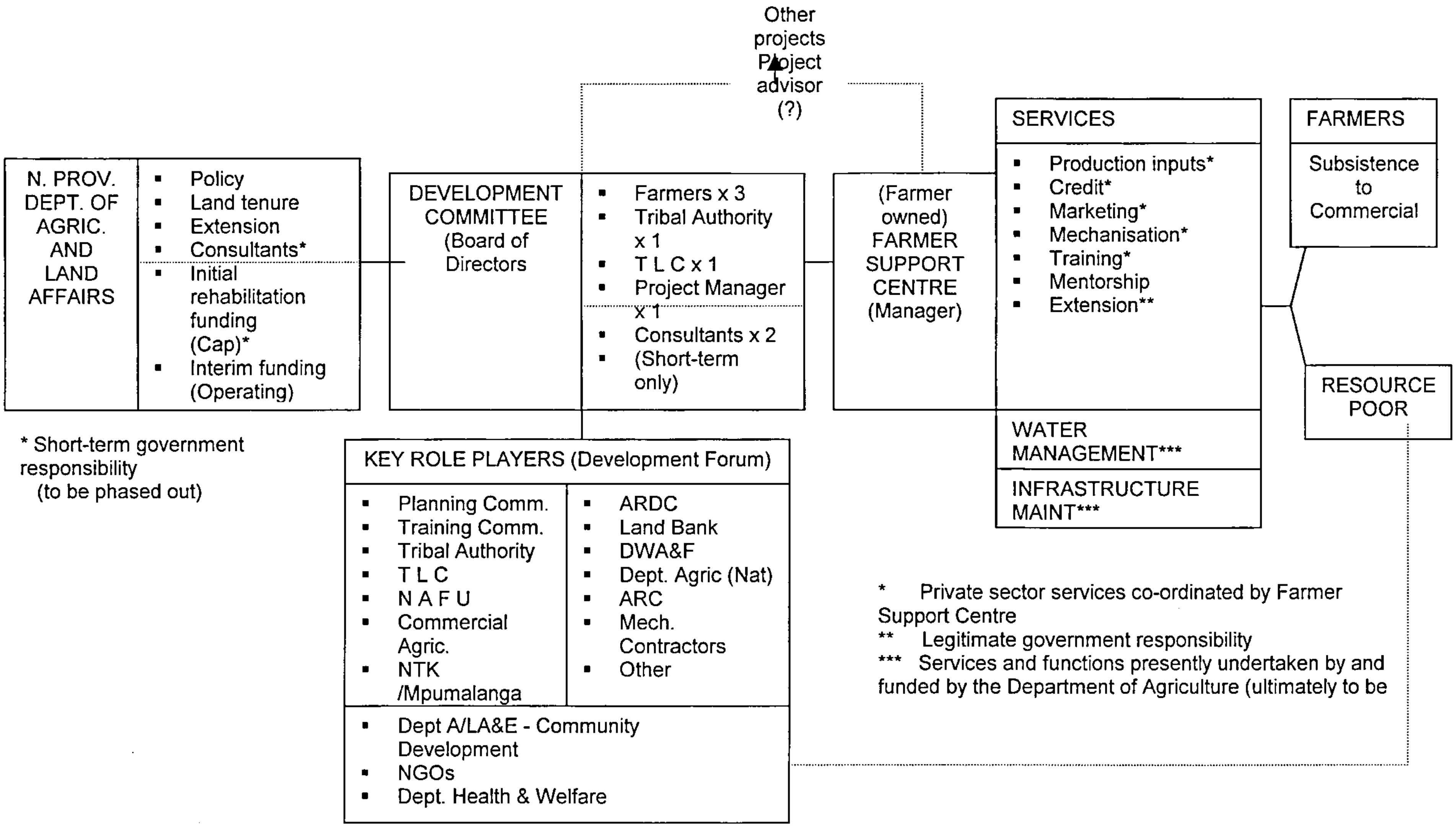
SOCIOLOGICAL ASPECTS

The social aspects with regards to the Dingleydale/New Forest Irrigation scheme are critically important for the feasibility of the schemes and will have to be addressed as such. Although much useful information was gathered, a full social impact assessment should be undertaken before any decisive steps are taken towards the reallocation of water from the Sand River.

General social aspects that arose:

- importance of women with regards to household upkeep, farming, handling of finances;
- role of the elderly as primary source of income (pension) and as farmers themselves;
- level of education and ages within the household;
- formal employment on local projects and self-employment in home-businesses;
- availability of limited services and infrastructure, eg, electricity, telephones, roads;
- role of irrigation canals with regards to domestic water supply and use.

Figure 2-A-3: Irrigation Scheme - Proposed Project Structure



Aspects that arose regarding the scheme:

- issues surrounding land allocation and tenure;
- driving forces behind production on the scheme; and
- availability of support services and the need for financial resources.

There are a number of organisational structures present in the area, which include: local government, tribal authority, community-based, non-governmental and local structures. There needs to be careful and adequate liaison with and within these structures in any developmental procedures that may occur to alleviate any negative feelings within the structures themselves and ultimately within the communities.

ECONOMICAL ANALYSIS

The Dingleydale/New Forest Irrigation scheme is a very important economic structure in the Bushbuckridge region. Although pensions seem to be the most important source of household income, agriculture (through the schemes) is a source of fresh vegetables and fruit throughout the year, and a source of employment, both permanently and seasonally. Access to land in the schemes also serves as a source of security for households who perceive it to be a buffer against times of economic hardship.

The productivity of the two schemes is above that of other similar schemes in the country. The farmers are more experienced and more geared towards commercial production. The biggest economic barrier that the farmers are facing is missing markets1. The farmers do not have access to secure input markets: contracting services for mechanisation is often not delivered in time for planting, farmers travel long distances to the nearest co-operatives, who do not always stock the inputs or the quantities that the farmers require. Farmers do not have access to production credit in the form of inputs (ie, they cannot obtain fertiliser, seed, etc and pay for it after the harvest). Labour is abundant and labourers are paid in cash and in kind. This contributes to other households' food security.

Poor roads and insufficient communication infrastructure inhibit farmers' access to remunerative product markets. They sell their produce in the local market, but they compete with 'imports' from other towns. They are unable to look for markets outside their region, since most of them do not have their own transport or means of communication. It is therefore not the inefficiency of the farmers that causes concern, but rather structural inadequacies in the region.

The crops that are currently produced are those that comprise the local diets. If productivity is increased by only 15% over a period of four years, the schemes can be sustainable. In addition, the schemes can become the main source of inputs for Small, Medium and Micro Enterprises in the region.

Agriculture is often perceived as an inefficient user of water. This is certainly not the case with these two schemes. Farmers are used to water shortages in winter, but they effectively incorporate dry land crops to overcome this barrier. In addition, the source of summer water supply is also being used by community members for household consumption.

It is estimated that the Dingleydale/New Forest irrigation scheme is generating annual returns in cash and kind of approximately R20 million. Apart from the direct benefits to households depending on the schemes, it also has multiplier effects2 into the regional economy. It is important to note that agriculture is a prominent employer of labour (both seasonally and permanently) and creator of incentives for small business development.

The structural constraints can be overcome through the use of institutions such as sharecropping, outgrower schemes, joint ventures, build-operate-transfer initiatives, etc. Commercial farmers in the region have indicated a willingness to assist the developing farmers with these institutions. This can

[1] *Missing markets is a term used in Neo-Institutional Economics to describe the situation where a market for a particular good or service is not accessible due to institutional and geographic barriers.*

[2] The term 'multiplier effects' refers to the impact of an injection into one sector of the economy on the rest of the economy. Agriculture is today recognised as the sector with the most profound and far-reaching multiplier effects in an economy. In other words, agriculture is linked to many other sectors in the economy.

play a positive role in the development of agriculture in the region, and also in the development initiatives planned for the region.

Figure 2-A-4: Scheme income with management class B/C (Hydro = VTI)

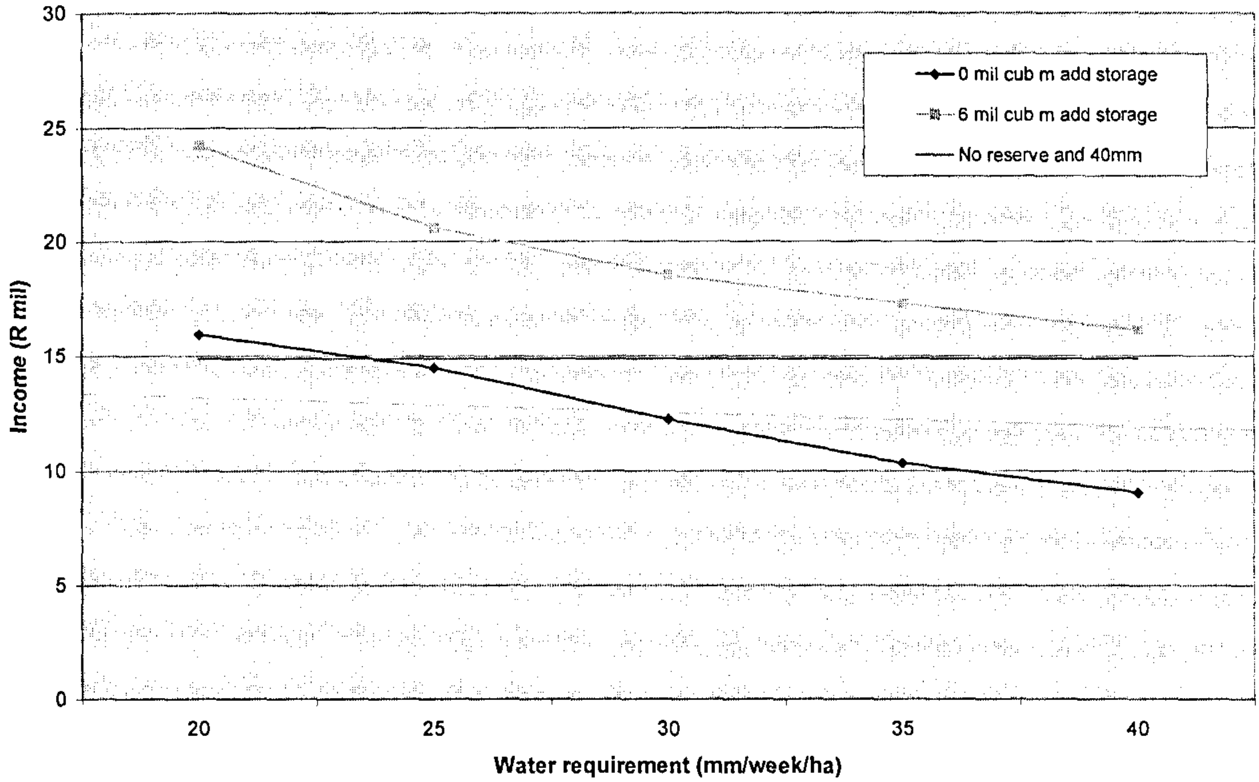
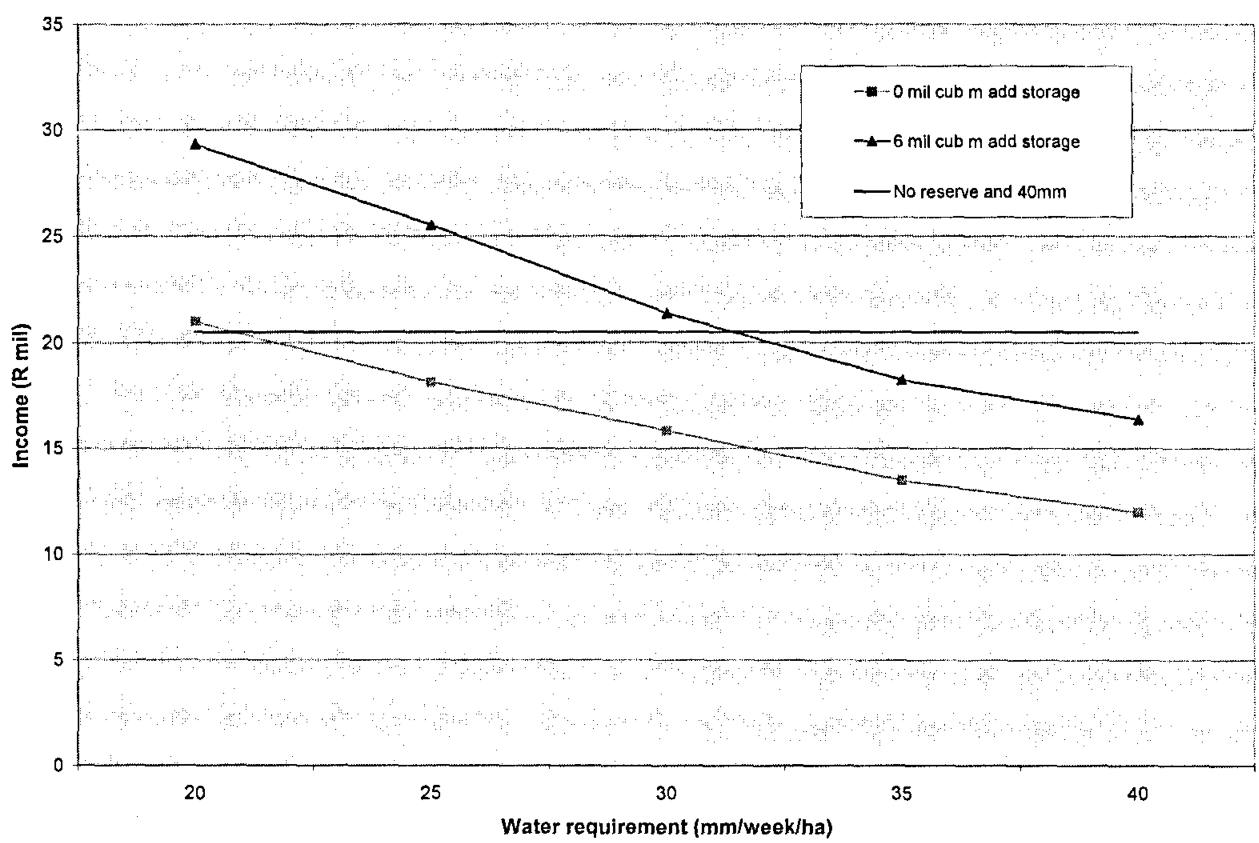


Figure 2-A-5: Scheme income with management class B/C (Hydro = ACRU)



INFORMATION REGARDING SCHEME REHABILITATION

With the current interest in the rehabilitation and development of rural communities, many discussion documents and policies are being put on paper for implementation. Examples of functioning projects can also be used for reference in this development. Examples are attached of the above documents that may be applicable in the implementation of the foreseeable rehabilitation of the scheme. Aspects covered herein are those of; land tenure, proposed policy, evolutionary development initiated through training and communal property associations.

DIRECTION FOR FUTURE DEVELOPMENT

The potential of the area with regards to agriculture, natural resources, sociological and economical aspects appears to be favourable:

- The natural resources potential is equivalent to the high production areas of the Lowveld eg. The Onderberg
- The people on the scheme have considerable competence that can be built on.
- Market opportunities exist locally and seasonally but need further development.

The main current constraints that should be addressed:

- The present water supply fluctuations;
- The deteriorating infrastructure;
- The lack of institutional structures.

The scheme directly influences the lives of at least 10 000 people (farmers, labourers and families). This number can be dramatically increased with the rehabilitation and resulting increase in production on the scheme. At the full development potential revenue from this area can be similar to that of the conservation enterprises.

The above indicates that the scheme not only has the potential for improved production but also impacts greatly on the region. It is imperative therefore that development will be initiated and promoted for the area to realise its full potential.

RECOMMENDATIONS

Dingleydale/New Forest irrigation schemes have formed communities that have developed around the farming activities of the schemes. Even though some original farm plots are not being actively farmed, a good number of the original plots are under cultivation most parts of the year. Withdrawal of government support has led to the decline in the quality of irrigation infrastructure at the schemes, lowering further the potential land area that can be effectively irrigated. The closure of traditional markets and lack of access to markets further afield, the absence of local input supplies and credit have deprived the community of potential income from farming. Yet the unique climate of the area would permit production of crops year round under irrigation. The recommendations that follow are aimed at restoring the productive potential of the Dingleydale and New Forest Irrigation schemes through co-ordinated actions. These actions are aimed at ensuring that the schemes contribute positively to a sustainable well being of the community by addressing the constraints identified by this study.

Organisation of user groups

A pattern for future management by the participants has been developed on the Thabina pilot project near Tzaneen. The core of the approach is the establishment of a Development Committee consisting of elected representatives of farmers' groups, which forms a 'board of directors'. The intention is that a project manager paid and appointed by the scheme participants will be the executive arm of the Development Committee and will have direct responsibility for scheme management and support services. The manager will be responsible for farmer support and it is anticipated that he will do this through outsourcing, not by developing scheme owned equipment or trading enterprises. The manager will be expected to mobilise existing specialised resources.

Production inputs

Existing co-operatives, commercial organisations, etc encouraging, for example, a branch of an existing co-operative on a negotiated basis to set up in the scheme area.

Credit

Liaison with land and commercial banks, suppliers, etc. An important function is assisting and training farmer participants in how to submit loan applications.

Mechanisation

Inevitably this will be on a contract basis but planning will be important. Farmers should be empowered through training to do quality control on mechanisation services.

Training

This aspect is discussed elsewhere.

Mentorship

Liaison is essential if participants are to achieve the required level of efficiency.

Extension

Specialised extension may continue to be a DOA responsibility but the chances are that alternately extension officers will be appointed by and responsible to the 'Directors'.

There is enormous willingness and support from the community for the rehabilitation of the schemes. It is however vital that the community should work together in a development forum so that they interact with each other as well as with the larger community. As a group, they should participate in planning as well as in later implementation of the rehabilitation.

Research

A well-planned research programme, including on-farm research, must be established. Extension managed trail plots are available at Dingleydale and can be utilised for demonstrations and trials. The current research activities of the ARC-Grain Crops Institute at the schemes will be continued. These trials include cultivar evaluation of maize and groundnuts as well as a nitrogen and potassium fertilisation trial. The proposed research programme will have to be thoroughly planned in collaboration with local extension staff and the farmers.

Services

In order to strengthen the cropping system, it will be vital to establish support and expertise for the establishment of a local seedling nursery. A Farmer Support Group represented by members of the ARC, the private sector and local extension staff, to act as a parenting body and to render advisory services on a continuous basis will be necessary.

Training

It was established that farmers need training in order to improve their productivity and yields on the schemes. This production training should include the following areas:

- Soil preparation methods.
- Soil fertility principles, fertilisation programme and the use of fertilisers
- Principles of pest and disease control and the correct use and management of chemical products
- Growth and supply of seedlings.
- Planting and cultivation practices of various crops.
- Crop rotation principles and management

Additionally, extension officers should provide training to farmers not only in farming, but also in processing vegetables, in business management skills such as record keeping, budgeting, planning, scheduling of production activities, information acquisition and application on a continuing basis. Farmers have expressed a desire to acquire and/or sharpen these skills.

On farm demonstration plots

Technical training was identified as an essential component of development with a view to improving the levels of crop production. One important way to strengthen the training program will be to conduct on-farm demonstrations of appropriate technologies and production practices. It is believed that exposing farmers to a wider range of candidate technologies will speed up the rate of adoption. Although crop yields at the scheme are reasonably good, it is assessed that the production levels can be improved. It is hoped that farmers will be able to see what can be achieved in their fields.

The objective of the demonstration will be to introduce the farmers at the scheme to alternative technologies and cropping practices while creating an opportunity for farmers to develop optimal production practices. Based on the production constraints and the training needs that were identified during the survey, the focus of the demonstrations will be on the following aspects of crop production:

- Irrigation methods
- Soil preparation methods
- Lime application
- Fertilisation based on soil analysis
- Certain cultivation practices
- Cultivar screening
- Pest control programmes

Land tenure

Land tenure is one of the fundamental issues requiring resolution in the rehabilitation of schemes. Schemes were developed at the time when there was no question of there being private ownership of irrigation plots or farms. The lands on which the schemes are located have a variety of land tenure situations. In most cases, the land was tribal, but in the cases of some of the larger schemes, the ownership was vested in the developing authority.

The whole concept of ownership of the land will need to be re-examined. Naturally farmers occupying holdings on schemes desire individual property rights that will allow them to enjoy true ownership of the land and the development on it. This is still controversial in that there is a view that this takes what belongs to the community and enriches and empowers a few select families from that point in time onwards. There is also the issue on some schemes that people currently holding the plots were allocated them through unacceptable processes viz. apartheid, favouritism by the chief, etc, and are therefore not the legitimate holders. The absence of such land disputes can be an important positive criterion in the prioritisation of scheme development. The development of the individual plots and consequently, the whole scheme will be influenced by the direction taken by land tenure legislation. Increasing the ownership will lead to better land utilisation and more conservation efforts. Methods of ensuring that the community members feel this sense of land ownership vary. They include the use of Communal Property Associations or Section 21 companies.

Infrastructure

When implementing the new Water Act in the Sand River catchment, it is very important that the existing farmers must not be influenced negatively. It is thus very important to implement water saving measures at the schemes. The most cost-effective measurement being the replacement of the distribution canals with pipelines at a cost of R6,00 million with a return of R1,75 million per annum. This will 'save' 6 mm/(week/ha) or 3 000 m^3/ha per year. The other measures can then be implemented in later phases. It is also possible that, with all the water saving measures in place, the existing area irrigable is not going to be met with the implementing of the reserve flow, depending on the hydrology. Additional storage facilities must then be provided.

Chapter 3

PARTICIPATORY IRRIGATION PLANNING

See also Irrigation Design Manual (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

3.1 INTRODUCTION 3-1
3.2 QUALITATIVE RESEARCH 3-1
3.2.1 Basic principles 3-1
3.2.2 The interview 3-2
3.2.3 The Sondeo method 3-4
3.2.4 The Rapid (Relaxed) Rural Appraisal method 3-5
3.2.5 The Participatory Rural Appraisal method 3-6
3.3 PARTICIPATORY IRRIGATION PLANNING 3-8
3.3.1 PIP objectives 3-8
3.3.2 PIP team composition 3-9
3.3.3 The Strydkraal and Mooiplaats PIP 3-9
3.4 THE WAY FORWARD 3-11
3.4.1 The need for policy and strategies 3-11
3.4.2 Participants in PIP and policy formulation 3-12
3.5 CONCLUSIONS AND RECOMMENDATIONS 3-14

APPENDIX 3.A. NEW LOOK AT THE PIP APPROACH 3-15
APPENDIX 3.B. EXAMPLES OF THE PRA VISUAL TECHNIQUES 3-17
APPENDIX 3.C. THE PIP PROCESS 3-24
APPENDIX 3.D. EVOLUTIONARY DEVELOPMENT INITIATED THROUGH TRAINING (EDITT) 3-27

3.1 INTRODUCTION

Participatory planning follows the pre-feasibility report and may be concurrent with the full feasibility report. It is in itself an important component of design and can pave the way to farmer-managed irrigation development and ultimate success. 'Participatory planning' means that all affected parties take part in planning a development, and the approach to development (as the term is used in South Africa by the RDP) is now based on the so-called bottom-up approach, allied to transparency. In the case of irrigation planning, this means that the members of the community and all other parties who are directly or indirectly affected by what is being planned must be involved from the outset. The process, from initial concept through feasibility studies, design and construction, and on to operation, must be so managed that the people concerned are part of the process, and ultimately feel comfortable about accepting responsibility for the project.

There are accepted procedures and methods for ensuring that communities are involved and consulted. These procedures, however, have seldom been detailed in the brief given to consultants for minor projects. It is simply accepted that, if the proposals have been discussed with the community, preferably in open meetings where all concerned can have their say, minimum requirements for a transparent bottom-up approach have been met. However, this minimum discussion with the community is not enough, even for minor projects. The brief should detail the requirement for active participation by all parties.

For major projects, consultants have normally been appointed separately for the engineering/agricultural aspects and the social aspects. The groups have tended, in a spirit of considerate co-operation, to avoid 'interfering' with each other's disciplines, believing that 'the cobbler should stick to his last.' This scientific and administratively convenient approach is possibly partly responsible for the dismal failure of irrigation as a development initiative in South Africa.

However, in recent years, it has been established that engineers and social scientists and other people from widely differing disciplines and interests can harmonise when involved participatively in development.

It is the active participation that makes the difference. A major change takes place in the planning relationship when an engineer, for example, accepts that the social scientist can make valid contributions to the engineering aspects of an investigation, and vice versa, and that the most important element is the community and not academic discipline. It is noticeable that major South African government departments such as the Department of Water Affairs and Forestry are also moving in the direction of greater interaction between disciplines such as engineers and social scientists, particularly at management level.

International and local experience indicates that it is essential to undertake in-depth participatory planning in South Africa, if a project is to be sustainable and self-supporting. Participatory planning is a qualitative research technique, and there have been important changes in international concepts of co-operative and participatory approaches to development based on qualitative research principles. Qualitative research is, however, an unfamiliar concept to all but a limited number of practitioners and, for this reason, the principles of qualitative research, as well as some successful qualitative research procedures, are reviewed in this chapter. The chapter concludes with an example of Participatory Irrigation Planning (PIP) undertaken in the Northern Province, and examines the lessons learned.

3.2 QUALITATIVE RESEARCH

3.2.1 BASIC PRINCIPLES

Scientists of all disciplines, including social scientists, are more familiar with quantitative research, which collects and relies on figures and statistics from a large sample population, and is aimed at achieving results that are generalised for a larger population. In many respects, qualitative research is the opposite, as its results are not generalised, nor can they be presented in terms of statistics. Qualitative research, though, is more in-depth and is particularly useful in identifying the important issues that need to be considered by a researcher in a specific situation or for a small population.

al (1994) points out that planners and researchers often use statistics because it is expected ...m. Results from questionnaire surveys, regardless of their internal validity (that is, whether they accurately reflect the situation that was studied) or external validity (that is, whether they are generalisable for the whole area or population), are often accepted simply because the findings can be summarised in a quantitative form.

The first and perhaps foremost difference between quantitative research and qualitative research is that quantitative researchers transfer their own structures or frameworks onto the situation being studied. They therefore use set categories and structured questionnaires, with no allowance for exceptional cases. In contrast to this, the qualitative researcher is concerned with an open-minded study of the situation as it exists, avoiding any preconceived ideas.

The second major difference between the two research methods concerns the position of the investigator in the process. In qualitative research, the person doing the evaluation tends to become more and more involved in the situation being studied, whilst the quantitative researcher attempts to observe from a distance.

The qualitative technique is most appropriate when investigations are aimed at understanding the essence of the situation, and where people are the main source of information on the subject, such as in development planning. The technique is not appropriate if the researcher is seeking an explanation of what is happening in terms of causal relationships. In such instances, methods associated with experimental designs are more fitting. Qualitative techniques should also not be used if the researcher is seeking representative information about a large population. Sample surveys using questionnaires as the research tool are more effective in such situations. (Questionnaire procedures can, however, be used to assess how the conclusions reached through qualitative research are generally applicable.)

In situations where qualitative methods are recognised as appropriate, researchers need to consider the nature of their research question and factors such as available time and resources, the type of validity and degree of precision needed, before selecting their methodologies. Also, while qualitative research is particularly valuable in its own right in the study of technical and managerial issues, it can be a valuable supplement to more conventional approaches. When quantitative data is available, it provides a valuable base for the more people-oriented qualitative interviews. Similarly, once specific attitudes and needs have been identified, it may be desirable to assess the scale and distribution of perceptions by means of quantitative methods (Chambers, 1992a&b.)

The elements of qualitative research methods will now be considered.

3.2.2 THE INTERVIEW

The interview is the basic building block of most qualitative research methods. It is also a tool that is often used as part of the study and analysis phase of extension programming (Bembridge, 1991; Van Den Ban and Hawkins, 1988; Benor *et al*, 1984; Cernea *et al*, 1985).

Interviews are so important in all participatory research methods that the notes that follow are quoted in full directly from Crosby *et al* (1994).

3.2.2.1 Interview approaches

Interviews can be classified into three main categories based on the degree of control and structure imposed on the interview by the researcher (Bernard, 1988).

Informal interviews have no structure or control. Examples are chance encounters and discussions.

The unstructured interview is carefully planned, but minimum control is exercised over the responses. Such interviews are arranged and the interviewer has an idea of what he is looking for, but the format of the interview simulates an informal discussion. This interview technique is often used for exploratory investigations.

During semi-structured interviews the interviewer is in full control of the interview and uses an interview guide. Despite this, the interview is still flexible enough to allow the researcher and respondent to identify and follow new leads. Semi-structured techniques are often used in situations where there is limited time for the interview.

All these kinds of interviews can be used with groups or individuals.

3.2.2.2 The properties of the researcher

The researcher plays a central role during the interview. The interviewer's personal characteristics influence interaction with the interviewee and, ultimately, the quality of the observations. The degree to which the interviewer is committed to doing justice to the object will reflect his/her objectivity, and ultimately influence the internal validity of the research. The following characteristics need to be taken into account when selecting and training researchers.

Objectivity. During an interview, the researcher becomes an instrument to measure a given situation. Within this context, his/her subjective experiences are likely to influence both the interview and the interpretation of the information collected. Objectivity can never be absolute and one can at most only strive towards it. The basic meaning of objectivity in a methodological context is doing justice to the object of the study (Smaling, 1990a).

Sensitivity and empathy. The interviewer should also be sensitive to various moods, meanings, nuances, expressions and responses, and be able to interpret those. These traits are essential for successful interviewing (Mascarenhas, 1991).

Sensitivity enables the researcher to identify leads for new lines of questioning and assists in making the respondent feel at ease. If the researcher can identify negative moods and feelings in time, potential disasters can be avoided.

Another important pre-requisite for successful interviewing is empathy. The empathetic interviewer tries to see the world through the object's eyes. This concept is similar to role-taking (Smaling, 1990b).

Enthusiasm. One of the keys to successful interviewing is the ability to express an interest in the object of study. The desire to learn from others is subconsciously communicated during the interview process and, unless the interviewee feels that the researcher is interested in what he is saying, he is unlikely to open up and share information.

Communication skills. The interviewer should also have the ability to make people talk and establish an interchange that reveals authentic, interesting and useful information. Good listening skills are essential for effective communication and the competent researcher will also apply this principle when conducting interviews...

3.2.2.3 Unstructured and semi-structured interviewing techniques

An important characteristic of unstructured interviews is that the researcher prepares before the interview by thinking about the topics that need to be covered. During the actual interview, the interviewer exercises as little control as possible and allows the respondent to determine the course of the interview. Probing and questioning is based on information provided by the respondent and is not associated with an interview schedule.

Semi-structured interviews differ from unstructured interviews in that the researcher develops an interview schedule before the actual interview. The interview schedule is a list of the key concepts that the researcher aims to cover during an interview. During the actual interview, the schedule is not used like a questionnaire, but as an unobtrusive memory aid. Semi-structured interviews are therefore slightly more controlled than unstructured interviews, but are still flexible enough to allow for probing and the pursuit of leads.

Unstructured and semi-structured interviews are the basic building blocks of composite methodologies developed for use by persons not specifically qualified in the social sciences. These include Sondeo, Rapid and Participatory Rural Appraisals, and Farming Systems Research. On their own, unstructured interviews are very effective for the study of sensitive topics such as sexuality, conflict, violence or politics (Bernard, 1988) and of relatively unknown subjects. They are also useful in the beginning of a study to help with the definition of a research problem and the development of interview schedules. Some researchers use unstructured interviews to establish rapport with people before starting with their actual research.

Semi-structured interviews can be used to cover an infinite range of research topics and are just as effective on their own as when used in conjunction with other techniques. This technique is most useful when there is limited time, and little or no opportunity for further visits, and is particularly suited to researching technical and management-related issues.

Semi-structured interviews should also be used if more than one interviewer is involved in fieldwork, in order to ensure that approximately the same topics are covered during interviews.

3.2.3 THE SONDEO METHOD

3.2.3.1 Functioning as a multi-disciplinary team

Hildebrand (1981) developed the Sondeo qualitative research method as a result of his experience with multi-disciplinary teams working on World Bank projects in Central America.

He established that there are several characteristics which are critical to an efficient and functioning multi-disciplinary effort: first, those concerned must be well trained in their own field; secondly, they need a working understanding of – and must not be afraid to make contributions in – one or more other fields. Team members must not feel the need to defend themselves and their field from intrusion by others. Working together, all members of the team should view the final product as a joint effort in which all have participated and for which all are equally responsible. That means that each must be satisfied with the product, given the goals of the team, and be willing and able to defend it.

Perhaps the most critical characteristic required to achieve success in a multi-disciplinary team is this identification with a single product in which all participate. The product can be complex and involve a number of facets but it should result from the joint effort of the whole team and not contain strictly identifiable parts attributable to individual team members. Failures of multi-disciplinary efforts in agricultural institutions usually result because teams are organised as committees that meet occasionally to 'co-ordinate' efforts, but in which the crop work is left to the agronomists, the survey to the anthropologists, and the desks to the economists. In these cases, there is not a single identified product but, rather, several products or reports purporting to be concerned with the same problem.

3.2.3.2 The purpose of the Sondeo

The Sondeo research method is intended to provide the information required to orient the work of the technology-generating team. The cropping or farming systems are determined, the agro-social-economic situation of the farmers is established, and the restrictions they face are defined, so that any proposed modifications to their present technology are appropriate to their conditions.

The primary purpose of the Sondeo, then, is to acquaint the technicians with the area in which they are going to work. Because quantifiable information is not required after the survey in order to interpret the findings, no questionnaires are used, so farmers are interviewed in an informal manner that does not alienate them. At the same time, the use of a multi-disciplinary team serves to provide information from many different points of view simultaneously.

A Sondeo study should be completed in a working week.

3.2.3.3 Sondeo methodology

The following is a description of the methodology for a 'standard' six-day operation. It is applicable, with adaptation, to virtually any development situation. Many of the Sondeo elements were incorporated in the PIP described later in this chapter.

Day One. The first day is a general reconnaissance of the area by the whole team as a unit. After interviewing a farmer, the group meets privately to discuss each one's interpretation of the interview. In this way, the team members begin to become acquainted with how other members think.

Interviews with farmers, or other people in the area, should be very general and wide-ranging because the team is exploring and searching for an unknown number of elements. The contribution or point of view of each discipline is critical throughout the Sondeo because the team does not know beforehand what type of problems or restrictions may be encountered. The more disciplines that are brought to bear on the situation, the greater is the probability of discovering the factors which are, in fact, the most critical to the farmers of the area.

Day Two. The interviewing and general reconnaissance of the first day serves to guide the work of the second day. Teams are made up of pairs, one agronomist or engineer and one person from socio-economics ideally, who work together in the interviews. The teams scatter throughout the area and meet again after the first half-day. Each member of each team discusses what was learnt during the interviews and tentative hypotheses are formed to help explain the situation in the area. The doubts raised during the discussion serve as guides to the following interview sessions. During the team discussions, each of the members learns how interpretations from other points of view can be important in understanding the problems in the area.

The importance of these discussions following a series of interviews cannot be over-stressed. Together, the group begins to understand the relationships encountered in the region and starts to define the possibilities. During the second day, there should be a notable convergence of opinion and a corresponding narrowing of interview topics, so that more depth can be acquired in following days on the topics of increasing interest.

Day Three. This is a repeat of Day Two and always includes a change in the make-up of the teams after each discussion. A minimum of four interview-discussion cycles is necessary to complete this part of the Sondeo.

Day Four. Before the team's return to the field for more interviews, each member is assigned a portion of the report that is to be written. Then, knowing for the first time the topic for which each will be responsible, the teams regroup in the fifth combination, and return to the field for more interviewing. Following another discussion session, the group begins to write the report of the Sondeo. All members should be working at the same location so that they can circulate freely and discuss points with each other. In this manner, the interaction among the disciplines continues.

Day Five. As the participants are writing the report, they invariably encounter points for which neither they nor others in the group have answers. The only remedy is to return to the field on the morning of the fifth day to fill in the gaps that were found the day before. A half-day can be devoted to this activity, together with finishing the writing of the main body of the report. In the afternoon of this day, each team member reads his written report to the group for discussion, editing and approval. As a group, the team should approve and/or modify what is presented.

Day Six. The report is read once again and, following the reading of each section, conclusions are drawn and recorded. When this is finished, the conclusions are read once again for approval, and specific recommendations are then made and recorded, both for the team and for any other agencies that should be involved in the general development process in the area. All of the members should be able to defend all the points of view discussed, and the conclusions and the recommendations made.

The report. It is obvious that the report will appear to be one written by ten different persons in a hurry, which is exactly what it is. It is not a benchmark study with quantified data that can be used in the future for project evaluation, rather it is a working document to orient the development process and it served one basic function in just being written.

3.2.4 THE RAPID (RELAXED) RURAL APPRAISAL METHOD

3.2.4.1 The techniques

Rapid Rural Appraisals (RRAs) were originally developed to provide quick and reliable information for agricultural and rural development project planning. They were conceived as an alternative to questionnaire surveys (Chambers, 1980; Subhadhira *et al*, 1988 Chambers, 1992b).

The RRA method is based on direct observation and interviews with people and can be described as 'good investigative journalism' (Pratt *et al*, 1988). The techniques used in RRA are not totally new – most are being used in other contexts. Its originality is vested in the principles that guide its application. These principles are defined by the Khon Kaen school (Subhadhira *et al*, 1988).

- The research process is exploratory, highly iterative and aimed at rapid and progressive learning.
- Research topics are examined from several points of view (triangulation).
- The use of indigenous knowledge is emphasised. This is based on the premise that rural people and farmers know their local conditions and environment well.

- Teamwork, where researchers from different backgrounds work closely together, is also emphasised.

3.2.4.2 Applications

Virtually any research topic can be covered using RRA techniques. This method is at its most powerful when it is used by a multi-disciplinary team as part of project planning. Other applications include problem identification for purposes of developing product specifications and management procedures, and for extension programming. RRA can also uncover questions that can be tackled using more intensive policy-focused research (Pratt *et al*, 1992).

3.2.5 THE PARTICIPATORY RURAL APPRAISAL METHOD

3.2.5.1 The characteristics

During the late 1980s, users of RRAs started to realise that there is a greater need for the active participation and involvement of rural people and farmers in the research process. This gave rise to the development of Participatory Rural Appraisals (PRAs). The PRA has its origins in applied anthropology, Farming Systems Research and RRAs (Chambers, 1992a). The main distinction between PRA and RRA is that PRA gives the people 'studied' greater control over the research agenda, information collection and analysis. It also limits the role of the researcher and specialist to facilitation. The high degree of farmer participation in the case of agricultural research is based on the premise that farmers know their own circumstances best. Their ability to analyse their own farm systems, determine their own priorities and adjust their practices accordingly is also recognised and promoted (Chambers, 1992a&b).

The techniques used in PRA are also very similar to those used in RRA. Semi-structured interviewing and direct observation are, however, augmented by visual or graphic techniques such as participatory modelling and mapping, transects and diagramming, which are described below in Section 3.2.5.3. These visual or graphic techniques are particularly powerful when working with illiterate farmers.

The use of PRA has many advantages, some of which are that:

- It enhances the mutual exchange of information between farmers and specialists;
- Information tends to be more reliable than when other more conventional methods are used; and
- Information gathering becomes an inseparable part of the processes of planning and extension (Chambers, 1992a&b; Pratt *et al*, 1992).

3.2.5.2 The role of facilitators

The role of the facilitators in PRA is to initiate and observe. They introduce the participating farmer group to the PRA techniques, which are usually graphic and which enable the farmers to analyse and understand their position and to develop plans for the future. This information is of great value to all concerned with development in the area but this is not the primary objective, which is to empower the community to evaluate the situation and do their own planning.

PRA is not an 'instant' process. Facilitators may spend a week or more with a community before they have gathered the information they need, and much depends on their skill and patience. Facilitators must also be trained by participating in a training PRA and then acting as co-facilitators on two or more PRAs before they operate alone.

Most interested people, including engineers and scientists, can acquire the skills required to be a facilitator, but not everyone has the personal characteristics required.

3.2.5.3 Standard PRA techniques

Some of the standard visual and graphic PRA techniques applied are outlined below. Further details and examples of the visual and graphic material developed during an appraisal are included in the discussion of the Participatory Irrigation Planning (PIP) exercise later in this chapter.

Transects. A transect is a systematic walk through the village living area and/or surrounding areas (fields, etc) with key informants. Transect walks are to observe, ask, listen, discuss and identify technologies, zones, problems, opportunities and solutions; and to find out why people do things and how it all fits into the overall survival pattern.

Transect walks can be used for assessment, planning, monitoring and evaluation of resource management and development projects. They can be used to identify issues relating to the land, land use, crops cultivated, local cultivation patterns, local irrigation technology, water-, plant- and land conservation, erosion, soil types, local vegetation, use of wild plants, resources in disrepair, eg, dipping tanks, etc. The participants later put the information gained into diagrams or maps. A transect walk can be used for general observation and to discover things that the farmers may not have mentioned. It can therefore serve as a guide to what issues need to be explored, ie, it can be a good introductory exercise. Transects can provide a broad perspective of the area or can provide detailed information on specific topics.

Time line. This is the technique used to establish what happened in the past and what the present situation is, where participants discuss and record major events in their community and attach dates to each event. It serves as a source of reference for further historical work and can also be used for an indication of previous development interventions.

It is a good introductory exercise to use with the whole group, before splitting up and exploring deeper, more complex areas. The time line technique can be used to explore specific issues – related to health and land use, for example. Sometimes, however, when it is used for such specific issues, the practicalities of the exercise differ from those of a general time line.

Mapping. Mapping is simply drawing the area in question and is useful as a central tool around which other areas can be explored using other methods. Community maps are essential to establish facts such as the locality of problem areas and of proposed new lands. Everybody gets the opportunity to make a contribution and, for this reason, maps should first be drawn on the ground and, when finalised, copied onto paper. At least one team member should copy the map or maps onto paper, to keep a permanent record.

Social maps show the village itself. Resource maps of the area surrounding the village can be used to show the crops planted; soil types; rivers and water points; roads; land use, productivity and holdings; physical features such as hills, mountains and erosion; types of natural vegetation (forests, grassland); irrigation patterns; and conservation planning. Historical maps and maps indicating future possibilities and needs are also useful.

Participants can draw a map of what the area used to look like and then change it or draw another one showing what the area looks like now. Maps can also be used to show the ideal location or a variety of possible locations of a new school, water tank, telephone routes, etc, or just to show what the farmers would like their area to look like in the future. (Maps of the sea have even been done with PRA, indicating depths, fish types, etc.)

Time trends. Time trends show quantitative changes over time and can be used to portray those changes in many variables, eg: number of cattle and livestock; amount of land cultivated or left fallow; erosion; natural vegetation; crop yields; migrancy; irrigation management; and water supply. On one time trend analysis (also called an historical transect), information on more than one of these issues can be ascertained.

It is important to include older people in a time trend analysis because they have the information relating to the past, which needs to be found and shared. A facilitator would explain to participants what he/she would like to find out, eg, the change in agricultural and land use over the past fifty years. People who feel knowledgeable about this should then be happy to participate. Materials used are paper and pens, or concrete (a floor) and chalk. The headings could be represented by objects such as a mealie cob, grass or money. For the representation of changes, beans, leaves, mealie cobs, etc, could be used, with many of these objects to show when there was a high yield and few of these objects to show when there was a low yield.

Venn diagramming. Venn diagrams (named after the man who created them) show the key institutions and individuals in a community and their relationships and importance. They can be used in a number of ways: different-sized circles or squares can identify and show the relationships and/or relative importance to the community of institutions, people, sources of income, facilities, problems, needs, etc. The larger the circle or square, the more important the need, etc. The distance between the community and the circle can also denote the nature of the relationship.

Seasonal diagramming. This creates a calendar showing the main activities, problems and opportunities throughout the annual cycle in diagrammatic form. It helps identify the times of greatest difficulty and vulnerability, or other significant variances that have an impact on the people's lives. It can be used to look at things like: indigenous seasons, crop sequences, crop pests and diseases, climate, migrancy, credit, income and expenditure, labour demand for men, women and children, non-agricultural labour, diseases of people and cattle, milk production, availability of clean drinking water, amount of fruit and vegetables bought, prices, etc.

The seasonal diagram (or seasonality chart) is often done in the form of bar graphs and/or matrixes. This technique is often used after issues of importance to the community have been discussed, ie, it is not usually used as an introductory exercise. The facilitator would choose participants who know the issues being investigated and would like to share their knowledge (farmers, landowners, tenants, school teachers, etc), and would discuss what he/she would like them to do, ie, show how certain things change throughout the year. Then they would decide for themselves whether to use paper and pens, or the ground and a stick, or concrete and chalk. Water problems and labour needs are often identified during this exercise. To see if and when activities overlap, team members then draw up proper charts.

3.2.5.4 Application

PRA techniques can be applied to virtually any investigation. Their benefits are greatest if the research is linked to the planning and implementation of a development project. Participatory mapping and matrix ranking can, for example, be used to identify community irrigation lands, water resources and priorities for development. The information obtained can in turn be used for the development or redevelopment of a water improvement plan or an irrigation scheme by a team consisting of specialists and community members. PRA has been developed primarily for application where there is a need to harness the knowledge of small farmers and to ensure transparency in decision-making.

3.3 PARTICIPATORY IRRIGATION PLANNING

3.3.1 PIP OBJECTIVES

The phrase 'Participatory Irrigation Planning' (PIP) was coined by the project research team. It is a synthesis of the Sondeo research method, the Rapid Rural Appraisal (RRA) method and the standard Participatory Rural Appraisal (PRA) method, all of which were described above. It means that all participants are invited to take part in the process of identifying, analysing and solving problems so that all options are considered before recommendations are made. The PIP method is not preclusive; in fact, it would certainly be quite possible to develop other and possibly better combinations for irrigation planning. The sincere wish, however, is that effective procedures based on qualitative methodologies will develop out of these beginnings.

Participatory planning is necessary because it is wrong to assume that the term 'development' as used by the RDP necessarily implies exchanging the old for the new: Inevitably, development requires an amicable union of old and new technologies. Nevertheless, it is often assumed that people who do not have the means to make a decent living also lack the knowledge to do so, ie, that their technology is inappropriate. Because of this, developers may rush in with new ideas and techniques without establishing whether methods already in use are adequate or not. However, an unsophisticated irrigation method may be found to be the most effective for its intended purpose. PIPs should therefore be used to ascertain which old and new technologies should be united in each situation.

The circumstances and scales of irrigation schemes that need to be investigated are wide-ranging. The potential problems that may be encountered can also vary widely. That is why, once it has been decided, as a consequence of the pre-feasibility study exercise, that it is worth going ahead to investigate a project further, participatory irrigation planning becomes essential, to take account of the specifics of that project.

It is important that the participatory assessment is not confined just to the potential irrigators but also considers the impact of any proposed development on other members of the community, small businesses in the area, traditional leaders, transitional councils and the various government departments associated with rural development. Where feasible, all stakeholders should participate in the PIP process.

'Planning' implies the gathering of facts, analysis, conclusions and decisions, before the final drawing up of programmed development. Planning must go further than the short-term restoration of infrastructure because a community must plot a course into the future that will ensure the sustainability of the project, which can involve a wide range of activities and organisations. One of the main objectives of a participatory irrigation planning exercise is to empower a community to do its own planning.

3.3.2 PIP TEAM COMPOSITION

All the people involved in the investigation, the facilitators, the farmers and all the other stakeholders are really part of the PIP team. However, the 'PIP team' is generally understood to include as co-facilitators any experts from outside the local community, called in to be part of the group. The participatory processes do not come naturally so this part of the team is particularly important. Facilitators should have a certain amount of training although, even then, there are many individuals who still feel uncomfortable when required to apply the methods. The best solution to this is to develop exercises and procedures that make the task a natural one for both the people doing (ie, facilitating) the investigation, and the farmers and other stakeholders who are the subjects of the investigation.

The particular exercises and procedures adopted and the size of the team facilitating the investigation will depend on the physical size and diversity of the scheme, as well as on the degree to which the team members, as individuals, can cope with the technical aspects. For some situations, good local knowledge and a sound grasp of irrigation and crop production principles may be sufficient. A team of two people, one biased to the technical side of irrigation and the other a generalist, could then facilitate an investigation. Two people are suggested as a minimum so that one can take notes while the other guides the interview.

There are, however, situations where half a dozen technical specialists are needed to cope with all the vagaries of soils, water quality, suitability of climate for the cropping programme, mechanisation, sustainability and economic viability, hydrological investigations, internal organisations of the community, management structures, etc. The facilitator is then faced with the task of orchestrating a multi-disciplinary team, not easy at the best of times.

Participatory planning cannot be done in a hurry. No matter what technique is used, it is essential to ensure that the community becomes thoroughly familiar with the issues at stake; and it takes time to build up the necessary relationships with the various members of the community so that good communication can occur. It takes even more time to guide the community in analysing their own situation and planning for the future.

If it is accepted that, for successful, economically sustainable irrigation, yields must be up to acceptable levels, then purely theoretical guidance to the farmers is of very little practical use. They need to know what the 'acceptable levels' of yield are, and what can be done safely under their particular working circumstances and climatic conditions to achieve those yields. It may require the integrated input of a number of specialists to come up with a recipe that can be guaranteed. It may even be necessary to undertake field research to obtain the necessary practical knowledge.

It is not possible to give guidance unless there is certainty about the methods and practices that can be applied so an actual PIP exercise is described below as an example.

3.3.3 THE STRYDKRAAL AND MOOIPLAATS PIP

3.3.3.1 The background

The PIP exercise was undertaken after the three Strydkraal and Mooiplaats communities farming some 300 hectares on the Arabies-Olifants irrigation scheme in the Northern Province expressed the wish to become independent managers of their own irrigation affairs. The communities were facing specific problems as a consequence of heavy flood damage so the facilitation team included specialists from a range of disciplines equipped to address the particular problems in the area. There were in the team, therefore, crop-, soil- and climate researchers, irrigation and drainage engineers, small-scale mechanisation specialists, extensionists, social scientists, and financial- and small-business advisors.

The task of the team of experts was to find workable solutions for the problems specific to the area, with the full participation of the community – solutions suitable, not only to the soil, climate and resources of the area, but also to the people. The specialists had not had prior exposure to participatory methods so that the exercise doubled as a training course for them in these techniques.

3.3.3.2 The techniques

A number of the standard PRA and Sondeo techniques were applied but, in this case, the co-facilitators were essentially the technical specialists, reinforced by local extension officers, development and health workers, and Farmer Committee chairmen (see for a list of participants and their organisations). Participation in the various skills of listening, inspecting, observing and arguing together substituted for the Sondeo approach of visiting individual farmers in pairs. Members of the team were expected, not only to advise on matters related to their own field of expertise, but also to contribute to the solution of problems faced by other disciplines. A valuable part of the PIP exercise is the practice of regrouping at the end of every day to discuss, interpret and analyse the information gathered.

An essential element of PIP, taken from PRA, where many of the participants are illiterate, is the use of visual techniques. These may require drawing on the ground (or paper), constructing models using soil, stones, leaves and twigs, and developing 'spreadsheets' using seeds or stones to fill in the cells. It is important that the participants do this themselves after due consideration. The facilitator finally makes a copy as best he can to have the final product on record for all.

The PRA techniques applied in the PIP are discussed below (see Appendix 3.B for examples of the visual techniques).

Time line is the technique used to establish what happened in the past and what the present situation is. In this exercise, for instance, it was learnt that irrigation had not been possible for the past two years. The team found out what crops were last planted when, and that flooding was the reason for low yields. It emerged from talks with the community that there was a great need for enlarging the dam to irrigate a new area.

Community maps are essential to establish facts such as the locality of problem areas and of proposed new lands. Everybody has an opportunity to make a contribution. For this reason, maps are first drawn on the ground and, when finalised, copy on to paper.

Seasonality charts are useful to indicate when the planting, fertilising, weeding, harvesting and selling of the different crops take place. Water problems and labour needs are often identified during this exercise. Proper charts are then drawn up to see if and when activities overlap.

Transects were done on three main areas, ie, on flood-damaged lands, proposed new lands, and food gardens. In this way, information about existing pipelines, electricity supplies, fences and soil types was gathered.

Pairwise ranking of problems is a highly effective way of identifying priorities. Participants are asked to list problems and indicate their rankings. The results showed that the most important problem was flooding, followed by land damage and implement maintenance, then came water storage, then salinity and credit, and, lastly, the availability of markets.

3.3.3.3 The process

The PIP took place in nine consecutive days of very hard, yet pleasant work for the whole team. Work started at 07:00 in the morning and continued until 21:00 or 21:30 in the evenings, including the days on which fieldwork took place.

The PIP team learned the PRA techniques and principles in one-and-a-half days – a task that would normally take at least twice as much time. This short cut was justified by the fact that the team was able to apply the techniques effectively when they joined up with the communities.

It is not easy to describe the experience of meeting with and getting to know and appreciate a community battling with desperately difficult circumstances. For this reason, a 'diary' of the first PIP is included as Appendix 3-C.

3.3.3.4 What the PIP established

According to the farmers, the re-planning of the scheme in 1984 and the introduction of sprinkle irrigation to replace flood irrigation resulted in a dramatic improvement in production but this was not sustained. The reasons for a steady drop in yields until production virtually ceased on some plots were not clear. The previous three seasons, however, had been disastrous, with drought and water shortages being followed by locusts and floods. There was salinity, probably resulting from over-irrigation when water was freely available, over-fertilisation with fertilisers containing potassium (which already occurs naturally), and lack of maintenance of drainage ditches.

Food security and the local sales of products such as vegetables were previously not permitted on the plots, where the concentration was on cash crops such as cotton and wheat, marketed by the parastatal. There was one very well-constructed and well-run community garden with twenty-two members, and a second one had been mooted. In addition, there were a number of unofficial gardens that were constructed between the canal and the formal farming plots, obtaining water from the canal by means of unofficial off-taps. In several cases, plot holders had developed these foodplots because, with the commercial irrigation and tillage practices currently practised, it was not possible to diversify, even though it was presumably permitted by the time the PIP was done.

The Strydkraal community included some three hundred farmers and twenty-two members of the community garden, but there were reportedly another 1 200 people who would like to have a plot. Any re-planning action would have to take note of this desire and the development of community gardens, foodplots and some expansion of the conventional plots needed to be considered.

Strydkraal was essentially a dormitory area, with the bulk of income being derived from pensions and wages earned in the major urban centres. It was privileged in that it was next to the river and had water and access to good soils, unlike most of the many surrounding villages and towns.

3.3.3.5 Subsequent actions

The natural reaction immediately after an exercise of this nature is to attempt to rectify the identified wrongs and relieve immediate needs. Priority was given to improving water supply, restoring irrigation equipment damaged in floods or worn out, organising production credit, and identifying both crops that would provide higher returns, and ways of ensuring that the tractors were kept in good repair and were available when needed.

Through the full support of the Northern Province DOA and the ARDC, assisted by institutes of the ARC, most of the objectives set just after the PIP have been met. Essentially, this has amounted to restoring the status quo. The danger is that, while this can relieve immediate hardships, it does not in itself ensure the future sustainability of the scheme or the well-being of the community.

Possibly insufficient attention was given to the long-term irrigation development strategy along the river. At this stage, predicting the future is difficult, but there is a case for planning for infrastructure that will provide the greatest possible flexibility for independent development.

3.4 THE WAY FORWARD

3.4.1 THE NEED FOR POLICY AND STRATEGIES

There is a perception that the principle reason for the almost complete failure of irrigation as a means of promoting development was the top-down approach that was followed, and that the main remedy is to transfer the schemes and their management to the farmers themselves. PIP was developed as a tool to facilitate and rationalise this process. Preliminary experience indicates that the PIP approach can bring new insights and understanding, but will be of little value if the assumptions on which future development is based are flawed.

Future development should be based on the assumption that irrigation is only one facet of the bigger issue of rural development in resource-poor provinces. The factors that make irrigation possible (considered in detail in Chapter 2, which deals with feasibility studies), viz, the availability of suitable soil and water and a climate that is conducive to crop production, are rural development assets and should be seen in this context and not in isolation.

There does not seem to be a general rural development policy and this is understandable. Circumstances vary so much that it is probably only possible to develop specific strategies applicable to provinces' regions and sub-regions. Irrigation must, however, be part of the wider activity of rural development.

3.4.1.1 Polices and strategies for Strydkraal and Mooiplaats

The Strydkraal-Mooiplaats PIP proved successful in assessing the status quo and defining immediate corrective action, but it achieved little in terms of long-term planning and the development of policy. The people of the community that took part in the Strydkraal-Mooiplaats PIP knew their own situation and had valuable suggestions to make on reconstruction and future management but they could only do this in the context of the world they knew. The facilitators were not in a position to sound them out on alternatives because no alternatives have, as yet, been formulated at policy level.

What are the essential policy matters that need to be decided? The Strydkraal-Mooiplaats situation can be used as an example to illustrate the need for direction. The 300 farmers have plots of 1.25 hectares each allocated to them, presumably by the tribal authority. Their experience since the early 1980s has been with sprinkle irrigation, where four farmers take it in turns with piping and sprinklers. Water is supplied by canal and a series of pump stations from the Arabie-Olifants irrigation scheme. The management was initially handled by an agency and latterly by the Department of Agriculture, assisted by farmer committees. Cropping was prescribed by the management agency and the farmers were paid out the balance left at the end of the season, after expenses were deducted from the proceeds realised for the cotton, wheat, groundnut, or maize crop. The production of garden crops for own use or sale on the 'official' plots or with 'official' water was strictly prohibited.

The farmers broke away from the management agency and now have greater freedom of action, but are so conditioned that they find it virtually impossible to think up alternatives.

What are the scenarios that could have policy implications?

- Continuation of present farming activities but with greater freedom of crop choice and 'own' management of the scheme;
- Reorganisation of the scheme to cater for 'commercial' farming and holdings of an economically viable size, say 10 hectares;
- Maintenance of present plots but with the upgrading of infrastructure to allow irrigation versatility and possible 'natural' integration into larger holdings;
- Concentration on the food security aspect, with the area being divided up into 0.1 hectare plots to allow for many more participants, or possibly a combination of this with maintaining some of the existing plots;
- Development of a communal citrus estate feeding a central pack house and/or juicing plant;
- Downgrading of the scheme to reduce additional capital investment and concentrate on community gardens and foodplots on good soils; or
- Provision of additional reticulation and support for home gardening on the generous plots on which the houses have been erected.

How would these various scenarios relate to the regional plans for rural development (if any) and how can PIP or associated participatory techniques contribute to the creation of policy? It must not be forgotten that the responsibility under discussion is to plan irrigation, not to solve all the problems of the deprived rural communities.

3.4.2 PARTICIPANTS IN PIP AND POLICY FORMULATION

Since undertaking the Strydkraal-Mooiplaats PIP, it has become apparent that, as well as technical specialists, the facilitation team should include generalists who know the area and the people. It is also important to pull in representatives of all those engaged in rural administration and development.

The PIP approach to the various stakeholders in a project is discussed in the concluding sections of this chapter.

3.4.2.1 The present or proposed participants (farmers) in a scheme

The request for the up-grading or development of a new scheme will normally come from the participants (farmers) themselves. Participatory investigations will inevitably concentrate on them in the first instance. The PIP procedure enables the team to get to know the people, the situation on the ground, the aspirations of the farmers and the things they believe should be put right. There will be suggestions as to what should be done and how it can be done. Normally, the shortcomings of management and extension personnel will be accurately presented. This provides a valuable understanding of the situation that was rarely achieved using conventional approaches to evaluation. There may also be innovative new proposals and those can be followed up subsequently.

The team will be able to assess the participants as farmers and individuals. They will see whether there is a spirit of enthusiasm, whether they are helping themselves, whether their present crops are satisfactory, whether they understand irrigation, and whether there is a potential for success.

It is important to look at the local organisations and committees that they may have set up themselves. Are these effective; is there a constitution; have they come up with local arrangements to tackle the land tenure problem (for example, sharecropping); and have they found a market for their surplus produce?

This knowledge of the irrigation fraternity can be of considerable value to the policy-makers, in that it can bring an element of humanity into decision-making.

3.4.2.2 The resource-poor

It has been estimated that 60% of the people in the deep rural areas are resource-poor. They do not have access to land or jobs and own no livestock. They are rarely considered when an irrigation study is being undertaken and, while it is not suggested that the concentration should be on these people (it is not the purpose of the exercise), they should not be left out of the reckoning. The PIP should include PRA-type interviews with their representatives, particularly women, in order to establish their interest in growing vegetables and to assess their experience and ability.

It may then be possible to provide for this group by tagging foodplots and/or community gardens onto the existing or proposed scheme infrastructure. This was done in the case of the original flood schemes in the Eastern Cape and an evaluation of what happened would be valuable. There are frequent requests for community gardens on the grounds of the poverty of villages but the cost of the infrastructure for such independent gardens is very high. A better understanding of the degree to which irrigation can assist the resource poor would be of value in policy formulation.

3.4.2.3 The informal business sector

This sector is the local distribution channel and includes the village stores serving isolated communities, bakkie and kombi operators and hawkers. Only too often, the produce they sell originates from the large regional markets and is unnecessarily expensive for the rural communities. Representatives from this sector should be included in a PIP team because marketing can make or break an irrigation project. Inside knowledge of the way in which local trading operates, and of the degree of support that the irrigators can expect from this sector is essential. No PIP investigation is acceptable if this is not taken into account.

The informal sector includes the tractor contractors who provide mechanisation and transport services. In most communities, there are so-called 'bush mechanics' that keep the vehicles on the road at reasonable cost. Could they not play a part in keeping irrigation equipment operational? They too should be consulted in a PIP exercise.

3.4.2.4 The formal business sector

In the irrigation planning context, this includes the co-operatives, banks, suppliers of equipment and inputs, and the farmer organisations that process, package and market fruit and other specialist products. There are many organisations that have worked closely with small-scale farmers and have provided valuable services, ranging from credit and specialist advice, through to the supply of appropriate inputs.

The participation of these organisations in introducing practical expertise into PIP activities can go a long way towards promoting policies that are realistic and can lead to sustainable small-scale irrigation farming. In addition, the close contact the commercial concerns will develop by participating will enhance their understanding of small-scale farmers and their needs and this should be to the benefit of all.

3.4.2.5 Regional councils and rural development organisations

There are organisations specifically concerned with planning and implementing development in the rural areas. It is important that they participate in PIP activities. This has been difficult to arrange in the past, partly because irrigation was considered an independent activity and the preserve of the Departments of Agriculture (DOAs), and partly because of a lack of capacity on their part. Circumstances are changing, however, and it is unthinkable that irrigation schemes can be initiated and implemented without the close co-operation of the authorities in the area. The arrangements for consultation and participation should be made at local level.

3.4.2.6 Departments of Agriculture and parastatals

The management and maintenance of the previous irrigation schemes has been handled by these organisations and the last few years have not been easy. The policy when many of the later schemes were implemented was largely influenced by the financier, the Development Bank of South Africa (DBSA), and was reasonably clear-cut. Because development is such a long process, we are now in a transitional phase in which their position is not so clear-cut, but it is important that the new policy be firmed up as soon as possible.

3.4.2.7 Traditional leaders and institutions

It is important that the role of the traditional authorities in a democratic South Africa be seen in a positive light. Land tenure is a continual problem but irrigation is dependent on effective co-operation and, in many cases, it was found that the farmers themselves, acting with and through the traditional authorities, had developed satisfactory solutions. It therefore goes without saying that these authorities should be fully recognised in all PIP activities.

3.5 CONCLUSIONS AND RECOMMENDATIONS

Initially, it was not appreciated that establishing policy for future development would be a major issue, and that participatory techniques would be part of the process. It was assumed that, after appropriate consultation with the farmers, what should be done would have been established and that all that remained would be 'bottom-up' planning and implementation. It was also assumed that the concentration would need to be on technical detail and farmer-based implementation, not on how irrigation should be integrated into rural development and sustainability. These assumptions have since been found to be erroneous. Participatory processes, of which PIP is one, are essential to informed policy development.

Participatory techniques are gaining acceptance in the field. The main practitioners are extension personnel in the Provincial Departments of Agriculture and NG0s. The techniques in which training is being given are Participatory Rural Appraisal (PRA) and Road to Progress (RTP). It has been generally accepted that this is the approach for the future if agriculture is to develop into a viable proposition in the deep rural areas, but there is still a long way to go.

Field personnel are concentrating on training of staff and setting the process in motion so that there has been little time for innovation or experimentation. Senior management are generally not as yet fully in the picture. In the case of irrigation, the integration of technical aspects and the participatory techniques is a challenge. The important role that these techniques can play in policy development is also not fully appreciated.

It is essential that extension personnel versed in the participatory techniques and the specific needs of their agricultural communities are part and parcel of all irrigation ventures from initial assessment to implementation.

Recent South African experience in the application of participatory approaches could be shared at the symposium suggested in Chapter 2

APPENDIX 3.A. NEW LOOK AT THE PIP APPROACH

The following notes were written in connection with an unrelated project by one of the authors, who was a leading participant in the original PIP. A great deal of water had passed under the bridge since that original PIP and it is interesting to observe the developments in thinking.

The proposed project is aimed at revitalisation of the irrigation scheme as a community asset and, in doing so, drawing on the experience of farmers in the scheme. The revitalisation of the irrigation scheme will need to give priority attention to the following elements:

a) Institutional development, including the establishment or strengthening of a farmers' organisation, with membership rules and a management structure, to take ownership of the project and to manage and operate the scheme. The programme will include training support in operating and managing the scheme. The institutional development and capacity building will be responsive to an analysis of the gender roles in the scheme.

b) Development of products and services by the farmers' organisation, as required by irrigation farmers. This would normally include farmer training, access to mechanisation and input supplies. These products and services will be affordable and appropriate to the farmers' vision of a suitable marketing and production context for their scheme (eg, food security or high value export contracts, as two extreme examples). Thus, as appropriate, these services would include establishment of marketing contracts or regular outlets.

c) Strategy and guidelines for the gradual improvement and adaptation of the irrigation scheme in response to local management circumstances and market growth, to enable increased and sustained production and profitability.

3.A.1. *METHODOLOGY*

3.A.1.1 Interdisciplinary assessment of development potential

The physical and economic potential for sustainable development is assessed through a desk study and modified Sondeo approach before engaging the community in vision-building. With the Sondeo approach, a multi-disciplinary team visits the area and interviews key informants in pairs, to facilitate on-site exchange between disciplines, thus ensuring an integrated recommendation focussing on problem-solving of the issues.

3.A.1.2 Pre-development survey, vision building and participatory formulation of the community Development Strategy

The pre-development survey is a community vision-building exercise based on participatory analyses and semi-structured interviews with individuals and community groups, including a poverty and gender analysis. Current farming practices and training needs are assessed. Irrigation farmers and non-irrigators in the community are invited to participate in the analyses, so as to establish a thorough understanding of the development context and community priorities. The product of the pre-development survey is the community's Development Strategy, which reflects the vision, priorities and responsibilities of the community and other role-players in the development programme.

3.A.1.3 Institutional development: Establishment of voluntary farmer groups with elected management committees

Sustainable community-based development is dependent on strong institutional arrangements within the scheme and clear links with other relevant structures and service providers. To be sustainable, participation in the development should be voluntary and each group elects its own management committee. Capacity-building of the committee ensures that there is clarity on the responsibilities and functioning of the committee and that the committee can effectively interact with its group members, neighbouring committees and outside role-players.

3.A.1.4 Developing and conducting needs-based training courses for farmers and their committees in accordance with their Development Strategy and realistic access to inputs, support services and markets

These courses may include modules on agricultural production, financial management and record-keeping, institutional arrangements and scheme management and operation. Training requirements are identified by community members and other participants during the pre-development survey and vision-building.

3.A.1.5 Networking with role-players to establish services, input provision and markets

Current thinking on the economic regeneration of rural areas focuses on creating links between local initiatives through outsourcing the provision of services and products to local suppliers. This includes the establishment of small, micro and medium enterprises (SMMEs) to provide services and products to local development initiatives and institutions like clinics, hospitals, mines, tourist facilities, etc. In this context, irrigation schemes are both suppliers of produce and users of services and inputs from other SMMEs. The revitalisation of the irrigation scheme would include an analysis of the opportunities, and networking with potential role-players to establish the necessary links for input, service procurement and marketing of produce.

3.A.1.6 Labour-intensive construction and community project management of gradual and on-going infrastructure improvement

Experience with user-management of irrigation schemes world-wide has been mixed (as reported by the International Water Management Institute) and has often resulted in the continuation of a medium-term cycle of scheme degeneration and refurbishment. One of the positive alternative experiences, followed in the Indian state of Andra Pradesh, was to empower the farmer organisation to decide on and execute a programme of on-going infrastructure improvement. This resulted in continuous upgrading of the scheme and effectively broke the typical ten-year cycle of major decline and rehabilitation.

In this context, initial repairs to the scheme are kept to the minimum that is required to restart production. Further improvement and scheme extensions are undertaken in later phases, and in response to market forces.

To maximise the benefits of the development initiative to the broader community and to ensure that the capacity and know-how exists in the community, all construction is done on a labour-intensive basis under direct community management.

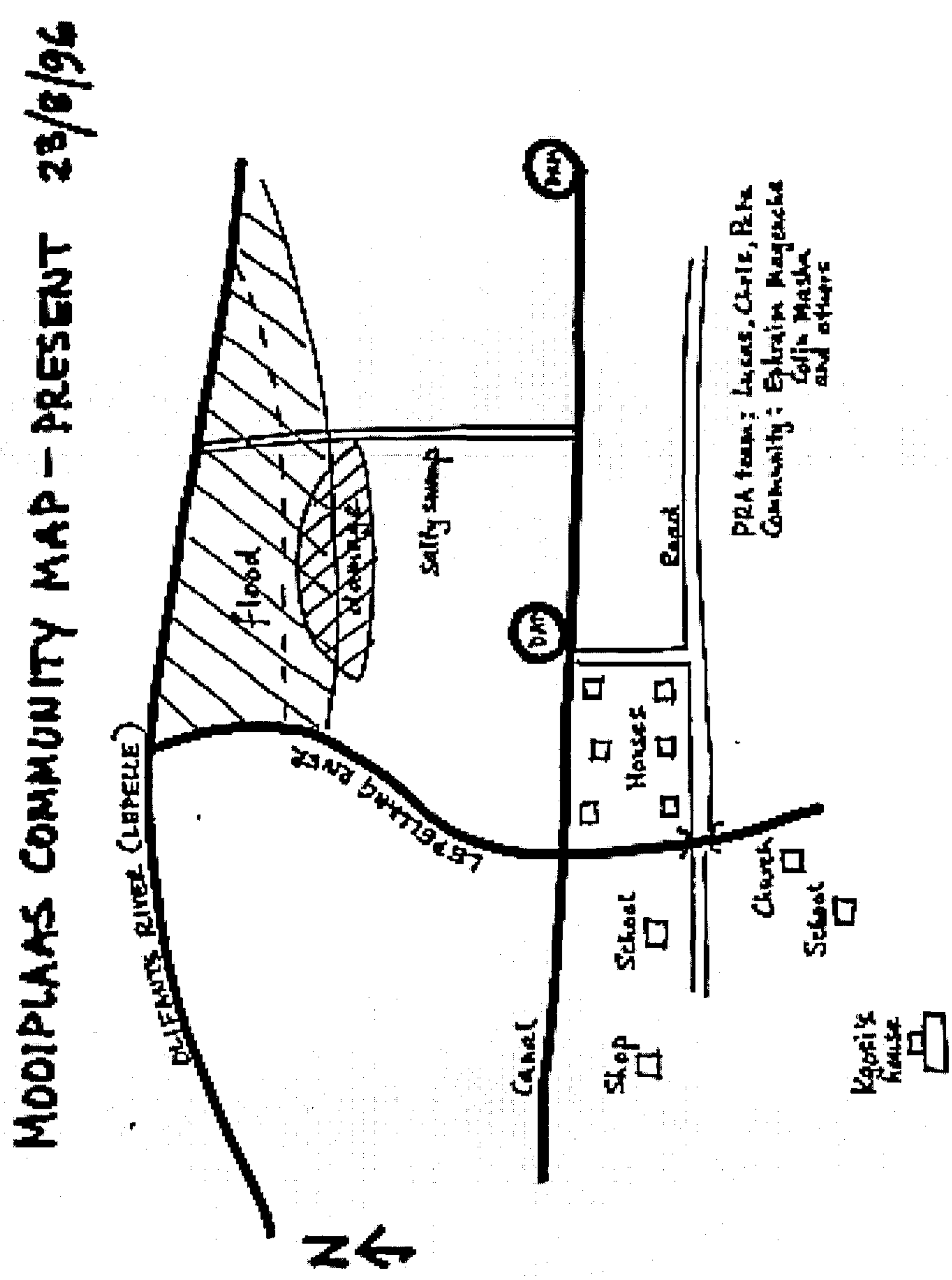
APPENDIX 3.B. EXAMPLES OF THE PRA VISUAL TECHNIQUES

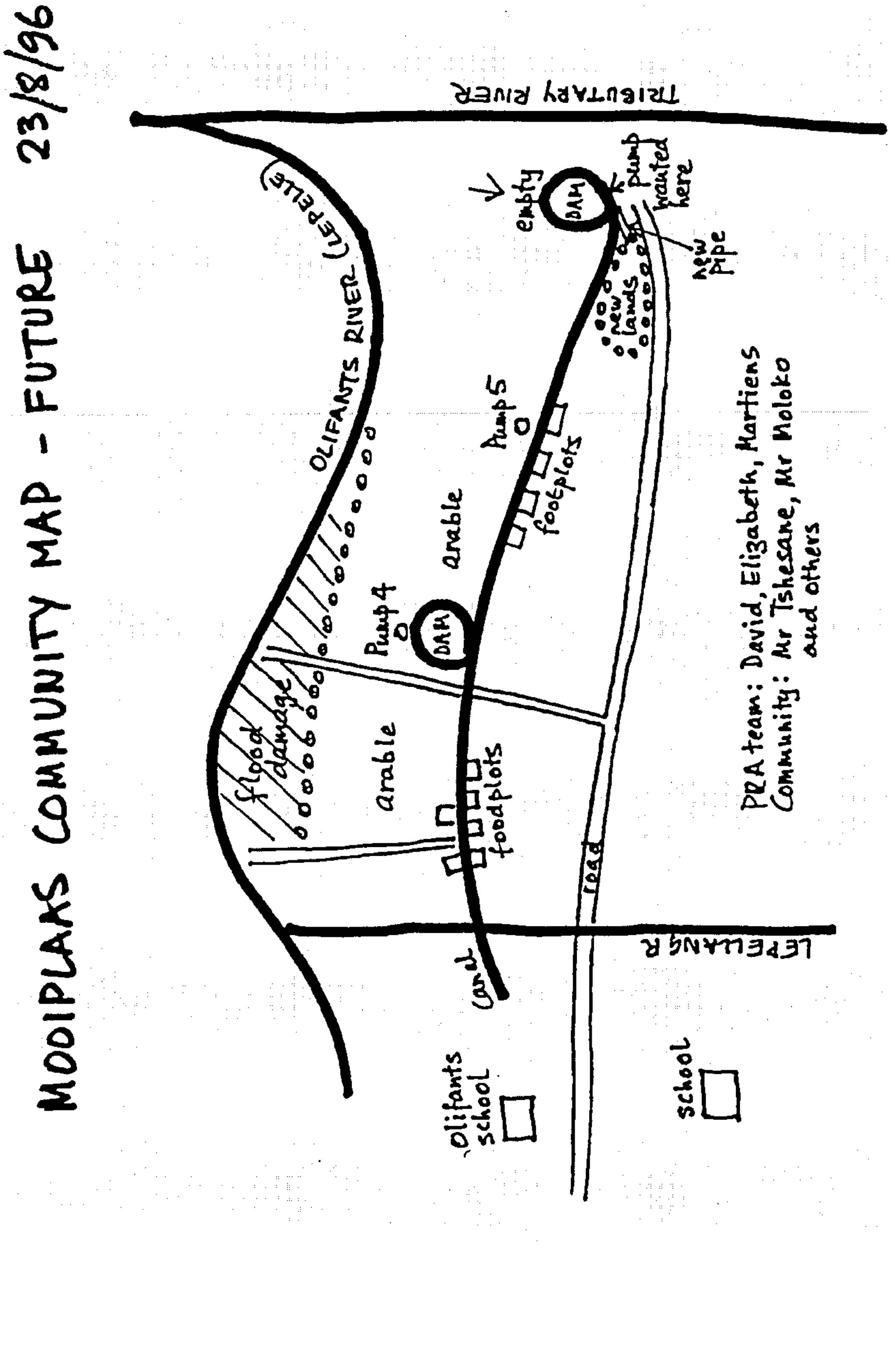
MOOIPLAAS TIMELINE 23/8/96

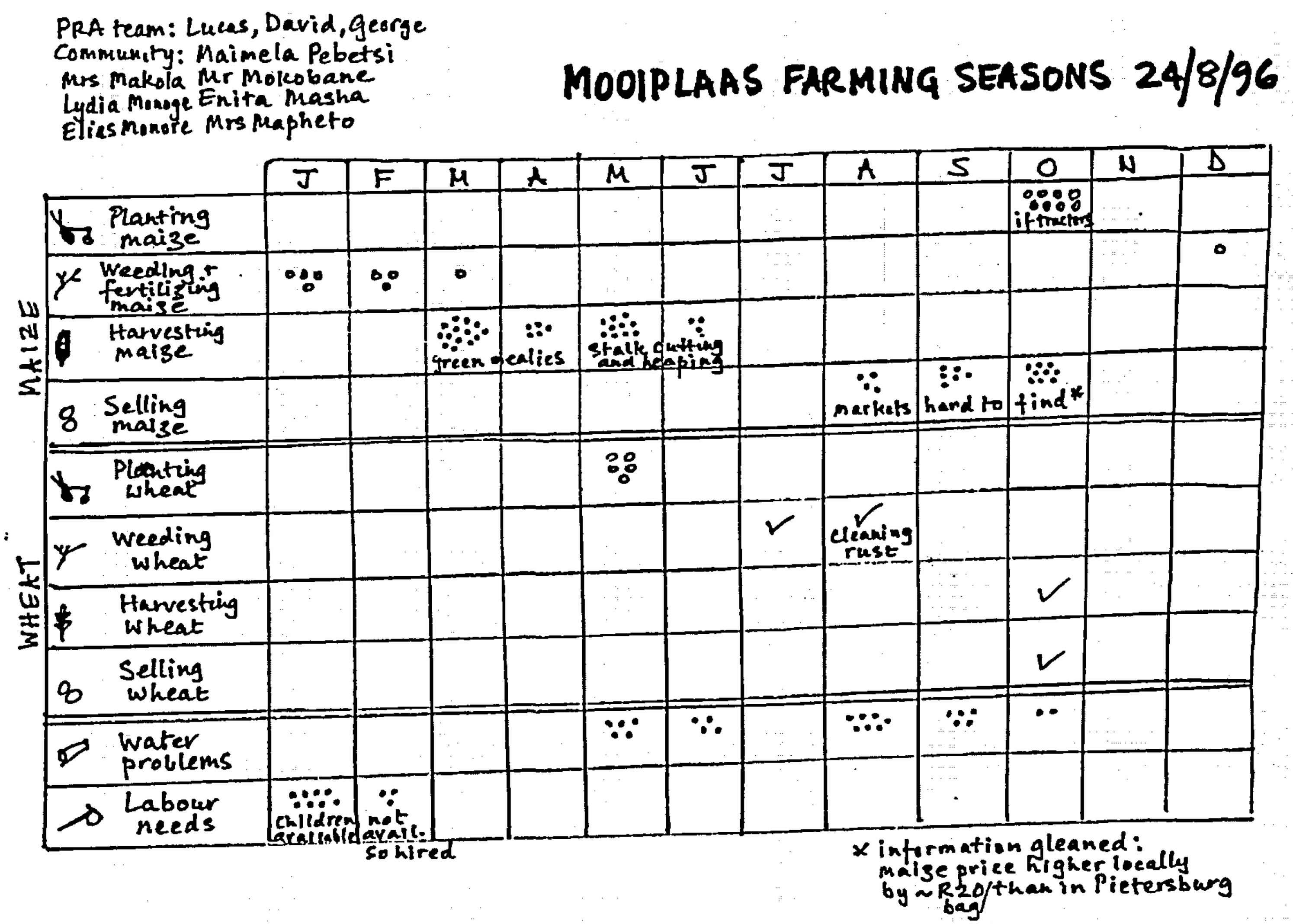
YEAR	COMMENTS
1947	Mud canal
1950	Using cattle on small lands, few water furrows
1952	Cementing of canal and small furrows
1953	Asked for bigger fields to invade forest from Extension off.
1961	More cementing of furrows. Ploughing only with cattle
1981	Lands levelled and small cemented furrows destroyed.
1984	Machines installed - bigger lands allocated. Introduction of sprinklers. Tractor ploughing started. Drainage installed. Better yields.
1985	Gardens along canal started – use of small portions because of no money to expand, or for fertilizer.
1986	No transport for manure because of money problems. Salination begins. Shortage of water, AMS monitors canal.
1993	Water shortages increase. AMS withdraws, Farmers' Associations formed. Change of crops. Cotton grown. Pumps and tractors broken.
1996	No ploughing because of floods. No drainage programme.

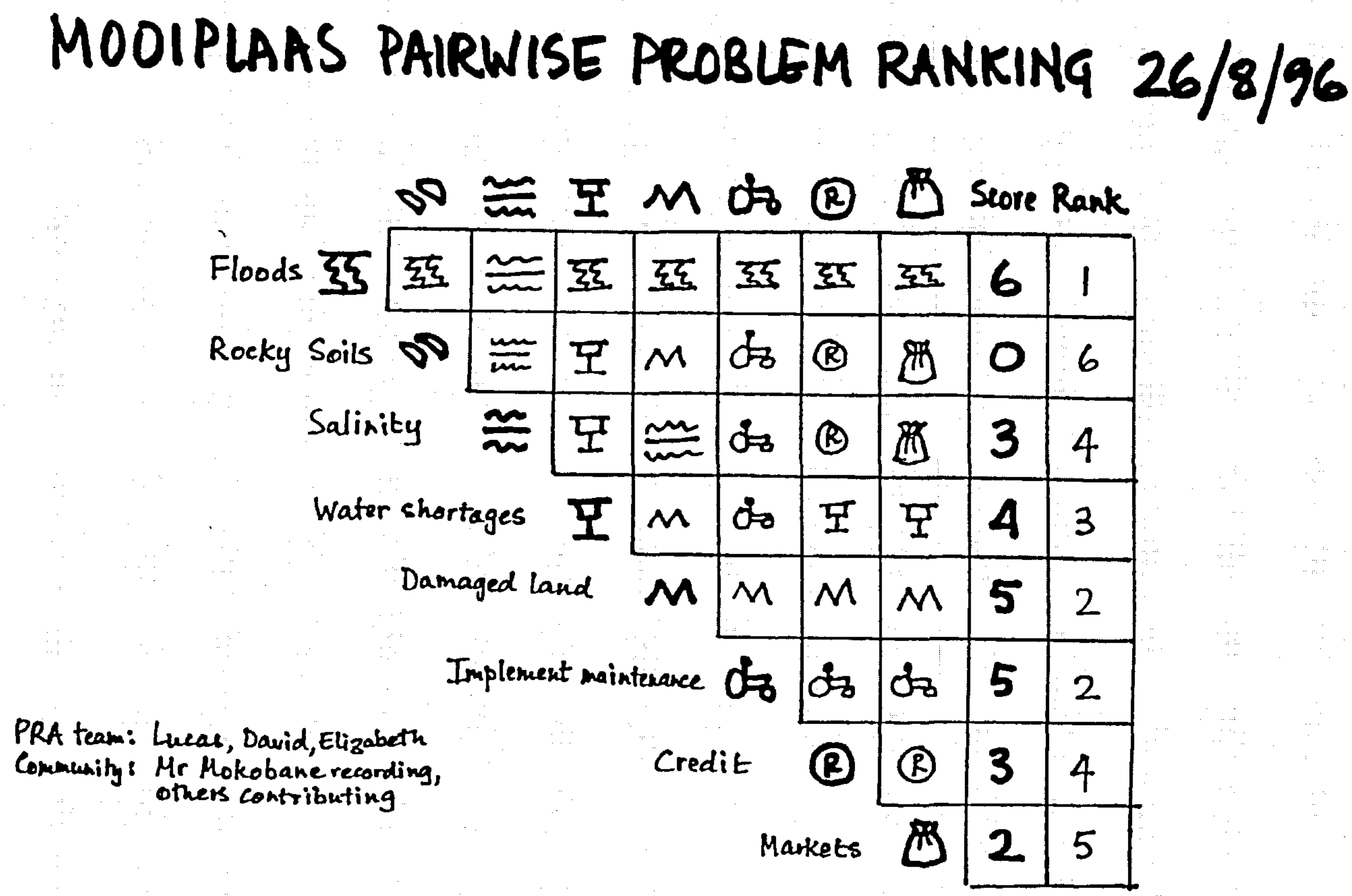
PRA team: Lucas, David, George, Elizabeth, Martiens.

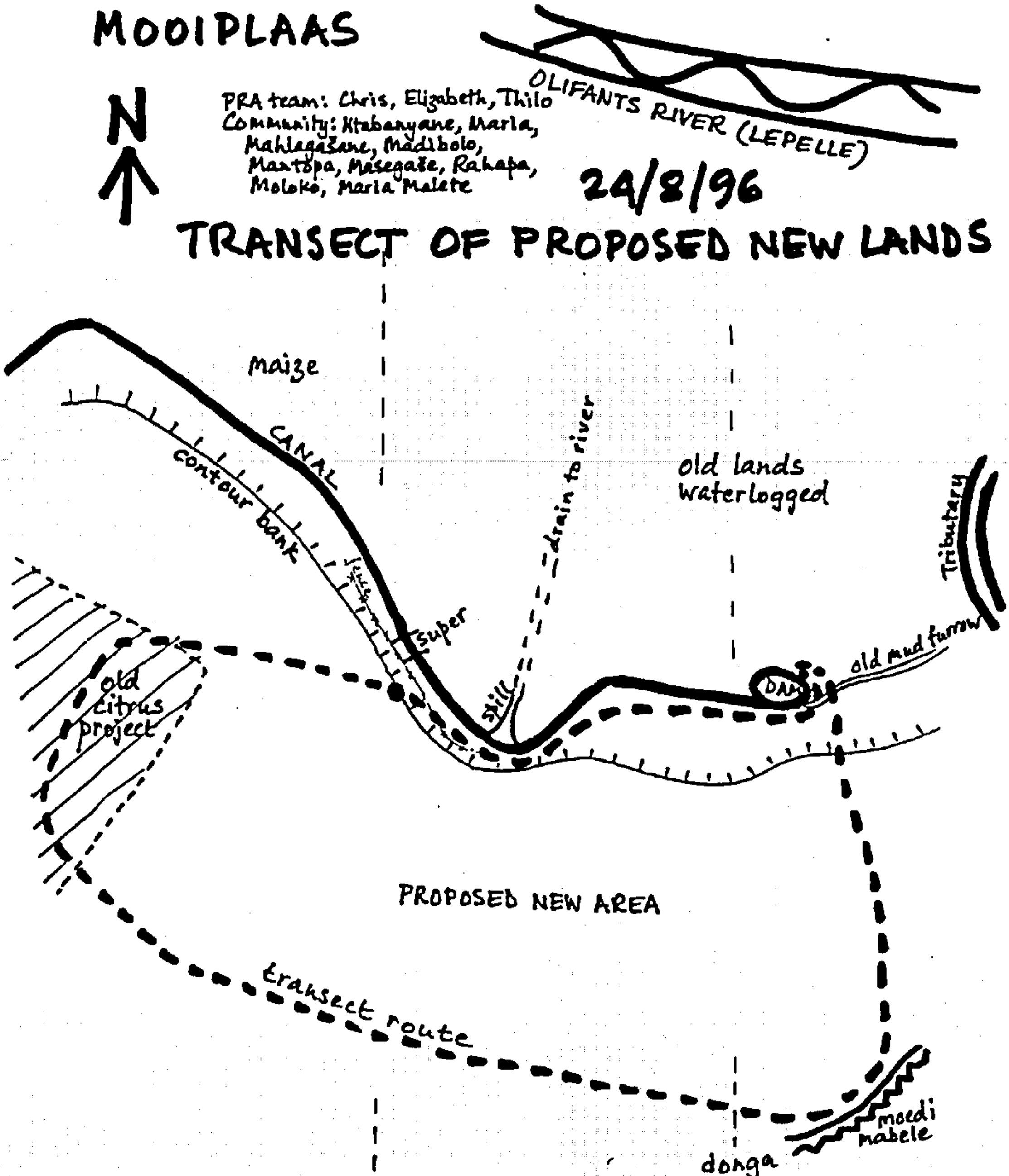
Community: Elias Monore with inputs from others.


MODIPLAAS COMMUNITY MAP - PRESENT 28/8/96
OLIFANTS RIVER (LEPELLE)
Flood
Salty swamp
DAM
DAM
Canal
Road
Houses
School
School
Shop
Church
Kgosi's house
N

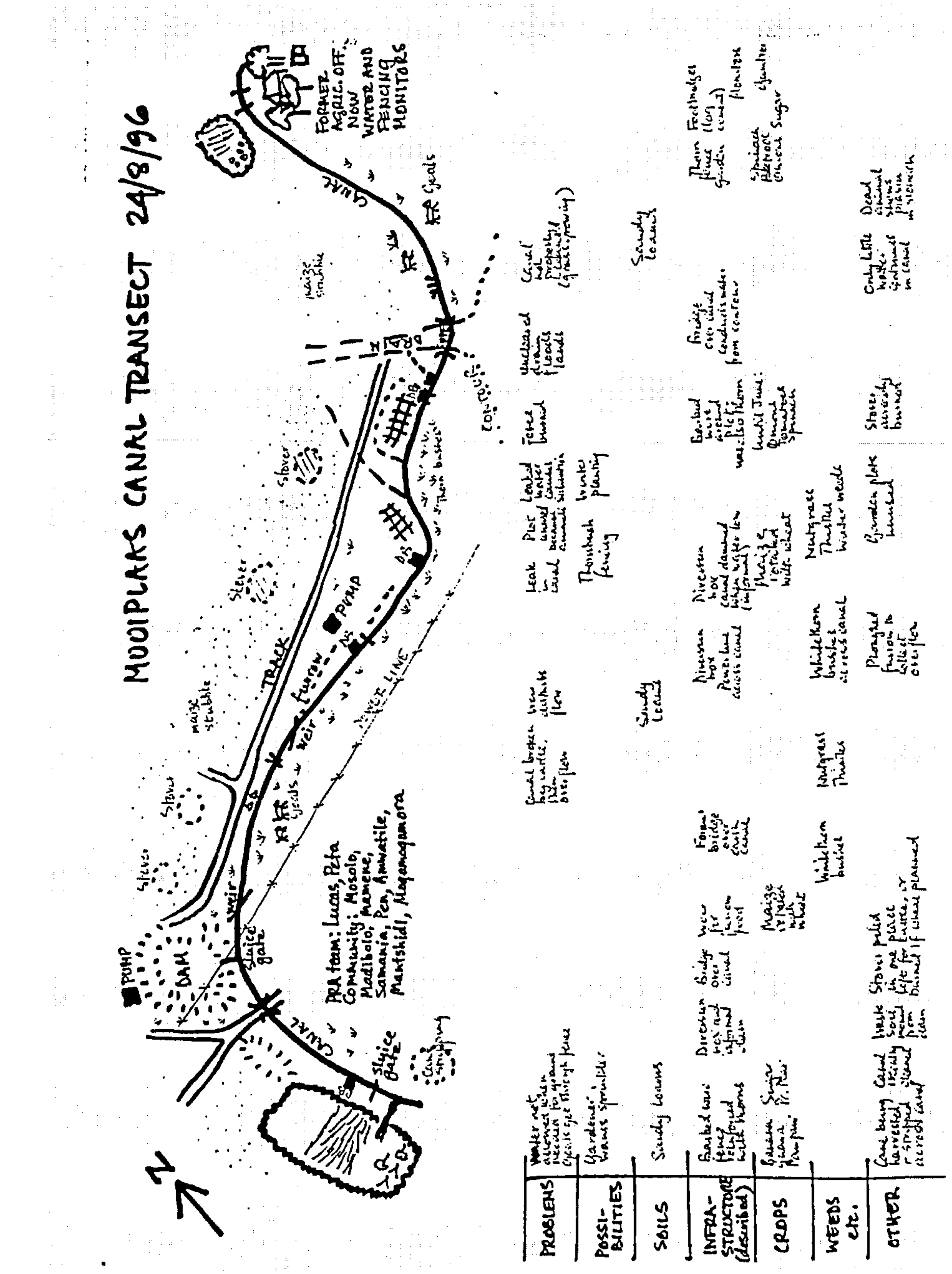

MODIPLAAS COMMUNITY MAP - FUTURE 23/8/96
TRIBUTARY RIVER
OLIFANTS RIVER (LEPELLE)
LEPELLANG R
empty
DAM
pump wanted here
new pipe
new lands
Pump 5
footplots
arable
Pump 4
DAM
flood damage
arable
foodplots
road
canal
olifants school
school
PRA team: David, Elizabeth, Martiens
Community: Mr Tshesane, Mr Moloko and others


PRA team: Lucas, David, George
Community: Maimela Pebetsi
Mrs Makola Mr Mokobane
Lydia Monoge Enita Masha
Elias Monote Mrs Mapheto
MOOIPLAAS FARMING SEASONS 24/8/96
J F M A M J J A S O N D
MAIZE
Planting maize
Weeding & fertilizing maize
Harvesting maize
Selling maize
WHEAT
Planting wheat
Weeding wheat
Harvesting wheat
Selling wheat
Water problems
Labour needs
if tractors
green mealies
stalk cutting and heaping
markets hard to find*
cleaning rust
children not available
not avail. so hired
* information gleaned: maize price higher locally by ~R20/bag than in Pietersburg


MODIPLAAS PAIRWISE PROBLEM RANKING 26/8/96
Score Rank
Floods 6 1
Rocky Soils 0 6
Salinity 3 4
Water shortages 4 3
Damaged land 5 2
Implement maintenance 5 2
Credit 3 4
Markets 2 5
PRA team: Lucas, David, Elizabeth
Community: Mr Mokobane recording, others contributing



PROBLEMS	Canal dirty, full of algae	Old lands waterlogged	dam too small
OPPORTUNITIES	clear proposed area and fence it (employment) 100 bags maize		dam enlargement pump from Lepelle River supplementing water into canal from Lepellang River
SOILS	Sandy loam	Sandy loam	black crust
OBSERVATIONS	existing system of cleaning canal: 2 weeks/farmer/section	bushes: Acacia karoo grass: curly grass, knack	


MOOIPLAAS CANAL TRANSECT 24/8/96
PRA team: Lucas, Peta
PUMP
DAM
sluice gate
weir
TRACK
furrow
PUMP
POWER LINE
CANAL
CONTOURS
maize stubble
FORMER AGRIC. OFF. NOW WATER AND FENCING MONITORS
N
PROBLEMS
POSSI-BILITIES
SOILS
INFRA-STRUCTURE (described)
CROPS
WEEDS etc.
OTHER

APPENDIX 3.C. THE PIP PROCESS

Wednesday – 21 August 1996. The PIP team met at the Lobethal Lutheran Mission Station for lunch, after which work started under the guidance of the co-facilitators, Marna de Lange and Thilo Thormeyer.

From the 'Hopes and Fears' session, it was apparent that the team was there with commitment and purpose to bring about real changes. Some fears of lack of co-operation and 'difficult to understand proceedings' were alleviated as we progressed.

The background to the PIP was sketched, emphasising that the PIP was arranged following a request from the community and their expression that they wanted to 'stand on their own feet'. The PIP team was therefore called together to help the farming community plan for their desired future. At the same time, the PIP was not an event in isolation, but formed part of the greater current and ongoing actions related to the Olifants Irrigation Scheme.

James Wulf of ARDC provided the team with information about the irrigation schemes and the position after the floods. This was followed by an introduction of each of the team members and how their current activities related to Strydkraal and Mooiplaats.

After dinner, the philosophy of and background to the development of the PRA and Sondeo methods were sketched.

Thursday – 22 August 1996. Thursday was devoted to getting familiar with some of the PRA techniques, including **mapping, timeline, Venn diagramming, seasonality charts and transects**.

In the evening, the team were briefed on the communities of Strydkraal and Mooiplaats, in order to prepare for fieldwork the next day. The advice of the two farmer leaders and the four local extension officers who were part of the PIP team was of great value in this regard. The team split into three sub-teams to facilitate work with the three communities of Strydkraal A, Strydkraal B and Mooiplaats separately.

Friday – 23 August 1996. Friday morning before breakfast, the three sub-teams planned their fieldwork separately. A session on the 'do's and don'ts of interacting with the community' was presented by Lucas Serage (one of the team members) before we left for the tribal offices at Strydkraal A. All of us were slightly apprehensive and not sure quite what to expect. Would people turn up at all? What if several hundred people turned up: how would we handle it?

On arrival at the Strydkraal tribal offices, we were delighted to find a group of about eighty people waiting outside – the typical situation, with the women sitting together on one side and the men conversing in a separate group. The women in the PIP team introduced themselves and sat down with the women of the community. This preliminary friendly and informal discussion broke the ice and was the beginning of friendships that would be forged over the next few days. The group grew to about a hundred people by the time the meeting started. In the formal meeting, which started at 11:30, the PIP team and the community were introduced to each other. Kgosi Masha spoke with empathy and passion about the farmers' dream of independence and the responsibility they and the PIP team shared to work together towards a better future. The formal gathering broke up at 12:30 when people were asked to group according to the three villages and gather outside under the trees to start work. Each group completed a timeline (history) covering cropping, natural disasters and other important events and mapped their village and farmlands.

By 14:30, everybody was exhausted and the community very hungry so each separate gathering concluded with an agreement to meet the following day at a time and place suggested by the community.

The PIP team visited the wheat cultivar trials on Kgosi's field, followed by a visit to the vegetable and short-furrow irrigation trials at the Wonderboom Experiment Station. The extent of the floods that passed through the previous year was evident at Wonderboom. We had dinner on our return to

Lobethal, and then reconvened for a report-back session on our findings and experiences of the day, with some brainstorming regarding planning for fieldwork the next day.

The general feeling after the first day was that, while it had been a long day with seemingly limited results in the form of hard facts, the main aims of the day had been achieved. The team had established a good working relationship with the community and Kgosi's support for the PIP was clear to all. Further, the team had become more accustomed to the use of the methods and to each other, so that we were better prepared for our further work. Friday was concluded at 21:30 with a presentation of another PRA method, **pairwise ranking**. Thereafter it was over to the sub-teams to prepare for their next day's fieldwork as and when they could. Most sub-teams agreed to meet at 07:00 Saturday morning to start their preparations before breakfast, in order to leave in time for their meetings with the communities scheduled for 10:00 at the lands.

Saturday – 24 August 1996. Saturday morning's fieldwork was much more varied, owing to the sub-teams' own focus, and the situation met with at each of the farms. Various transects were done on each farm, during which farmers pointed out their prevalent problems and opportunities while walking through their fields with the team members. Cropping and labour patterns were discussed, using seasonality diagrams; problems and opportunities were mapped; and a time trend recorded of decreasing yield on one plot, evidently as a result of steady salinisation due to various factors. Following the pattern set the first day, the PIP team reconvened after dinner to report back on the day's work. This time the amount of information gathered and analysed was almost overwhelming.

Now the question arose: What to do with all this? It was decided to devote Sunday morning to a technical session to assess the possibilities and opportunities before our next meeting with the communities on Monday morning

Sunday – 25 August 1996. On Sunday morning before breakfast (07:00-08:00), Charles Crosby introduced the team to the purpose of the technical session and developed some guidelines along which the technical sub-teams could structure their discussions. Four broad subjects were identified from the results of the previous two days' fieldwork and the PIP team members were free to join the technical interest group of their choice.

The four topics: **Drainage and Land Use Planning; Irrigation and Water Supply; Cropping Patterns and New Crops;** and **Training** were discussed for the rest of the morning.

Work stopped between 9:30 and 11:00 to leave the team members free to join the church service in the Lobethal church or spend their time on devotions as they chose.

After lunch, the team departed on a study tour of the intensively irrigated Loskop scheme, and the Arabie Dam and surrounding areas. This tour was arranged by special request of the local extension officers and provided a welcome break in the tight nine-day schedule. It did a great deal to boost morale and build team spirit. From then on, singing became an important element in proceedings!

After dinner the team convened for report-back on the technical sessions of the morning. There were interesting developments. The crop group had developed a 'new' **crop ranking** matrix that the communities applied with effect, while the irrigation and water supply group came up with suggestions for upgrading the irrigation system to facilitate individual farmer independence. Peta Jones concluded the day by explaining the **problem tree** technique.

Monday – 26 August 1996. The sub-teams met with their groups for a morning in the field. This was a follow-up session and was an opportunity to present some of the ideas developed at the technical discussions. In addition, various techniques were applied to assist the farmers to formulate needs and develop action priorities.

The Mooiplaats community was eager to help with land drainage, the identification and development of new lands to replace plots wiped out by the floods, the clearing of canals and weirs, and the extension of the tailings dam at the end of the canal to increase irrigation possibilities.

The Strydkraal A group assessed the possibilities of alternative crops, together with the application of hop-along and dragline sprinkler systems. The extent of flooding was accurately indicated on all plots by the Strydkraal B group, and future land use scenarios were discussed. The crop selection matrix was applied to assess possibilities.

In the afternoon, the team regrouped according to technical interests and visits were made to important places on all three farms. Improved water supply and distribution, citrus and vegetable production, and drainage and land-use planning received particular attention.

Tuesday – 27 August 1996. Tuesday was spent collating the information gleaned from the fieldwork and technical sessions and preparing sub-team reports [to] be consolidated into a comprehensive project report that will be widely circulated.

Copies were made onto A4-sized sheets of paper of all the exercises on flipchart paper generated by the community, so that the A4's could be included in the report and the original flipchart copies could be returned to the community before our departure.

Wednesday – 28 August 1996. On Wednesday morning, the PIP team was accompanied on a tour by Kgosi Masha, members of his council and members of the Farmers' Committees to key points in the area. This enabled them to share the PIP team's interpretations of the findings of the past week's work with the community, and their recommendations. This was a valuable session, and the community leaders could clarify some aspects to the members of the PIP team.

Wednesday's fieldwork session with the three farming communities was conducted at the tribal offices, so that the full group could convene afterwards for report-back to each other and to Kgosi Masha.

A representative of each community then presented these community plans to the full meeting. Charles Crosby concluded this final meeting with the community with an overview of the work done during this first PIP exercise. He expressed his appreciation that even more people had gathered for this final meeting than for the first one a week earlier, indicating the communities' commitment to seeking solutions for their problems. He stressed that this was only the beginning of a period of close interaction towards fulfilment of the communities' dream of independence. Kgosi Masha reinforced this, reminding the community and the PIP team of his statement during his welcoming address, that a journey of a thousand miles begins with one small step – the first few steps had been taken and everyone should be committed to continue on the journey.

The meeting was concluded very late at about 19:00, but everybody stayed to the end – even those community members who lived quite a distance away. Transport was quickly arranged to spare these people the hour's walk back to their villages.

Kgosi Masha treated the PIP team to a braai at the agricultural offices and stated that the events of the past nine days had been an eye-opener to him.

Thursday – 29 August 1996. On Thursday morning before breakfast, the team shared thoughts about the events of the previous day, and the communities' priorities, as they were evident from the communities' plans.

The rest of the morning was spent in developing a detailed action plan for the immediate future, based on the needs and priorities of the community. It was appreciated that action had to be taken to maintain momentum but that it was important that this be limited to what could be done without compromising team members' own, or other, organisations. It was surprising just what was possible if the experience and competence of members could be harnessed.

APPENDIX 3.D. EVOLUTIONARY DEVELOPMENT INITIATED THROUGH TRAINING (EDITT)

These notes on the concept of evolutionary development initiated through training were written in 1999 by a PIP participant. As in the case of Appendix 3.A, it is interesting to note the similarities to and differences from the thinking in the pioneering PIP exercise.

Participatory planning methods require in-depth consultation with the community and its leaders. It is proving virtually impossible to undertake this task as an academic exercise in isolation – there are too many expectations raised. In addition, how can we expect people to make important decisions on their future when all they have experienced has been hardship and poverty?

Change, as has been proved so often on irrigation schemes, cannot be brought about by presenting people with infrastructure and equipment overnight and expecting them, with the aid of 'extension', to be successful farmers. The policy proposals in the Green Paper acknowledge this and cater for development over time and for the phasing out of concessions and special support as people and organisations find their feet.

This participatory process owes much to the 'development through training' initiative implemented by Johann Adendorff at Phokwani in the Northern Province some ten years ago. He succeeded, with the support of a handful of Lebowa Agricultural Corporation (LAC) colleagues and two seconded extension technicians, in revolutionising the lives of 7 000 small farmers over a period of some four years. The transformation from the normal four to five bags to the hectare to producing 11 000 tons of surplus maize for sale to the co-operative was achieved by women and old men farming independently under dryland conditions.

Evolutionary Development Initiated through Training (EDITT) is based on facilitating development so that participants progress to independence and new technical and economic levels within familiar surroundings and circumstances, and with full recognition of their intrinsic knowledge, experience and worth as people.

As the name indicates, the approach is based on two premises. The first is that development, and redevelopment, should not be 'instant' but evolutionary. The second is that development must start with training if the process is to have any hope of success. Participants must be well-informed and have the opportunity to expand their knowledge of irrigation farming and related activities.

Training can increase production to levels that improve the position of a community significantly without the need for drastic change (Adendorff, de Lange and Crosby, 1999). With success based on knowledge and experience comes the competence to participate in planning and implementing evolutionary development. This is not a short-term approach. Full rehabilitation and privatisation of a scheme could take ten or more years. From the outset, an important objective would be to achieve reasonable financial viability, taking into account initial external assistance, both technical and financial.

This approach would include the progressive rehabilitation of infrastructure rather than a 'once off' upgrading of the whole scheme to a predetermined standard. Water supply provision and irrigation system development would be in phase with the development tempo of the farmers and in accordance with their needs. Initially, water provision might be temporary in nature.

EDITT has a number of key elements.

Training is initially concentrated on participants who respond to an invitation to form small groups with a common interest in improving their agricultural production. The training is 'hands on and site specific' with follow-up during the season on the farmers' own fields.

Training can only be targeted if it is preceded by a careful assessment as to why the group is not presently achieving satisfactory production and what corrective action is required. The initial objective must be to demonstrate significant improvement within the limits of present circumstances, provided this is technically possible and practically feasible.

The scope and nature of the rehabilitated project, and eventual training requirements, must be assessed in the light of natural resources (water, soils, climate and crops), support requirements (infrastructure, finance, input provisioning and marketing) and the role of the scheme in promoting the interests of present and potential participants. It is essential to look beyond the *status quo* because the interests of all may be best served by new land occupation and crop patterns.

Effective institutional and land security arrangements are essential, as is access to support services. These are times of change and the way forward is not yet clear. There is, however, reason to believe that 'top-down' approaches in any guise are doomed to failure. New structures should have their origins in the people directly involved 'on the ground'. The initial starting point could well be the original groups and their committees.

The role of planners is not to prescribe but to facilitate. This includes integrating and interpreting the facts gathered in co-operation with the communities, and presenting understandable options for development in the foreseeable future. A long-term strategy aimed at full independence is desirable, provided it is flexible and allows for opportunities to change direction and even exit if necessary. Infrastructure and services should be developed in harmony with requirements, leaving room for innovation and risk taking. Funds should not be committed now for an uncertain future.

- Initially, development would be low key, possibly starting with the groups of people who were most interested in developing their plots, and would progress sequentially until the basic skills of irrigation farming had been mastered. It can be expected that the sphere of participation would snowball. This is normal and desirable.
- Training based on building confidence and competence is the key to the process. Not only training of the farmers, but of the extensionists, of the people that will be managing the schemes, and of the suppliers of inputs and equipment.
- Evolutionary development would allow time for extension officers and farmers to become competent – allow time for satisfactory financial and marketing arrangements to develop. There would be a natural process for defining the extent and nature of the final development.
- Land tenure, in all its forms and with all its implications, is a major factor in future development, particularly in irrigation schemes that demand relatively high investment. An evolutionary approach would allow the various models of land tenure to be evaluated through implementation on a progressive basis.
- The far-reaching implications of this process should not be under-estimated. While, obviously, some general rules will emerge, each scheme will be unique in size, nature, the people concerned, management and the quality of the natural resources. Each scheme will demand inputs from knowledgeable, practical people.
- Particularly in the early stages, rule-of-thumb solutions will have to be avoided. In time, in specific areas, it can be expected that a pattern will emerge. Engineers and agronomists will need to develop crop and irrigation systems that meet the present circumstances of the farmers, while not losing sight of future developments. It becomes a challenge to consultants to plan the infrastructure and crop production development to coincide with and support suchan evolutionary approach. The way in which the consultants are appointed and paid will have to be such that it enables the process. Continuity of involvement is important because there is always the danger that new consultants could derail the process through not properly understanding the reasoning that led to prior decisions and designs.
- It is important in the interests of sustainability that the interests of the community as a whole, and not only those of the irrigation farmers, are taken into consideration. There can be no question of sustainability if the process is sabotaged by excluded or shabbily treated community members. The process through which property rights are obtained and the nature of the rights is what counts.
- Recent legislation has changed the situation significantly: There are now many possibilities. These differ, however, from the conventional procedures that are followed when freehold land is purchased outside the communal land tenure areas and usually imply some form of communal ownership and the legal right to negotiate loans and raise funds from their participants.
- Land tenure issues cannot be standardised, as each scheme is unique. The possibilities and implications of new legislation have not yet been fully explored. Indeed there has been, as yet,

little implementation in the deep rural areas. The farmers themselves are in a difficult position in that the extent of scheme rehabilitation and their own future activities are still unknowns.

One possibility is a Communal Property Association (CPA) under the Communal Property Act, and another possibility is a Water User Association (WUA) under the new Water Act. (It is not yet clear how the CPAs and WUAs can complement each other, especially on irrigation schemes associated with multiple rural villages.) There are also other possibilities, including Section 21 companies.

Chapter 4

MANAGING CROP WATER REQUIREMENTS

See also *Irrigation Design Manual* (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

4.1 INTRODUCTION 4-1

4.1.1 Crop production and irrigation requirements 4-1

4.1.2 Estimating crop evapotranspiration 4-2

4.1.3 Designing for irrigation management 4-2

4.2 CROP PRODUCTION UNDER IRRIGATION 4-2

4.2.1 Introduction 4-2

4.2.2 Role of canopy cover 4-3

4.2.3 Crops and cultivars 4-3

4.2.4 Agronomic practices 4-4

4.2.5 Climate 4-4

4.2.6 Evapotranspiration 4-4

4.2.7 Plant population 4-6

4.2.8 Economics 4-6

4.3 ESTIMATING CROP EVAPOTRANSPIRATION 4-7

4.3.1 Introduction 4-7

4.3.2 Using SAPWAT 4-7

4.3.3 Climatic data 4-7

4.3.4 Reference evapotranspiration (ETo) 4-7

4.3.5 Developing the crop factor 4-9

4.3.6 Water requirement 4-10

4.3.7 Scheduling planning 4-10

4.3.8 Scheduling and planning outputs 4-11

4.4 CROP FACTORS APPROPRIATE TO SMALL-SCALE IRRIGATION 4-13

4.4.1 Introduction 4-13

4.4.2 The influence of planting date and locality 4-13

4.5 DESIGNING FOR IRRIGATION MANAGEMENT 4-13
4.5.1 Introduction 4-13
4.5.2 Pre-scheduled irrigation with progressive depletion of soil water 4-15
4.5.3 The appropriate utilisation of the soil water reservoir 4-17
4.5.4 The impact of water shortages 4-18
4.5.5 Augmenting rainfall 4-19
4.6 GENERAL CONCLUSIONS AND RECOMMENDATIONS 4-22

APPENDIX 4.A. THE IMPLICATIONS OF SAPWAT IN DESIGN 4-22

FIGURES AND TABLES

Table 4.4.2: Seasonal values (mm) for late varieties of cabbage and peak monthly ETcrop and irrigation requirements for several localities and planting dates. 4-13
Table 4.5.3.3: Water application programme and minimum effective irrigation requirement (IR) mm per cycle for WHEAT (170 days season) with a target yield of 6 000 kg/ha 4-16
Figure 4.5.6.4a: The effect of planting density on grain yield of maize at various water levels – 1985/86 4-20
Figure 4.5.6.4b: The effect of planting density on grain yield of maize at various water levels – 1986/87 4-21
Figure 4.5.6.4c: The effect of planting density on grain yield of maize at various water levels – 1987/88 4-21

4.1 INTRODUCTION

Irrigated crops are generally expected to use more water but to have considerably higher yields than rainfed crops. The estimation of crop water requirements is therefore an essential starting point, first when considering the viability of either farm-scale or major irrigation projects, and later when planning their development. Inappropriately high estimates can have a major impact on decisions whether or not to go ahead with irrigation policy or design. However, even if a project gets the go-ahead, inappropriately high estimates of crop water requirements can diminish the eventual economic viability and operational sustainability of a project.

It is generally understood that irrigated crops will be stressed for such projects and that yields (or production levels) will be dangerously reduced if they suffer water shortages. The procedures currently used in South Africa to estimate crop water requirements and develop irrigation strategy therefore aim *at ensuring that irrigated crops are not subjected to stress as a consequence of water shortages.* This means that they aim at ensuring "a disease-free crop grown in large fields under optimum soil, water and fertility conditions, and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, FAO No 24, 1977).

Planners and engineers apply these procedures without modification, when planning irrigation schemes for all farmers, big or small. This has led to an anomalous situation. Storage and conveyance works and in-field irrigation equipment are designed for the projected yields that can be expected under optimum conditions and cater for peak periods of crop water requirements. The circumstances of small farmers are allowed for negatively by adjusting the estimates of projected yields downwards, without allowing any positive adjustments to estimates of other factors. The consequences are unfavourable financial projections that can mean project proposals are needlessly rejected on the grounds that the project is unsustainable. The small-scale farmers may, as a consequence, be denied a scheme that would, in fact, have been sustainable. This would not happen if a more realistic approach, in balance with the expected yields and practices of small-scale farmers, were utilised to estimate crop water requirements. The realistic approach would be to weigh up the factors that influence crop production and irrigation crop water requirements for each scheme proposal, in order to determine, first, sustainability and then, development priorities.

4.1.1 CROP PRODUCTION AND IRRIGATION REQUIREMENTS

This project has disclosed that there is little understanding in South Africa of the factors that influence crop production and crop water requirements in irrigation. This applies across the board, if one excludes a small group comprising scientists engaged in irrigation research, scheduling consultants and perceptive input suppliers and farmers. This is to the detriment of all irrigation but is especially detrimental for small-scale farmers, who also face resource, market and management constraints.

The present estimation procedures relate to the water requirements of the crop when it is achieving full yield potential. In most small-farmer situations, however, the crop is not managed to achieve full yield potential. This is because small farmers are risk-aversive. They are reluctant to incur the cost of the inputs required to achieve full yield, and the danger of losing this investment if something goes wrong, so they seldom aim for high yield levels and instead adopt a conservative approach to promote sustainability. In the long term, this cuts costs by relatively low planting densities, a tendency to plant on wide beds, and fertiliser applications that are lower than is normal in conventional irrigation practice. Consequently, at maximum cover, the canopy may not cover 100% of the land surface and approximates to the canopy of a good rainfed crop, rather than that of a conventional irrigated crop. The nett results are yields that, though less than maximum, are still high, and irrigation requirements that may be significantly lower than those presently used in estimations of sustainability.

Irrigation can, however, only be sustainable if yield is at an adequately high level. It is essential that sound farming practices are applied and there can be no question of indifferent crop yields. Low yield levels are probably the main reason for the failure of so many small-scale farmer irrigation schemes. There is therefore an urgent need for a better understanding, at all levels, of what constitutes a water 'shortage' for a crop and what is required to promote adequate yield levels.

It is with no apology that the first section of this chapter focuses on water use efficiency (WUE) and is largely literature-based.

4.1.2 ESTIMATING CROP EVAPOTRANSPIRATION

The current procedures applied in planning and design for estimating crop evapotranspiration are due for updating. This is because of a move, away from the normal A-pan based method of estimating crop evapotranspiration, to the short-grass (Penman-Monteith) estimation method. The two methods are very similar, the main difference being the reference evaporation on which the estimates of crop evapotranspiration are based. The reference evaporation for the A-pan method is a flat water surface and the reference evaporation for the short-grass method is a living crop of short grass. The scientific fraternity and the industry providing equipment for irrigation farmers have accepted the advantages of changing to the short-grass method of estimating crop evapotranspiration, and the changeover will be implemented in the near future.

The short-grass method is a new one in South Africa, although internationally it has been the norm since the late 1970s. It is important to appreciate the impact of this change on planning and design, particularly in small-scale and emergent farmer situations. The procedures are dealt with in some detail in the second part of this chapter, where the discussion is centred on the programs that form the basis of the revised procedures.

4.1.3 DESIGNING FOR IRRIGATION MANAGEMENT

Another issue dealt with in this chapter is the need to take irrigation management methods into account at the design phase. The normal practice in South Africa is to design for peak crop water requirements. The designer's assumption is that the farmer will then 'schedule' and ensures that the timing or volume of irrigation is so managed that the correct quantity of water is applied when the demand is less than peak. **There is a distinct 'division of responsibilities' between the designer and the farmer. In the case of centre pivot and micro irrigation with electronic control, this is not an insurmountable problem but, under other circumstances, this gulf between designer and farmer is a serious deficiency.**

However, when both designer and farmer have the same understanding of crop/irrigation relationships, significant improvements and savings can be achieved through design. There are ways of designing to promote simpler and more efficient management of irrigation for the farmer. This is of particular importance when small-scale farmer projects are being planned and designed. These farmers face constraints that make non-standard irrigation management procedures more the rule than the exception and these should be addressed from the outset.

This chapter concludes with a discussion on designing for the effective on-farm management of irrigation water because the tools and methods are available but few practitioners know about them or how to obtain access to them.

4.2 CROP PRODUCTION UNDER IRRIGATION

4.2.1 INTRODUCTION

It is important that all concerned with the development of small-scale irrigation understand the basic principles of crop production under irrigation because there are many distortions and misconceptions that can cloud sound judgement.

The book, *Efficient use of irrigation water* by Professor G H Sankara Reddi and Dr T Yellamanda Reddy of the Andhra Pradesh Agricultural University, India, includes a chapter, 'Irrigation efficiencies and water use efficiencies' (pp 199–218), which provides a well organised and authoritative review. While irrigation in India is vast in comparison to South Africa, in both countries, water resources are limited in relation to needs and so available water has to be used as efficiently as possible. In both countries, small-scale farmers are significant. Extensive use has therefore been made of this publication in developing this section of the chapter, and the boxes contain selected abstracts.

It is important to have rules of the game when it is necessary to stray off the beaten track while developing norms and procedures appropriate to small-scale irrigation farming. People who are concerned with irrigation planning and design but do not have an insight into soil-water-plant relationships and agronomy must be able to skim through a short review of the factors that matter before making decisions. What follows is a short review of this kind.

Water use efficiency is a simple but seldom-used concept. However, it is a vital consideration when planning to use water for irrigation because, generally, when water use efficiency is high, the farmer makes a profit but, if water use efficiency is low, the farmer makes a loss. In simple terms, water use efficiency (WUE) can be described as the measurement of how much water to give the plant in its environment in order to yield a crop that can be sold for enough money to cover the cost of producing it.

Most of the water used by the plant is lost through evaporation and transpiration, together called evapotranspiration. As water used for metabolic purposes (crop growth) is only a small fraction of the total water used by the plant, it is ignored and the discussion of WUE that follows only refers to the water used for evapotranspiration. The factors that govern the WUE of crops are discussed in physical terms of the ratio of output (marketable yield or economic yield of crop) to input (irrigation water used).

Water use efficiency is the yield of marketable crop produced per unit of water used in evapotranspiration, ie,

WUE = Y/ ETcrop where,
WUE = Water use efficiency (kg/ha mm);
Y = Marketable yield of the crop (kg/ha); and
ETcrop = Evapotranspiration (mm).

4.2.2 ROLE OF CANOPY COVER

Once the soil surface has been fully shaded by the canopy, there is little increase in ETcrop, even if, through fertilisation and disease control, the leaves and consequently the crop yield increase considerably.

Under an optimal water supply, ETcrop is not dependent on the kind of plant canopy, provided the soil is adequately covered with crop, but is dependent upon physical environment, especially weather. Increasing the amount of plant canopy has, therefore, little effect on ETcrop. Obviously any practice that promotes leaf growth and the more efficient use of sunlight in photosynthesis without causing a corresponding increase in ETcrop will increase WUE. There is considerable opportunity in the field to increase the ratio of yield to water use and to improve WUE. This opportunity is maximised under irrigation where there is sufficient water for ETcrop to approach the potential set by nett radiation. Crop variety, agronomic practices, climate, ETo (reference evapotranspiration), irrigation, fertilisation, plant population and interaction of productive factors all influence water use efficiency.

4.2.3 CROPS AND CULTIVARS

Growing appropriate crops and suitable varieties of these crops in tune with water availability and environmental conditions is important, if irrigation water is to be efficiently used. However, small-scale farmers seldom pay attention to crop and variety selection and, although there are legitimate reasons for this, consolidated information on local selections is needed. This is because sound crop production practices result in efficient water use.

4.2.3.1 The importance of crop and variety selection

The expansion of growth and development in plants is the result of interaction between their genetic constitution and the environmental conditions in which they grow. Plant species, therefore, differ widely in their efficiency of dry matter production. **There are considerable differences in how much water different crops use to produce a unit of dry matter. There are also differences in how much water different cultivars of the same crop use to produce a unit of dry matter.** These differences are due to variations in their genetic build-up, which affect both morphological traits controlling the rate of transpiration and water absorption by roots from the soil and the physiological functions responsible for photosynthesis, respiration and translocation of photosynthates to plant parts. Varieties also differ in their adaptation to environment, in resistance to pests and diseases and in management levels. WUE can therefore be increased by selection of properly adapted crops with good rooting habits, low transpiration rates and improved energy consumption in photosynthesis.

4.2.4 AGRONOMIC PRACTICES

Timeliness is of paramount importance in irrigation farming. More often than not, small-scale farmers are **late with critical operations.** One of their main complaints concerns mechanisation and this problem must be solved if irrigation is to be sustainable.

Time, depth and pattern of sowing influence WUE by harnessing incident solar radiation to the maximum possible extent and producing a uniformly good crop canopy with mutual shading effect amongst the leaves. Timely sowing ensures proper temperature and other soil physical conditions that favour optimal crop growth and better competition with weed flora. Depth of sowing affects seedling emergence, vigour and final yield. Plant population and orientation influence WUE indirectly by influencing the interception and utilisation of incident solar energy that in turn influences crop yields.

4.2.5 CLIMATE

To understand irrigation, it is important to appreciate that climate impacts differently on yield and water requirement. The Lowveld is hot and the vegetation is lush, but ETcrop and irrigation requirements are modest. ETcrop is not indicative of potential yield, despite the desire of farmers to 'add more water.

> Weather affects both yield and evapotranspiration (ETcrop). **Evapotranspiration is an evaporative process** largely controlled by climatic factors, with energy from incident solar radiation and advected heat, and with vapour and heat flow phenomena controlled by atmospheric vapour content and wind movement. The **plant controls transpiration** and radiation utilisation in photosynthesis.

Solar radiation therefore drives both ETcrop and photosynthesis. Day length and cloud are the main factors influencing the radiation and this largely accounts for the differences in crop water requirements and potential yield between Nelspruit and Upington, Pietersburg and Stellenbosch.

> The amount of radiation determines the rate of photosynthesis and hence the **potential yield.** Other components of climate (temperature, day length, rainfall, etc) influence vital physiological processes and thereby determine the **actual yield.**

Relative humidity is a major factor in determining WUE, which results in the well-known phenomenon that irrigation is more efficient in the more humid areas than it is in the dry areas where it is really needed!

> The lower the relative humidity, the greater will be the ETcrop. **Low relative humidity, which increases transpiration without a corresponding increase in the production of dry matter,** will reduce WUE and there is an almost constant inverse relationship between WUE and evaporation rates. Light and temperature, which normally affect both transpiration and dry matter production, will either increase or decrease WUE according to which of the two predominates

4.2.6 EVAPOTRANSPIRATION

There are practices that can reduce ETcrop and consequently reduce crop water requirements when water supply is critical. These practices should be taken into consideration when planning, particularly in the case of community gardens. Irrigation practitioners tend to regard irrigation as a mechanistic process and to lose sight of the agronomic factors that can play such an important part in the efficiency of irrigation water use. However, irrigation farming must be good farming if it is to be sustainable, and there are additional little details that can play a part.

4.2.6.1 Ridges and furrows

The orientation of ridges and furrows with respect to solar trajectory will influence the nett solar radiation reaching the surface of the soil and so reduce the nett energy available for ETcrop. The south-facing side of an east-west oriented ridge had an average of 6.1°C lower temperature and the west face of the north-south oriented ridge had a 2.6°C higher temperature than a flat surface. Therefore, the south face of the east-west oriented ridges received less evaporating radiation and less water was lost in evaporation.

4.2.6.2 Weed control

Elimination of weeds in crops is the most efficient and practical means of reducing transpiration. Weeds compete with crops for soil nutrients, water and light and have a higher rate of growth and transpire greater amounts of water per unit of dry matter produced than the associated crop plants. Thus, for every gram of dry matter produced by weeds there is a corresponding loss of yield by the crop plant. One plant of common yellow mustard weed needs four times as much water as a well-developed oat plant. **Estimated reductions in yields of crops due to weeds in India are: wheat 6.3 to 34.8%, rice 9.1 to 51.4%, maize 29.5 to 74.0%, millets 6.2 to 40.2%, groundnut 29.7 to 32.9%, sugarcane 14.1 to 71.7%, and cotton 20.7 to 61.0%.**

4.2.6.3 Shelterbelts

Irrigated crops extract large quantities of energy from the air brought in from the nearby uncropped area in the form of sensible heat, which tends to equalise the differences in microclimates between adjacent small areas. This results in measurable differences in sensible heat transfer between upwind and downwind points. The amount of energy advected to the area depends on both the lateral component of wind speed and the difference in sensible heat between upwind and downwind surfaces. Greatest ETcrop loss of water occurs near the upwind edge because the air is drier, and decreases with distance downwind due to the progressive decrease in evaporative demand, depending upon microclimatic parameters.

Frequency of irrigation can therefore be reduced in shallow-rooted crops like onion, garlic etc., without affecting the yields adversely, by planting them on the leeward side and planting other, deep-rooted, taller crops like castor, maize, etc., on the windward side. For example, a deep-rooted tall growing species can be grown in rows aligned against the wind direction in a crop of groundnut.

4.2.6.4 Irrigation application

Inadequate soil moisture as well as excess moisture in the soil have an adverse effect on plant growth and productivity and are, therefore, conducive to low WUE. For each crop and combination of environmental conditions, there is a narrow range of soil moisture levels at which WUE is higher than with a lesser or greater supply of water.

4.2.6.5 Critical soil moisture tension

The optimum soil moisture content of the root-zone is the range of moisture fluctuating between field capacity as the upper limit, and the soil moisture tension level at which the yield of the marketable crop produce is reduced (as the lower limit). The differential response of crops to water stress at different stages of growth is not constant throughout the growing period for a given crop.

4.2.6.6 Frequent irrigation

In general, most crop yields increase when soil moisture level is maintained as near to field capacity as possible. Management programmes that prevent plant water stress even for short periods, optimise water use efficiency. The concept of high-frequency irrigation, which is the basis of drip irrigation, is becoming increasingly acceptable. The most efficient use of water occurs when there is ample water (but not excessive) because the complex photosynthetic process is more sensitive to protoplasmic stress than transpiration.

4.2.6.7 Fertilisation

Irrigation imposes a great demand for fertiliser nutrients. For irrigation to be profitable, yields must be high and higher yields mean greater nutrient uptake by crops, with the nutrient uptake being roughly proportional to crop yield. When the water supply is deficient, the stomata close and photosynthesis decreases. Less dry matter is produced and fertiliser nutrients are less efficiently utilised than when water is plentiful. Thus the interaction of moisture supply and nutrient supply is reciprocal. **[If the farmer cannot irrigate, it is a waste to fertilise; if he cannot fertilise, it is a waste to irrigate.]**

Increase in crop yield produced by increasing soil fertility does not produce a corresponding increase in ETcrop. On the contrary, wide differences in yield induced by differences in soil fertility may result in only small differences in ETcrop.

4.2.7 PLANT POPULATION

The higher yield potential made possible by the favourable water regime provided by irrigation, the high soil fertility levels resulting from heavy application of fertilisers, and the genetic potential of new varieties and hybrids, could be achieved only with appropriate adjustments of the plant population. Plant density has a direct effect on yield, solar energy capture (intercepting radiant energy), evaporation and shading of weeds and thus an indirect effect on WUE. Increasing the number of plants per unit area will reduce the amount of light available to individual plants, and light is most frequently the factor limiting productivity, so that yields ultimately depend on the efficiency with which light is intercepted.

4.2.8 ECONOMICS

All factors that increase plant production do so without markedly increasing ETcrop and will therefore improve WUE. Crop yield is an important determinant of how efficiently water is used and records should be kept. However, in applying any principles related to WUE, **the cost of achieving high yields should be taken into account**. Yield increase from fertilisers, plant population and irrigation decreases incrementally so that each successive unit of input produces less profit than its predecessor. Thus the most profitable crop production must stop short of maximum per hectare production. The highest WUE is also attained at a much lower level of production.

The general tendency is to over-irrigate, especially if water is not bought on the basis of quantity used. This tendency can be avoided only if information is available on the most efficient way to use water.

4.3 ESTIMATING CROP EVAPOTRANSPIRATION

4.3.1 INTRODUCTION

Information on the most efficient way to use water is gained through first establishing how much water is needed, ie, by estimating crop evapotranspiration. Currently, the generally accepted procedure internationally for estimating crop water requirements for planning and design purposes is CROPWAT (Smith, 1992), a computer program that is considered in greater detail in later sections. CROPWAT is a significant improvement on the previous A-pan based procedures but does not cater for variations in irrigation cycle lengths or partial wetting of the soil surface. It is appreciated that this should be addressed (Smith *et al*, 1996) but there is no indication as to when this will be achieved.

It is no simple matter to establish how much water a crop needs. In the course of this research, it was observed that small-scale irrigation farmers were able to 'get by' with significantly less irrigation water than had been estimated at the planning stage and that this could be ascribed to 'non-standard situations and crop production methods'. However, small-scale irrigation was not alone in using less water than expected because modern short-cycle systems such as centre pivot and micro irrigation are also managing with significantly less irrigation water than was estimated at the planning stage.

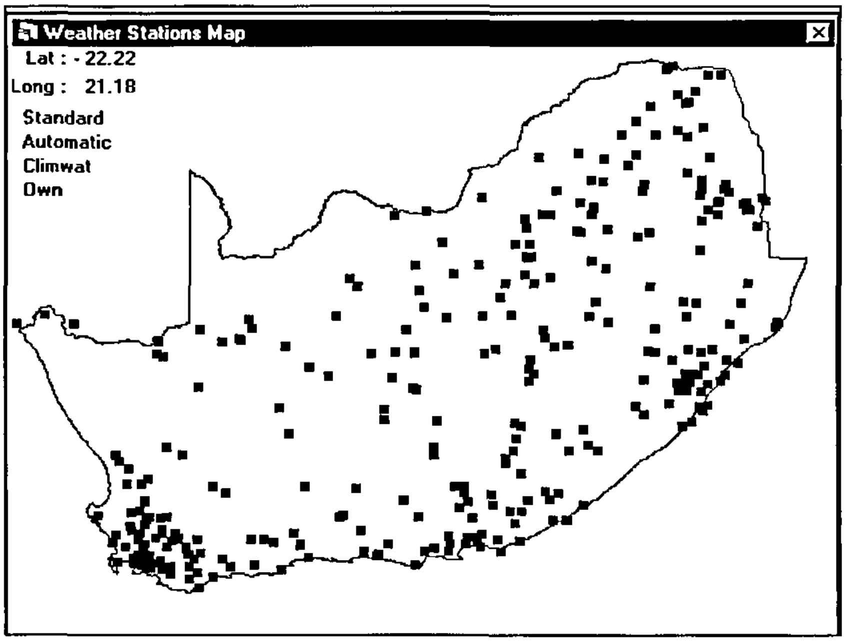
The solution, as indicated by Smith *et al* (1996), was to follow the practice applied in sophisticated crop growth models of dealing separately with evaporation from the soil surface and transpiration through the plant. The computer program SAPWAT Crosby *et al* (1999) includes this facility making it possible to modify crop factors to cater for non-standard situations and is particularly applicable to the planning and design of small-scale irrigation.

4.3.2 USING SAPWAT

What is provided here is an overview of how SAPWAT can be used and of the functional value of the output. Instructions on operating the program can be obtained by clicking on the 'What to Do' button on each screen while right clicking on items on the screens provides more detailed information. SAPWAT requires Microsoft® Windows 95/98/NT, approximately 10 MB of disk space and 8 MB of RAM.

4.3.3 CLIMATIC DATA

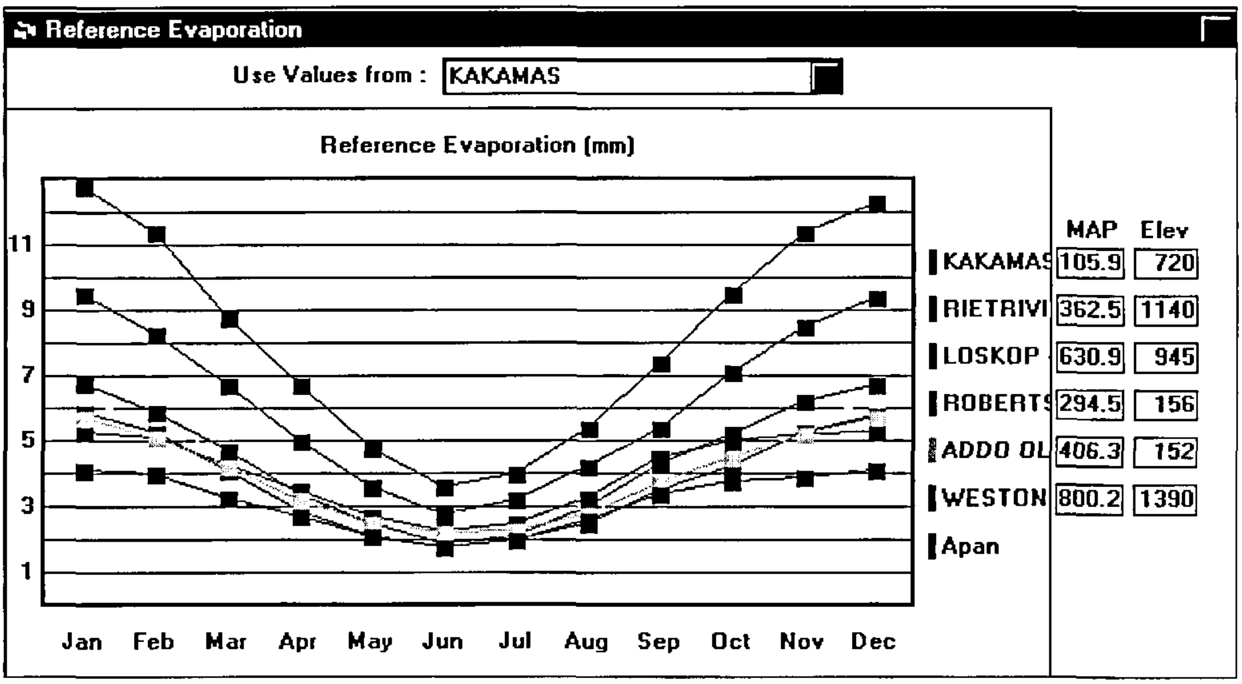
Select one or more weather stations from the 350 plotted on the on-screen map by double clicking on or near the station(s). The user <u>has</u> to use his judgement and experience when selecting a representative weather station. It is important to select a weather station that is representative of weather conditions at the site of interest, even if it is not the closest site. Microclimate effects are very significant, and need to be taken into account.



4.3.4 REFERENCE EVAPOTRANSPIRATION (ETo).

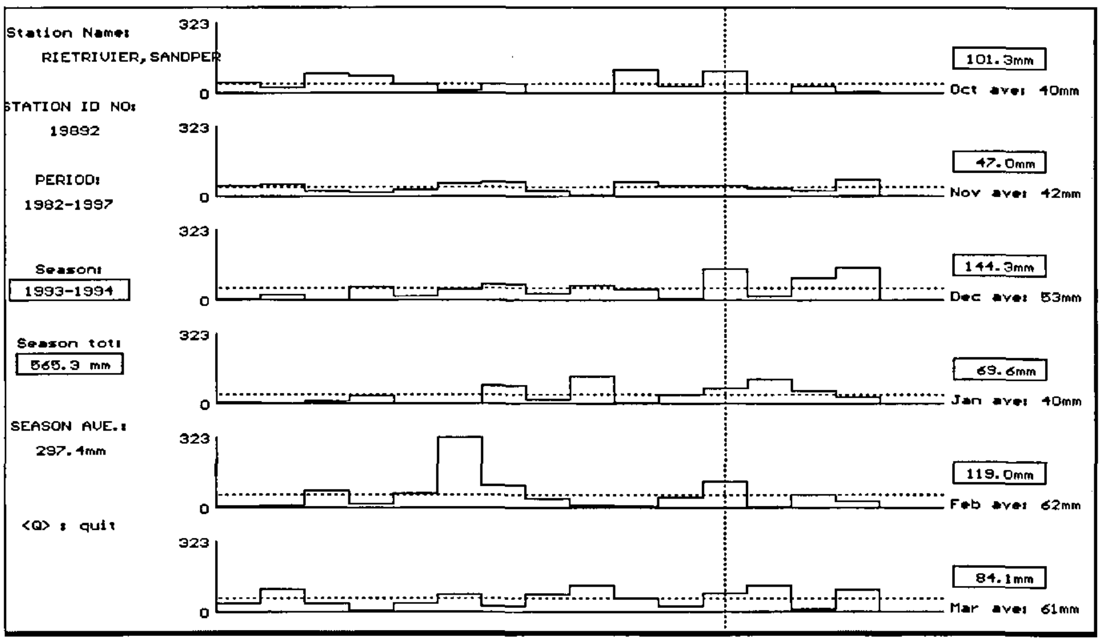
Long-term mean daily values are presented for each month of the year. As an aid to judgement, the screen also includes mean annual rainfall, elevation and, where available, monthly A-pan evaporation values. Calculated Penman-Monteith reference evaporation values for all the weather stations selected on the map are plotted.

For the particular weather station selected from the drop down list, A-pan evaporation for comparison is also plotted. As a further aid to choosing a representative weather station, the altitudes (in metres) and mean annual precipitation values (mm) are given.



4.3.4.1 *Long-term monthly rainfall records*

There is click button access to a graphic presenting long-term average rainfall and actual monthly values for each month of each year included in the weather records. This enables the planner and designer to assess the extent to which rainfall should be considered in developing irrigation requirements.



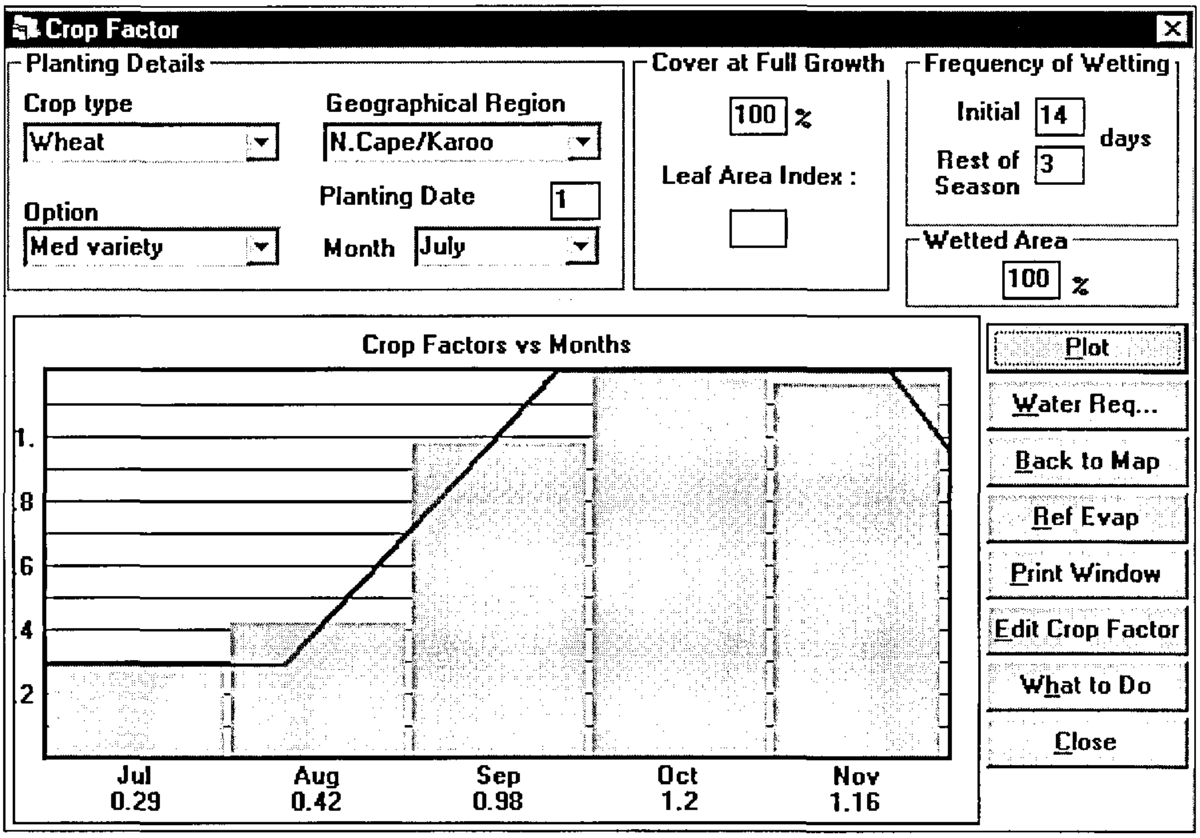
ETo and rain data for a selected station is automatically forwarded to the next stage of the process

4.3.5 DEVELOPING THE CROP FACTOR

This is the most important single aspect of SAPWAT.

4.3.5.1 Default crop factors

The Crop Factor window *enables the user to select the required crop from a menu, and to adjust the* crop factor to account for operational conditions. Clicking on the 'Plot' button updates the crop factor graph, which illustrates how the crop factor changes during the season. Appropriate details, including Crop Type, Options, Geographical Region and Planting Date need to be selected from drop-down menus before the crop factor can be plotted.



Crop time to maturity and growth stages will vary from one region to another and with planting dates. Varieties may also have different characteristics. This is dealt with by means of default values available through drop-down menus. The country is divided into seven regions based on seed company zones and a range of options is available for each crop. The user is free to modify or add options. The default crop factor is developed by selecting:

- A crop – wheat
- An option – medium variety
- The region – Northern Cape/Karoo
- Planting date – 15 June/December.

4.3.5.2 Modifying crop factors

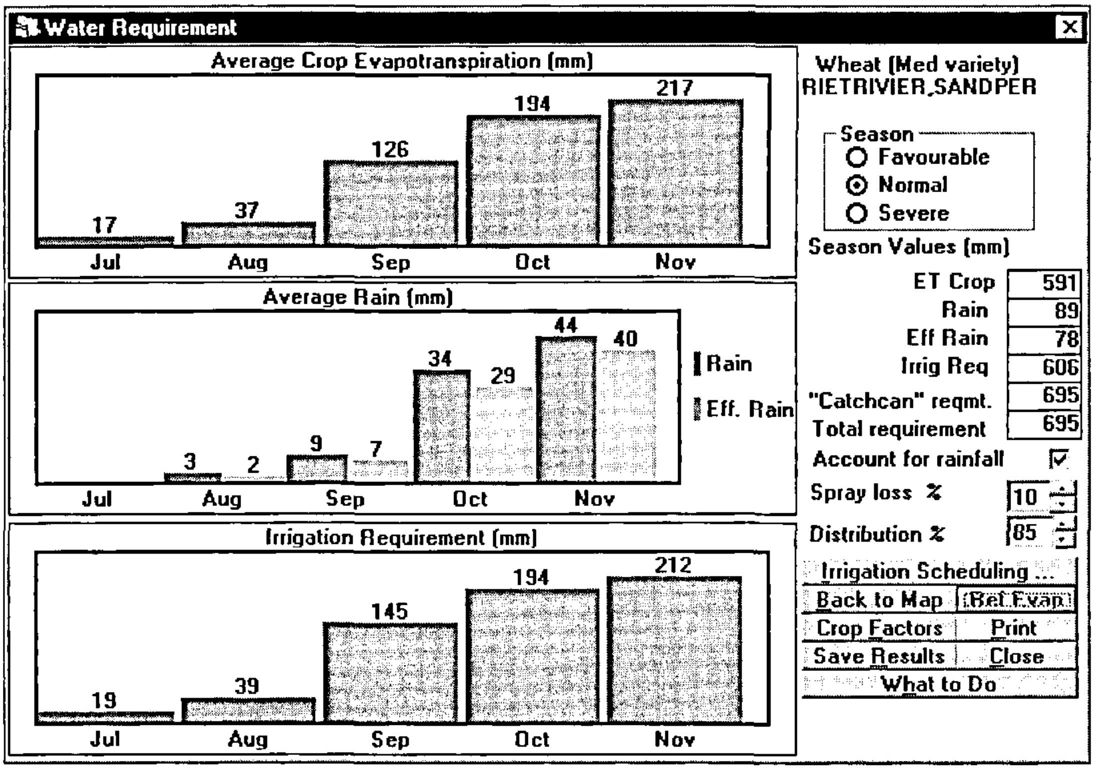
By modifying the crop factors it is possible to simulate the influence of a variety of irrigation methods and crop production practices. The following inputs can be varied to adjust the crop factor:

- If the cover at full growth is reduced to less than 100%, the effective Leaf Area Index is reduced, and consequently also the maximum effective crop factor value.
- If the time between irrigation events is increased, the soil is allowed to dry out, which reduces the soil evaporation and hence the crop factor, mainly during the first growing stage. Wetting frequencies for the initial and later growth stages can be specified separately for non-perennial crops.

- Reducing the wetted area to less than 100% reduces soil evaporation, and thus also the crop factor. The effect is most significant in the early growth stages, where soil evaporation predominates.

4.3.6 WATER REQUIREMENT

This screen completes the normal procedure for developing crop irrigation requirements. (This is as far as many designers want to go.)



The top window depicts ETcrop or crop evapotranspiration by month. The second window rainfall and effective rainfall and at the bottom window monthly irrigation requirement. Effective rain has been subtracted and efficiency taken into account.

Provision is made for favourable, normal and severe seasons on a one in five-year basis. Both ETo and rain are taken into account. The figures are on the right-hand side of the screen reflect the position for the season as a whole and may differ from the total obtained by adding the individual months. It is unlikely that each month in a season will be SEVERE or NORMAL or FAVOURABLE.

There are three additional buttons that relate to Efficiency, which can be included or left out. It is divided into spray losses that include run off and any losses experienced on farm before reaching field edge, such as losses due to pipe leakage and supply furrow seepage and distribution. These distribution losses include deep percolation and the lack of uniformity in system distribution or field variation.

The output is transferred automatically to the next screen when the scheduling button is activated. This section deals with planning and evaluating scheduling and management.

4.3.7 SCHEDULING PLANNING

The Irrigation Scheduling Window is used to simulate the effects of different practical irrigation scheduling strategies.

4.3.7.1 Soils

The user can select one of five 'typical' soils. The relevant soil properties are displayed, but cannot be changed. By selecting the 'Custom' soil type, the soil properties can be changed. For any soil, the initial percentage depletion and effective rooting depth can be specified. It is important to note that the initial depletion has a very significant effect on the total irrigation requirement. Starting with 100% initial depletion can dramatically increase the total irrigation requirement, as the profile has to be filled.

Rainfall event frequency

The user can vary the number of predicted rainfall events per month. Monthly rainfall is divided evenly between the different rainfall events. Setting the number of rainfall events to zero suppresses all rainfall for the month.

Irrigation strategies

Three irrigation Application Strategies are available. If 'Fixed Depth' is selected, a specified amount of water is applied at each irrigation, regardless of the soil moisture content. The irrigation timing is specified by the appropriate Irrigation Timing Option selected.

The alternative strategy is to 'Refill to Specified Level Below Field Capacity', that is, water is applied until a certain soil water deficit is attained. If the profile is already full, due to rain for example, no irrigation is applied. Filling to a specified level below field capacity (say 40 mm, to allow for rainfall) at timing determined by reaching a percentage (say 80%) of critical depletion, yields a close to optimum irrigation strategy, to which other simpler strategies can be compared.

Select User Defined irrigation if an irregular irrigation schedule is required. An irrigation schedule editing window will be displayed, and the customised irrigation schedule can be specified. Appropriate defaults are taken from the Irrigation Scheduling window. Using this option, the effect of missing an irrigation application, for example due to equipment failure, can be 'investigated'. In addition farmer scheduling patterns can be evaluated.

4.3.7.2 Effective rainfall

Water use is tabulated as an output on the scheduling screen. Total Rainfall is the rain that fell during the growth period. It will differ significantly from the figure given in the Water Requirement window only if the rainfall was suppressed during one or more months, using the Rain Events per Month inputs. The Total Rain Loss is the rainfall lost to run-off and deep percolation. It does not include rainwater stored between the current rooting depth and the maximum rooting depth. Effective Rainfall is the difference between Total Rainfall and Total Rain Loss, and is thus explicitly calculated, as opposed to the figure given in the Water Requirement window, which is calculated from an empirical formula. Rainfall efficiency is the ratio of Effective Rainfall to Total Rainfall, expressed as a percentage. It can be improved by not filling the profile to capacity at each irrigation, thus leaving room for rainfall.

4.3.7.3 Crop yield losses

These values are calculated by multiplying the yield loss coefficient Ky for a given stage by (actual water use/potential water use). If the plant is never under stress, ie, if the soil water content never drops below the lower limit of readily available water, no yield loss should occur.

4.3.8 SCHEDULING AND PLANNING OUTPUTS

The water balance module of SAPWAT utilises average monthly inputs but the processing is on a daily basis. The output from simulation runs can be exported to spreadsheets and further processed by the user to provide for specialised applications. The main output file can be exported with graphics to Excel and other compatible spreadsheets and can be used for a daily or weekly based real-time scheduling with provision for ETo and profile water contents. This facility is rough and ready but can complement the specialised real time scheduling programmes.

SAPWAT can be utilised to develop a pre-season programmes for irrigation similar to some aspects of BEWAB. There is however the additional benefit that the forecast programme can be modified in the course of the year as the season develops. This is of particular value where organisations issue farmers with weekly information on atmospheric demand and crop water use for the preceding week.

4.3.8.1 *Evaluating the results*

The soil water content is plotted on a graph that can be edited or printed. The lines plotted on the graph are the Soil Moisture Deficit, Readily Available Soil Water, Total Available Soil Water and a smoothed curve of the Soil Water Content. This, in conjunction with yield losses, enables the implications of management strategies to be assessed. Alternative scenarios can then be evaluated.

Irrigation Schedule Results

Day of Growth	Date	Kc	Avg Et0 (mm)	Et (mm)	Rain (mm)	Irrig (mm)	RAM (mm)	SMD (mm)	Root Depth (m)
1	11 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	1	0.300
2	12 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	1	0.300
3	13 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	2	0.300
4	14 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	3	0.300
5	15 Jul 2000	0.32	2.1	0.7	0.1	0.0	21	3	0.300
6	16 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	4	0.300
7	17 Jul 2000	0.32	2.2	0.7	0.0	0.0	21	5	0.300
8	18 Jul 2000	0.32	2.2	0.7	0.0	0.0	21	5	0.300
9	19 Jul 2000	0.32	2.2	0.7	0.0	0.0	21	6	0.300
10	20 Jul 2000	0.32	2.3	0.7	0.0	0.0	21	7	0.300
11	21 Jul 2000	0.32	2.3	0.7	0.0	0.0	21	7	0.300
12	22 Jul 2000	0.32	2.3	0.7	0.0	0.0	21	8	0.300
13	23 Jul 2000	0.32	2.4	0.7	0.0	0.0	21	9	0.300
14	24 Jul 2000	0.32	2.4	0.8	0.0	0.0	21	10	0.300
15	25 Jul 2000	0.32	2.4	0.8	0.1	0.0	21	10	0.300
16	26 Jul 2000	0.32	2.5	0.8	0.0	0.0	21	11	0.300
17	27 Jul 2000	0.32	2.5	0.8	0.0	0.0	21	12	0.300
18	28 Jul 2000	0.32	2.5	0.8	0.0	0.0	21	13	0.300
19	29 Jul 2000	0.32	2.6	0.8	0.0	0.0	21	13	0.300
20	30 Jul 2000	0.32	2.6	0.8	0.0	0.0	21	14	0.300
21	31 Jul 2000	0.32	2.6	0.8	0.0	0.0	21	15	0.300
22	1 Aug 2000	0.32	2.6	0.8	0.0	0.0	21	16	0.300
23	2 Aug 2000	0.32	2.7	0.8	0.0	0.0	21	17	0.300
24	3 Aug 2000	0.32	2.7	0.9	0.0	0.0	21	18	0.300
25	4 Aug 2000	0.32	2.7	0.9	0.0	0.0	21	19	0.300
26	5 Aug 2000	0.32	2.8	0.9	1.1	0.0	21	18	0.300
27	6 Aug 2000	0.32	2.8	0.9	0.0	0.0	21	19	0.300

Return to Scheduling Window

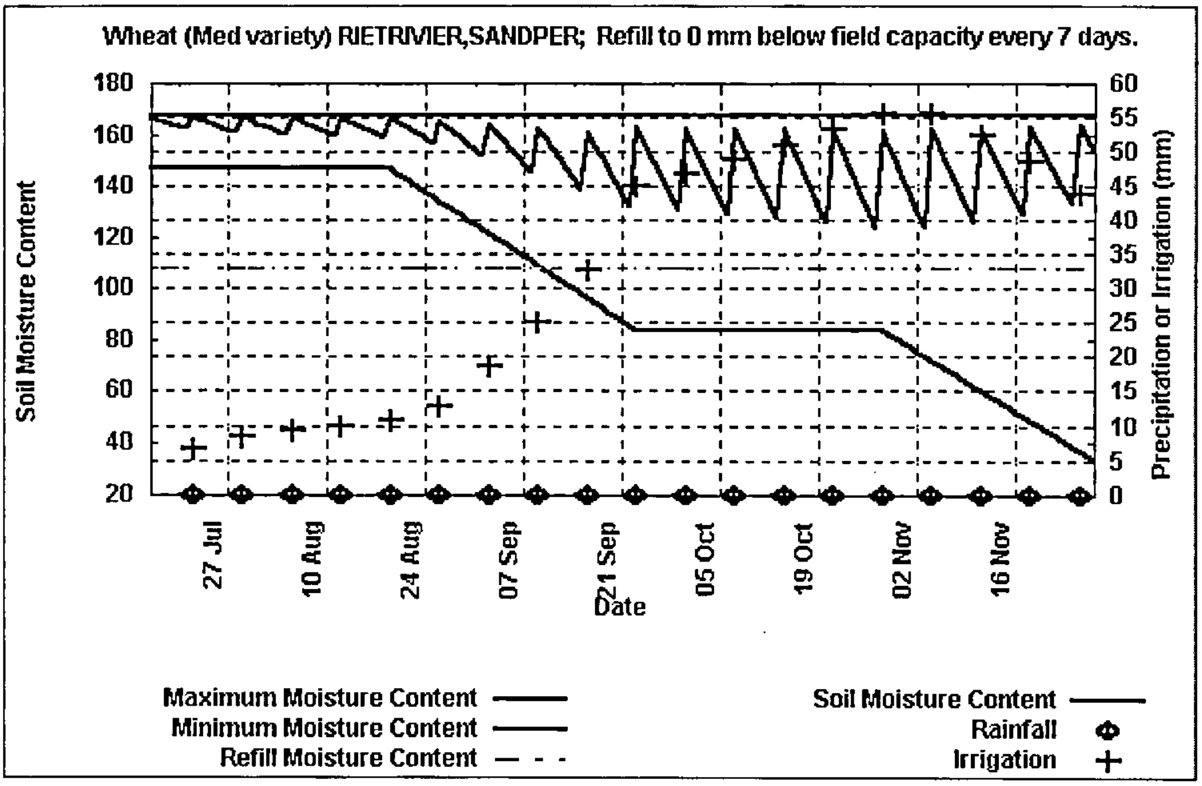
Print Window

Save Data to File

Save only Date, Et0 and Kc to comma-delimited file

Export as Excel Spreadsheet

Close Window



4.4 CROP FACTORS APPROPRIATE TO SMALL-SCALE IRRIGATION

4.4.1 INTRODUCTION

Small farmers are risk-aversive. They have limited cash available for purchasing inputs and fear losing this investment if something goes wrong, so they seldom aim for high yield levels and would rather play it safe wherever this is possible. One of the results of this is that they do not plant the seeds at the same density or fertilise to the same level as the equivalent large commercial farmer. Consequently, at full cover, the canopy is likely to be significantly less than 100%. Typical examples of this are cabbages and other vegetables grown on wide beds. The nett result of this is that the water requirements per hectare, if not per plant, may be considerably less than in the normal farming methods used, which are targeted at input-intensive farming.

A further facet that can reduce water requirements is the size of the wetted area from which evaporation takes place. Small farmers, if they are growing their vegetables in wide beds, very often use furrow irrigation, so that the wetted surface is possibly only 60% of the total land area.

The agronomic principles that are important in understanding irrigation are outlined in Section 4.2.4 of this chapter. Amongst them are non-standard factors, which should be considered in modern irrigation design but which have received little attention in the past. They are: maximum canopy cover achieved, area of soil wetted, frequency of irrigation, the influence of varieties and climate on growing season length, and location. By taking these factors into consideration, it is possible to develop crop factors that are applicable to most irrigation methods and irrigation farming practices. It is of especial importance in the case of small-scale irrigation. SAPWAT provides a convenient way of illustrating the interaction of these factors.

There is a school of thought that believes that all irrigation projects should be designed and built to provide for water for 'full commercial production' even if the present stage of development would be better served by a lower cost and simpler approach. The argument is that the objective should be to achieve optimum situation in the long term and that the lowering of standards' is undesirable. This question can only be answered by analysing each situation on its merits and then deciding on a suitable strategy. **What is unacceptable is the blind acceptance of 'rule of thumb' approaches that may, or may not, be valid.**

4.4.2 THE INFLUENCE OF PLANTING DATE AND LOCALITY

SAPWAT can be utilised to simulate, for example, cabbage irrigation requirements for a variety of localities and planting dates. Season lengths vary with planting dates and locality and this factor, coupled to atmospheric demand (ETo) differences during the growing season, has a major influence on ETcrop and irrigation requirements. Table 4.4.2 contains values from a number of sites, and illustrates the differing patterns of summer and winter water use.

4.5 DESIGNING FOR IRRIGATION MANAGEMENT

4.5.1 INTRODUCTION

Irrigation management is based on scheduling, which involves adjusting the quantity or the frequency of irrigation to suit the crop water requirements at different stages of the growing season. Scheduling is a complicated process, even for the best of farmers, although it is standard practice to design irrigation systems with the expectation that farmers will schedule.

This means that it is standard practice to design the capacity of the irrigation system to enable it to cope with the expected peak evapotranspiration (ETcrop). Then, earlier and later in the season, when the evapotranspiration is less, the farmer is required to schedule, ie, either to increase the periods between irrigation or decrease the amount of water applied at each irrigation, in order to ensure that over-irrigation does not take place.

Scheduling can be done, either by measuring the water content of the profile or by a profit-and-loss account method based on measuring atmospheric demand. The quantity or frequency of irrigation is then adjusted to prevent over-irrigation and water wastage. This is not easy for any farmer to achieve in practice and is particularly difficult for small farmers, who may not be very familiar with irrigation procedures and methods.

Nevertheless, the need to design to meet the peak requirement is justified, if the soil reservoir is the limiting factor, usually because of shallow soils or irrigation at long intervals. This was frequently the case in earlier days, when flood and conventional sprinkler irrigation were the main irrigation methods, although even then the need tended to be exaggerated. Even in the case of small-scale farmers, the frequency of irrigation can now be a week or less. Under these circumstances, simplified management strategies can be effective.

Table 4.4.2: Seasonal values (mm) for late varieties of cabbage and peak monthly ETcrop and irrigation requirements for several localities and planting dates.

Locality	**Planting month**	**ETcrop**	**Rain**	**Effective rain**	**Irrigation**	**Monthly Peak ETcrop**	**Monthly Peak Irrigation**
Robertson	March	210	124	82	138	52	44
Roodeplaat	March	265	95	63	195	81	79
Malelane	March	258	135	90	154	81	68
Taung	March	276	62	42	229	82	79
Alice	March	235	128	84	155	61	54
Robertson	Nov	435	38	29	399	171	163
Roodeplaat	Nov	433	317	234	193	173	83
Alice	Nov	398	253	181	234	153	109
Robertson	Aug	406	83	58	351	147	141
Roodeplaat	Sept	446	282	202	277	161	88

For shallow-rooted vegetable crops, it is necessary to irrigate at frequent intervals to prevent stress but, for deeper-rooted crops, as discussed in Section 4.5.2, managing the water in the soil profile can have many benefits, including reducing irrigation frequency. Managing the water in the soil profile can simplify scheduling or even make it unnecessary, because conventional scheduling is not necessarily the best approach to follow in the case of suitable soils and deeper-rooted crops. The much-maligned routine followed by many farmers who start irrigating at the beginning of the season and apply the same amount of water at the same frequency throughout may be the best option! This method results in over-irrigation early in the season, which builds up a reserve of water in the soil profile. This reserve irons out the peaks in the middle of the season and continued over-irrigation towards harvest builds up reserves for the following season.

Using this method can have an impact on the sizing of pumps and piping, and consequently on operating costs, in addition to reducing the possibilities of nutrient loss and salination. The farmer is protected in that his equipment will not permit gross over-irrigation, and there is a significant reduction in peak flow rates. However, the big advantage of this system is simplified management. It must, however, be consciously planned by the designer and intelligently applied by the farmer.

These strategies, with the exception of pre-programmed irrigation based on BEWAB (Bennie, 1993), are seldom applied in an organised way in South Africa although the increased appreciation for RURAFLEX electricity tariff concessions is stimulating interest. There is the perception that they are difficult to incorporate in design procedures, and planners, designers, equipment suppliers and farmers are all reluctant to venture into the unknown. The effectiveness of these strategies in specific South African circumstances is still unknown because, although they have been evaluated on a what-if basis with the help of crop-growth models, these models were not specifically tailored for use by irrigation practitioners.

SAPWAT includes modules that have an application in planning, design and evaluation, and these will be used in this chapter to explain and illustrate possible strategies.

In this section, the following are discussed:

- ETcrop and current South African design approaches;
- the implications of applying SAPWAT designing for irrigation management;
- managing soil water reserves and developing prescheduled irrigation;
- planning for water shortages; and
- augmenting rainfall.

4.5.2 PRE-SCHEDULED IRRIGATION WITH PROGRESSIVE DEPLETION OF SOIL WATER

4.5.2.1 Introduction

One of the irrigation strategies to emerge over the years is pre-programmed scheduling. Crosby (1992) discusses this in some detail but, because of the importance of these alternative strategies in small-scale irrigation farming, some aspects are detailed here.

Pre-programmed irrigation is usually associated with a managed progressive depletion of soil profile water. Where soils are deep, it is a practical proposition for a small farmer to use the buffer effect of the water stored in the profile. Irrigation management can be simplified, the danger of salination through over-irrigation minimised, and water supply flow rates significantly reduced. There is sufficient evidence, outlined in the following sections, to show that soil profile water can be used to simplify and improve irrigation management and should be taken into consideration where conditions are appropriate.

4.5.2.2 Progressive depletion of soil water

It has been practice to assume that early season irrigation need only keep pace with the demands of the juvenile crop and its relatively shallow rooting system. However, Bennie *et al* (1988) recommend maintaining a relatively full profile from early season to provide a reserve for the peak demand periods. Vanassche and Laker (1989) started drying cycles at various phenological stages and found that, even when a cycle was started early in the season, the maize plant was capable of extracting a surprisingly large amount of water from a full profile.

Bennie *et al* (1988) has shown the importance of the water reservoir in the soil profile in reducing the peak capacity requirements of irrigation equipment and supply systems. A soil with a measured plant available water capacity (PAWC) of 200 mm has in fact the capacity to supplement peak requirements by 2 mm per day for 100 days, or 4 mm per day for 50 days.

Martin, Stegmann, and Fereres (1990) support the high-frequency irrigation approach. High-frequency irrigation (usually at three- to seven-day intervals) is applicable to modern systems capable of high uniformity and controlled amounts of water application. With high-frequency irrigation, management allowed depletions or plant water stress thresholds become less important to irrigation timing, and relatively high soil water content is maintained in the upper root zone, where plant nutrients are usually in greater supply. .

High-frequency irrigation of field crops can be applied with either full or partial ETcrop replacement. High-frequency irrigation is suitable for management of systems with pumping capacities that are inadequate to replace mid-season ETcrop rates. The root zone profile is maintained near field capacity early in the season, when pumping supply is adequate. In the period of inadequate capacity (illustrated from Day 60 to 90), the crop water requirement is met by the successive partial ETcrop replacements from irrigation, rainfall, and the depletion of stored soil water. In late season (shown from Day 90), pumping capacity is adequate to supply irrigation at full ETcrop replacement, and the root zone deficit may not be reduced to a low depletion because there is still water in the soil profile. The Soil Conservation Service in the USA (1982) advocates much the same regime.

The use of light, frequent irrigation makes it practical to gradually deplete deep soil moisture during the peak use periods, when the system capacity is inadequate to meet crop moisture withdrawal rates. Light, frequent watering of the topsoil, plus the gradual withdrawal of water from the subsoil, can still produce optimum crop yield when the system capacity is limited.

However, when subsoil moisture is inadequate, light, frequent irrigation, resulting in heavy moisture losses from evaporation, may be an inefficient use of a limited supply of water and may also increase salinity.

4.5.2.3 Pre-scheduled irrigation

In arid and semi-arid areas, where rainfall is insignificant during the growing season, a normal irrigation schedule based on average climatic data can be computed. In such areas, the variability of ET from year to year is small and may be disregarded, so it is feasible to predict (or pre-schedule) normal irrigation dates and amounts for a specific soil/planting date combination (Martin *et al,* 1990).

The scheduling of irrigation by applying predetermined amounts at prescribed times or intervals, called pre-scheduled irrigation, is still the most widely used technique by South African irrigators. The technique is successful under low rainfall conditions, in deep soils with plant available water capacity (PAWC) values higher than 80 mm, and with crops that can control water loss under extreme conditions of evaporative demand. An example of this approach is shown in Table 4.5.2.3, taken from the BEWAB computer program (Bennie, 1992), which calculates water application schedules for different crop-soil combinations and management options. BEWAB gives details of the water application programme and minimum effective irrigation requirement (IR) in millimetres per cycle for wheat (170 days) with a target yield of 6 000 kg/ha.

Table 4.5.2.3: Water application programme and minimum effective irrigation requirement (IR) mm per cycle for WHEAT (170 days season) with a target yield of 6 000 kg/ha

PARTIAL CROP WATER REQUIREMENT (CWR) REPLENISHMENT DURING PEAK CONSUMPTION (FINISH SEASON WITH SOIL DRY)								
Days after planting	**Full CWR replen-ishment during peak**	**IR total**	**Profile fully wet at planting**	**IR total**	**Profile partially wet at planting**	**IR total**	**Profile dry at planting**	**IR total**
10	0	0	0	0	2	2	3	3
17	1	1	1	1	17	19	22	25
24	3	4	3	4	17	36	22	47
31	5	9	5	9	17	53	22	69
38	7	16	7	16	17	70	22	91
45	10	26	10	26	17	87	22	113
52	13	38	13	38	17	104	22	135
59	16	54	16	54	17	121	22	157
66	19	73	19	73	17	138	22	179
73	22	96	22	96	17	155	22	201
80	26	121	25	121	18	173	23	224
87	29	150	26	147	26	200	26	251
94	31	181	26	174	26	226	26	277
101	34	215	26	200	26	253	26	303
108	36	251	26	227	26	279	26	330
115	37	288	26	253	26	306	26	356
122	38	327	26	279	26	332	26	383
129	39	365	26	306	26	358	26	409
136	38	404	26	332	26	385	26	435
143	37	441	26	359	26	411	26	462
150	35	476	26	385	26	438	26	488
157	32	508	26	412	26	464	26	515
164	28	536	26	438	26	490	26	541

REMARKS

Profile available water capacity during peak consumption = 100 mm

Any precipitation more than IR mm per rainfall should be disregarded if the full replenishment option is being used.

Usable profile available water during peak consumption = 100 mm

The irrigation system should be capable of delivering 5.5 mm/day for the full SWB replenishment option and 3.8 mm/day for the partial replenishment option.

Pre-scheduled irrigation is relatively simple and effective for crops grown in winter in the summer rainfall areas of South Africa. There is very little variation in climate across the country and ETcrop is very consistent from one year to the next. BEWAB (Bennie, 1993) makes provision for moderate rain in summer, but measuring the actual rain received, plus rain in catch cans, is a pre-requisite of the method.

Note that the peak requirement, if the normal procedure of irrigating to match ETcrop is followed, would be the 5.5 mm/day, but only 70% of this, 3.8 mm, is required, if the partial replenishment option is followed. The irrigation applications remain virtually unchanged throughout the season so that management is simplified.

The simplicity of applying a BEWAB-type program in planning, design and scheduling, where applicable, **represents a giant step forward.** This is particularly true in the case of small-scale irrigation farmers and should be seriously considered by designers.

The scheduling module of BEWAB (Bennie, 1993) was linked to the original 1994 version of SAPWAT. SAPWATW can be used to develop the pre-scheduling programmes illustrated in the examples in Section APPENDIX 4.A.

Plant available water capacity (PAWC) research has required the accurate measurement of soil water extraction with the neutron probe at depths that were not possible with augers. Sampling with augers seldom took place below 1.2 m, a depth previously associated with maximum root zone depth. Streutker (1991) commented that he could hardly credit the high PAWC values published, until he realised the implications of the greater sampling depths, which are that, as the PAWC research and experience have confirmed, crops draw water from depths considerably greater than is currently assumed by designers.

4.5.3 THE APPROPRIATE UTILISATION OF THE SOIL WATER RESERVOIR

The conventional way of estimating crop water requirements is to assume that the complete surface area, and the profile below it, is wetted at irrigation and that the crop canopy effectively covers the full surface. This is typically done by commercial vegetable producers, equipped with micro, drip or even sprinkler irrigation. Vegetables are shallow-rooted crops but, if they are irrigated on a three-day cycle, the shallow soil profile contains sufficient water to cater for the crop between irrigation periods.

However, for many small farmers, a three-day cycle is not possible. Water may only become available once a week or every ten days, or even only every two weeks or three weeks. Frequently, this means that they must apply deficit irrigation by force of circumstances. However, it is noticeable that, generally speaking, small-scale farmers compensate for this by planting their crops at a wide row spacing, very often on beds, and at significantly lower population densities than the ones aimed at by well-equipped farmers. This is good thinking, very similar to the approach adopted by maize farmers in the western parts of the country, where rows are spaced at two metres instead of the usual one-metre spacing in the east where rain is more reliable. Apple farmers in the Western Cape are achieving much the same when they ridge along the tree rows and 'deepen' the soil.

These strategies mean that each plant has a relatively shallow, but extensive soil profile from which water can be drawn. Under these circumstances, the small-scale farmer will use much the same water per plant as the commercial farmer, but the small-scale farmer will use less water per hectare.

SAPWAT takes this situation into consideration when deriving crop factors for partial canopy cover, which is preferable to adjusting the crop *pro rata* based on wetted area. What is important is to relate back to the per-plant water requirement, rather than the per-hectare water requirement.

It is, however, extremely difficult to make accurate estimates of crop water requirements purely on theoretical grounds because management plays such an important role. Practical experience and quantified case studies are of great value in learning to make accurate estimates. This is illustrated by the comments of a senior designer with one of our largest irrigation firms:

> "Small-scale farmers frequently find it difficult to explain their requirements to an irrigation designer. They have an idea in the back of their minds based on previous experiences with elementary flood irrigation or watering crops by buckets or drums, but they cannot express it in irrigation terms. It seemed a logical assumption that the most understandable and acceptable solution would be for them to irrigate their whole area using sprinkle irrigation, because it

corresponds to rainfall. However, we eventually realised that the small farmers thought we were wasting water because they could come out with considerably less water than we were supplying and were still producing good crops.

"This is because, unlike large commercial farmers, who plant their full area to one crop in order to provide for the season or the year, small farmers plant their lands in smaller, more manageable sections. This is particularly true when vegetable crops are being produced on a relatively limited scale, and was especially noticeable in Lesotho. We provided a 12 x 12 m sprinkler line so that, with one, two or three pipe shifts, they could irrigate their whole area. However, they were dissatisfied with this because it wasted water by wetting the areas between the plants far too much, while too little water was reaching the plants themselves. The farmers made it quite clear that, when they planted pumpkins, they wanted to water those pumpkins individually, giving them five or ten litres a week, depending on climate and the availability of water.

"We therefore gave the farmers in Lesotho polyethylene pipes with button drippers that dripped on each specific pumpkin plant and they found this a much more satisfactory irrigation method because, when they felt that they had given the plant sufficient water, they stopped irrigating. They did not have an irrigation programme or a formal scheduling method.

"Thus, when we started taking the experience and preferences of the farmers into consideration, they liked our system much better. More and more schemes of this nature have been put into practice.

"It is not easy to estimate irrigation requirements for situations such as this using conventional methods because the acquisition and recording of field experience is essential. Yet, in water-short situations, make-or-break decisions can depend on these estimates."

4.5.4 THE IMPACT OF WATER SHORTAGES

4.5.4.1 Introduction

There is a perception amongst irrigation designers that, if the plant is subjected to stress as a consequence of a shortfall in water supply, the consequences will be disastrous. This is, of course, not the case. Although there are some crops such as maize that will suffer almost total yield loss if water stress occurs at the critical stage, if water is the limiting factor, then yield will normally simply be depressed. This is one of the reasons why yields are higher under irrigation than under rain-fed conditions. Satisfactory yields can, however, still be obtained with less water than is indicated by the various estimation procedures discussed in this chapter because a degree of water stress generally does not mean that the crop will be a write-off.

Many farmers believe that yield is directly proportional to the amount of irrigation water applied to the crop. However, this is only true up to a point. There can be many other factors that determine the yield obtained, including plant population, fertiliser policy, disease- and insect control, and the suitability of the crop variety planted. The law of the minimum applies. There will be a single factor that will determine the yield level. In many cases, this is not water but one of the other inputs. If water is not the critical factor in determining yield level, increasing irrigation amounts will be counter-productive.

As we have seen, WUE is largely dependent on the overall standard of crop husbandry, but deficit irrigation (described below in Section 4.5.4.2) is another accepted method of irrigation that, to be successful, requires sound management. Sound management and a high standard of crop husbandry can be achieved by using both BEWAB (Bennie, 1993) and SAPWAT to assess the effect of shortfalls in water supply on yield and to provide perspective on how much water is 'enough'.

4.5.4.2 The current status of conventional deficit irrigation

English, Musick and Murty (1990) state that deficit irrigation is an optimising strategy under which crops are deliberately allowed to sustain some degree of water deficit and consequently to experience stress and a reduction in yield. Deficit irrigation is widely practised, particularly in areas that regularly experience water shortages. In India, which has over one hundred million hectares of land that is regularly drought-affected, major irrigation projects are designed for extensive irrigation where available water is spread over a larger area than would normally be the case for full irrigation. The objective is 'protective irrigation' in which the water supply is used to augment yields and protect crops from complete failure, rather than to meet full crop water requirements.

An alternative and descriptive name for deficit irrigation is 'partial irrigation'. In other words, irrigation is applied, but not to the level where water ceases to be the limiting factor in production. Production will therefore be reduced by this partial irrigation, because water is the limiting factor. To some extent, this is the position under rainfed crop production. Normally, the inputs such as seed and fertiliser will be scaled down proportionately, in comparison with fully irrigated crop production. In the extreme situation, limited irrigation may amount to assuring normal rainfall.

Deficit irrigation is widely practised in the Great Plains of the USA, a semi-arid region characterised by limited and declining water supplies. It is common practice to irrigate roughly double the 'scheduled' area with a given amount of water, and some farmers have tripled the area. The USA Soil Conservation Service has accepted a reduction to 35% of system capacity for subsidy purposes (Crosby, 1992).

Many small-scale farmers in South Africa apply the principles of deficit irrigation, achieving a balance between inputs and water use. The strategy is particularly applicable when there are very definite water shortages because high efficiencies can be achieved under these circumstances.

This process can be facilitated by using SAPWAT as an aid when estimating crop water requirements. It becomes possible to add depth to design and facilitates consultation with policy-makers and farmers. The use of SAPWAT to make accurate estimates of crop water requirements is especially important for small-scale farmers, where non-standard situations are the norm.

4.5.5 AUGMENTING RAINFALL

4.5.5.1 Introduction

Effective rainfall will not be discussed in detail here because estimating the allowance that should be made for rain is never 'easy', although it is an element of all the procedures applied to estimating irrigation requirements based on ETo, and is normally empirical. SAPWAT incorporates a daily water balance that develops a value for 'rainfall efficiency' which is certainly much nearer to reality than empirical estimates. However, it is vulnerable in that the water balance is based on average monthly rainfall assumed to be evenly spaced at selected regular intervals throughout the month and the method of allowing for run-off that is very basic..

4.5.5.2 Rain in low rainfall areas

In the arid areas, rain is not a problem for designers; it can simply be ignored. In the semi-arid areas, there is still a tendency on the part of designers to ignore rain. This can, however, be counter-productive, because there are few parts of South Africa where the rain should be totally ignored. One reason is that, in the areas of low rainfall, there is little danger of deep percolation and runoff and, consequently, the rain that falls is efficient. Evaporation is catered for as part of the ETcrop calculation. In practice rain is regarded as a welcome buffer catering for leaching and undefined losses.

Subjectively, one always remembers the bad years where there was very little rain. However, if long-term records are examined, it is usually found that the incidence of drought periods is not as high as one remembers. We have seen that a shortfall in water supply to a crop will have a depressing influence but will not necessarily cause serious damage. It therefore becomes a judgmental decision as to the degree to which the irrigation predictions can take rainfall into account. A factor that should be considered is the situation in a season. How often is it that there are several successive months well below the normal rainfall? Or how often are bad months followed by good months? How often will the annual crop fail if rainfall is not included in the irrigation estimation?

4.5.5.3 Semi-humid areas

In semi-humid areas, rainfall is a major contributor to the water requirements of the crop. Under these circumstances, the normal methods for estimating effective rainfall can be misleading. Normally, this position arises for summer crops produced in the summer rainfall area. One approach, adopted for sugarcane production on the Natal coast, is to select an appropriate irrigation routine, in terms of both application frequency and amount, to obtain a satisfactory yield in normal years. It is accepted that, in a low rainfall year, there will then be yield depression while, in a high rainfall year, yields will be above average.

A real-time scheduling model based on daily climatic data is required if any real degree of certainty is to be achieved in the genuinely supplementary irrigation areas.

4.5.5.4 Pre-plant filling of profile to augment rainfall

An innovation, with precedent in the USA, is to limit irrigation to filling the profile before planting, and then to rely on rainfall. This appears to be a valid strategy in areas with deep soils. In the development context, it appears to have distinct possibilities.

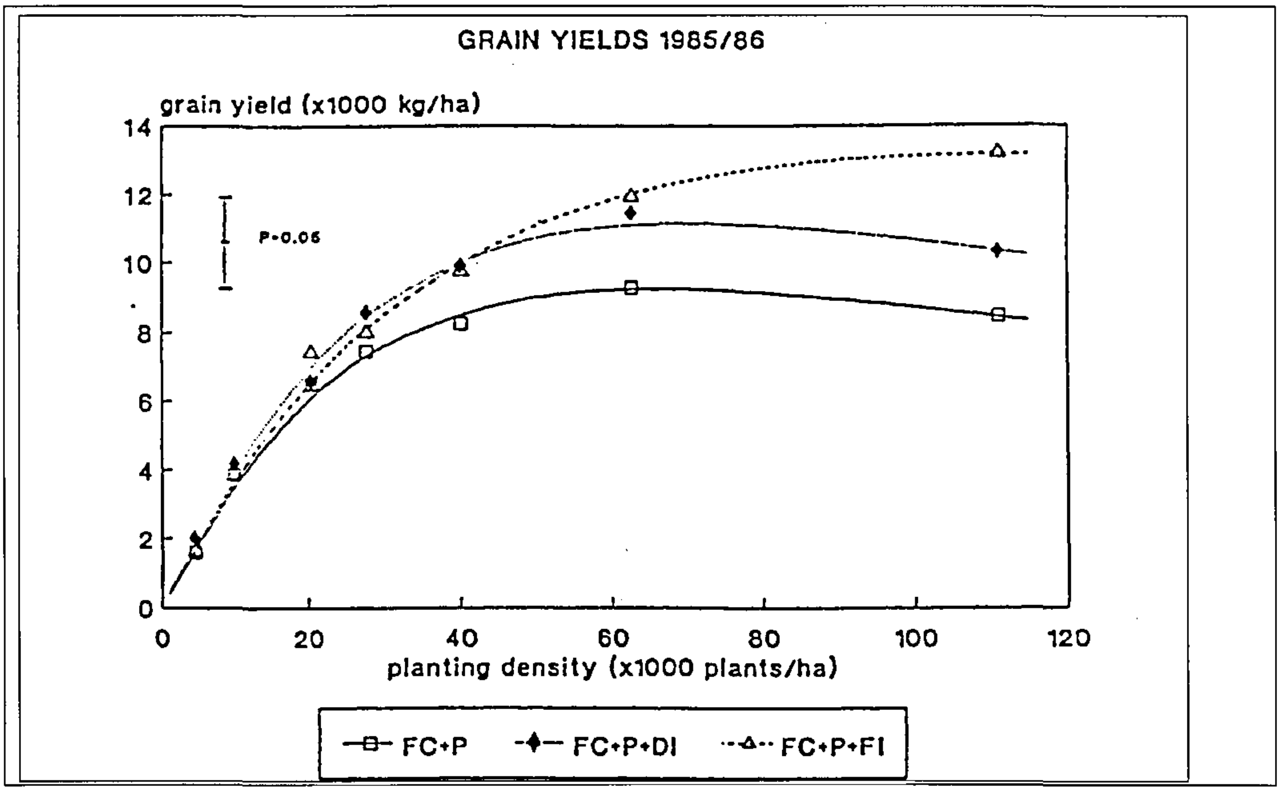
Further discussion here will be confined to the work reported by Van Averbeke and Marais (1991). Their experiments were done at Alice in deep soils and with a median annual precipitation of 619 mm. December and February long-term median rainfall is 64.3 and 71.3 mm. The potential yield under full irrigation is 12 t/ha in December, and irrigation accounts for 68% of plant water requirements in a median year and for 89% in a dry year.

One of the major treatments was to fill the profile to field capacity before planting, after which there was virtually no irrigation, except in 1986/87, when 100 mm was added later. In the graphs which constitute Figures 4.5.5.4a to 4.5.5.4c below, the treatment is identified by the letters FC + P (Field Capacity + Precipitation).

In the figures that follow:

- P was dependent on rain only;
- FC + P represents a treatment consisting of filling the profile before planting and then relying on rain to provide the balance of the water requirements; and
- FC + P + FI could be regarded as 'full' irrigation in that FI is the water added by irrigation to ensure the attainment of the target yield.

Figure 4.5.5.4a: The effect of planting density on grain yield of maize at various water levels – 1985/86



The yields achieved varied with the seasons but, at a realistic plant population of 20 000, plants/hectare, yields of 6 t/ha were achieved in 1985/6 and 1986/87. In 1987/88, a dry year when the no-irrigation treatment failed completely, nearly 4 t/ha was still attained. Research in the USA showed that irrigation can be done over a long period of time before planting but, with furrow irrigation, there was considerable wastage due to application inefficiencies. However, there would appear to be no reason why a single sprinkler line should not be used to fill the soil profile before planting. It would then be possible to irrigate a much larger area than would be the case under normal irrigation practice.

SAPWAT simulations indicated that a second light irrigation in January would be very desirable and could be feasible. This approach to irrigation will be discussed further in later chapters.

Figure 4.5.5.4b: The effect of planting density on grain yield of maize at various water levels – 1986/87

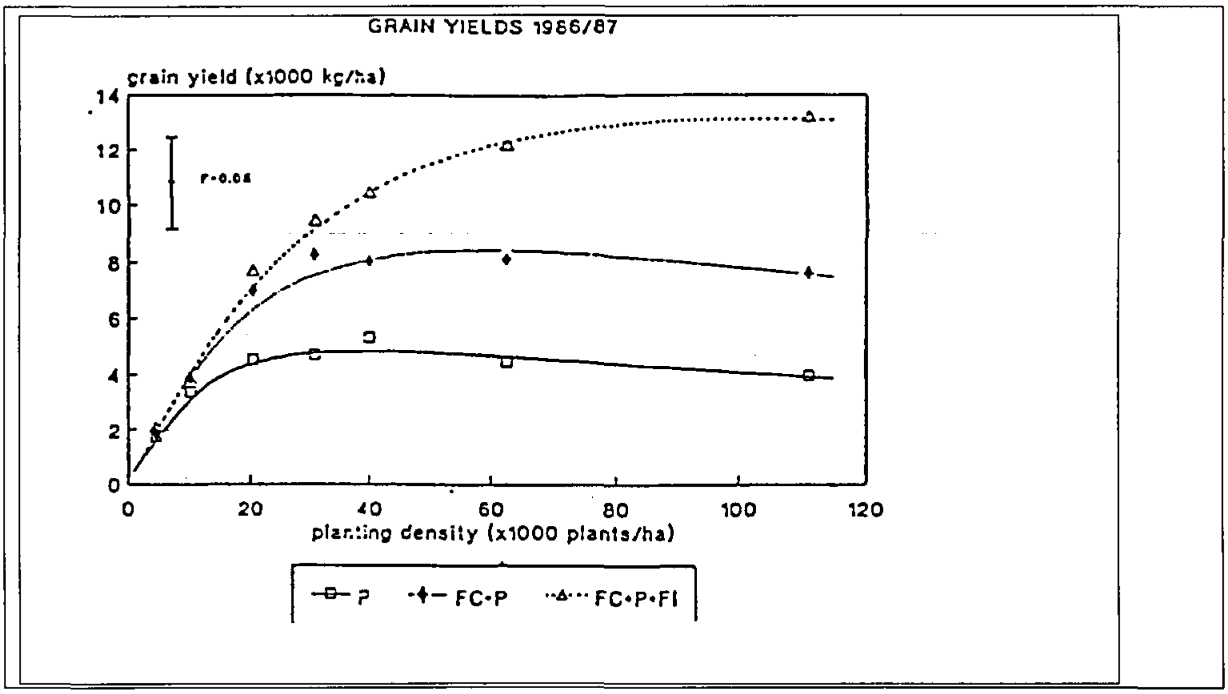
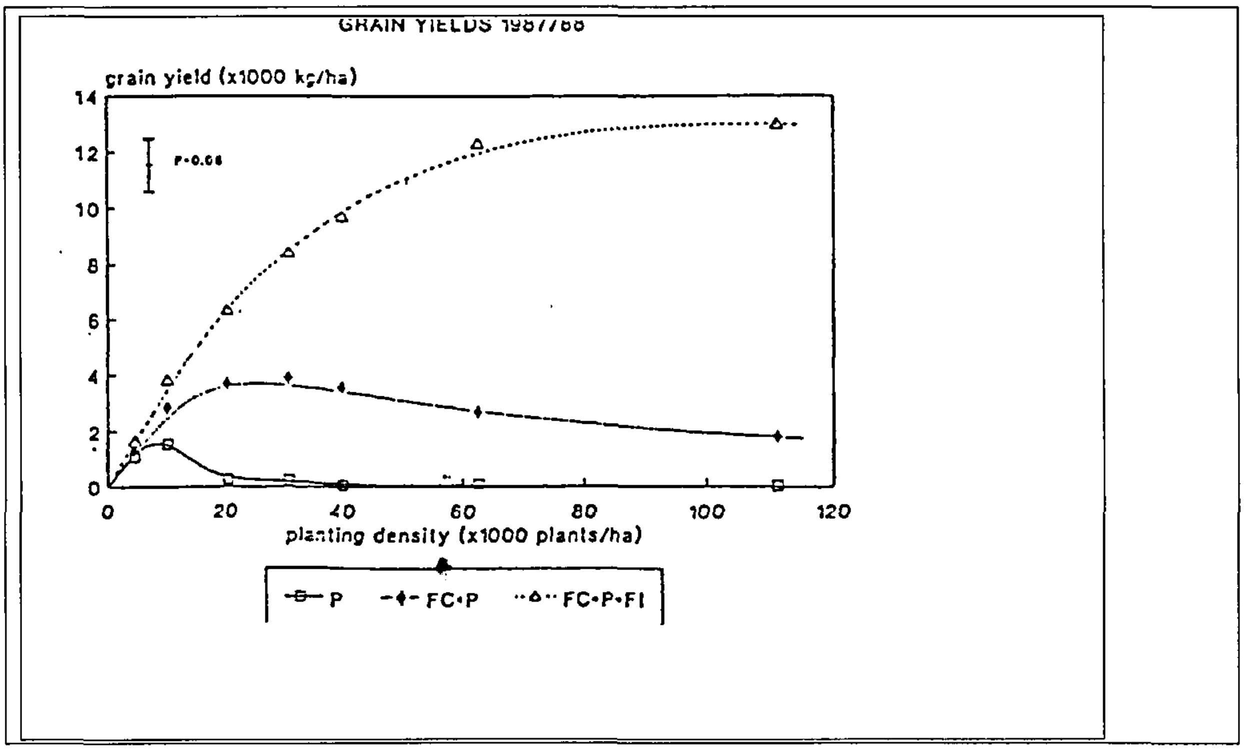


Figure 4.5.5.4c: The effect of planting density on grain yield of maize at various water levels – 1987/88



4.6 GENERAL CONCLUSIONS AND RECOMMENDATIONS

The limited understanding amongst irrigation practitioners of the agronomic factors that influence crop water use efficiency under irrigation was highlighted in the introduction and expanded on in this chapter. In the light of the increasing pressures on water resources, it is suggested that an appropriate *chapter on this subject be incorporated in the Irrigation Design Manual. The principles apply to all* irrigation farmers, and the additional aspects applicable to small-scale farmers should be identified and incorporated, where appropriate, in instructional material.

The switch to the Penman-Monteith (short grass) based reference evaporation (ETo) procedure for estimating evapotranspiration will be introduced in South Africa in the near future and will cater specifically for small-scale farmers and risk aversive crop production strategies. While this is not a major shift in procedure from existing methods, the finer points of difference probably justify some training. Probably any such training should be coupled to training in designing for greater water use efficiency.

In this chapter, it has been emphasised that planners and designers will need to augment the 'peak demand' approach to design with the facilities for 'designing for management' provided by the SAPWAT/CROPWAT/BEWAB software. Probably a chapter on 'designing for management' in the *Irrigation Design Manual* would be justified, but training would almost certainly be required if practitioners were to have the confidence to break new ground. Ideally, this training should take place in the irrigation areas, which would facilitate catering for the needs of small-scale farmers.

APPENDIX 4.A. THE IMPLICATIONS OF SAPWAT IN DESIGN

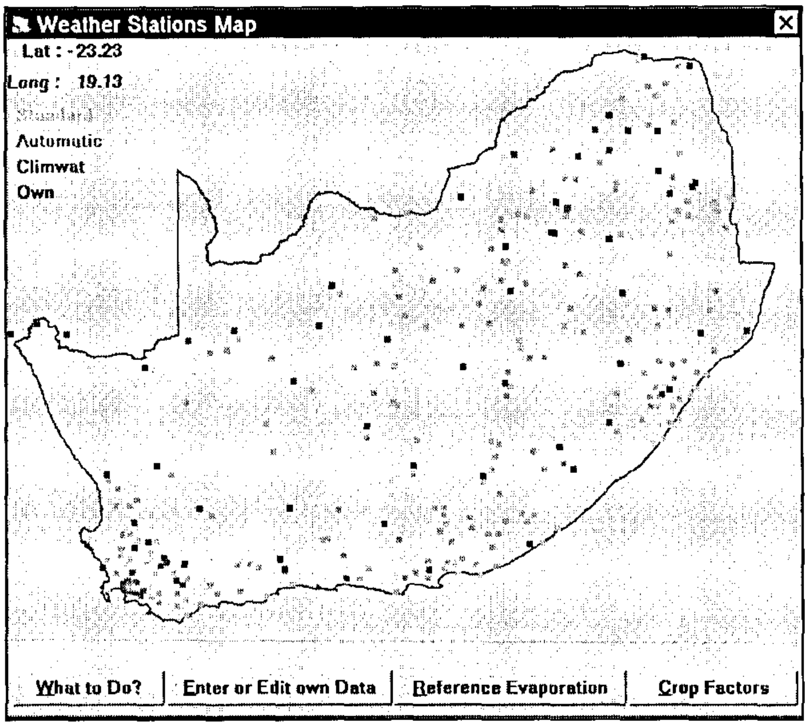
A variety of practical irrigation options can be assessed and discussed. The output includes irrigation and rainfall efficiencies, and the consequences for yield should there be a shortfall in irrigation supply. SAPWAT has an extensive database and it is seldom necessary to input external data. Inputs include soil- and crop rooting depths, initial profile water content, allowable depletion, and application efficiency and the program runs a simplified daily water balance.

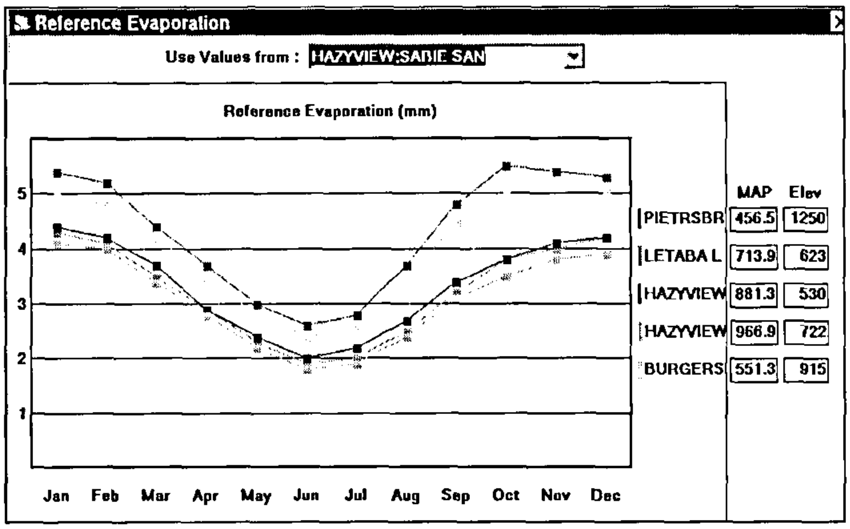
The objective is to promote simplicity and efficiency in design, construction and management by simulating a wide range of interacting options rather than by following rules of thumb that may or may not be appropriate to the particular circumstances of a scheme.

The example that follows is based on producing green mealies throughout the year in the Lowveld.

The first step is to select a suitable weather station. Five weather stations have been selected on the map by double clicking on appropriate dots.

The lowveld stations all have much the same characteristics, the Mean Annual Precipitation (MPA) and Elevation help one to group the stations.



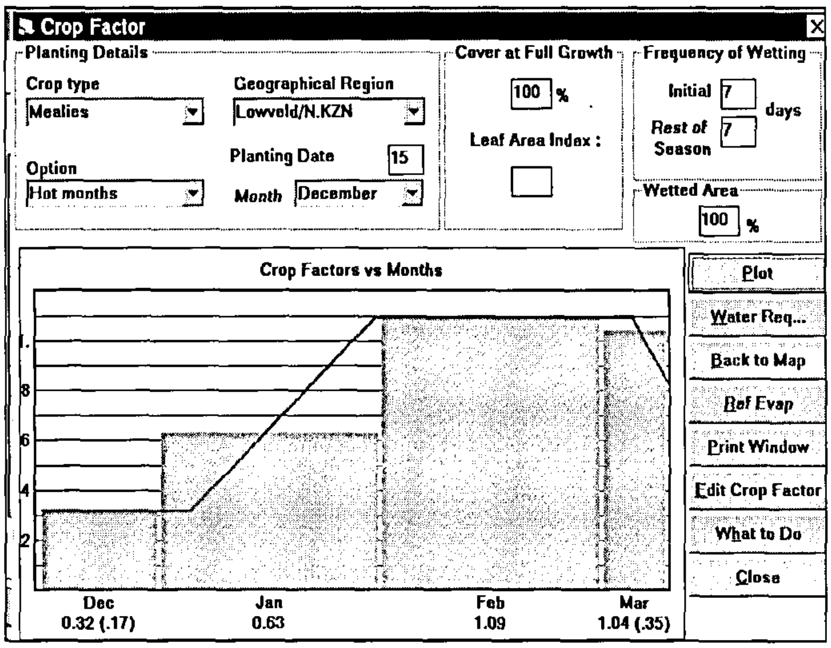


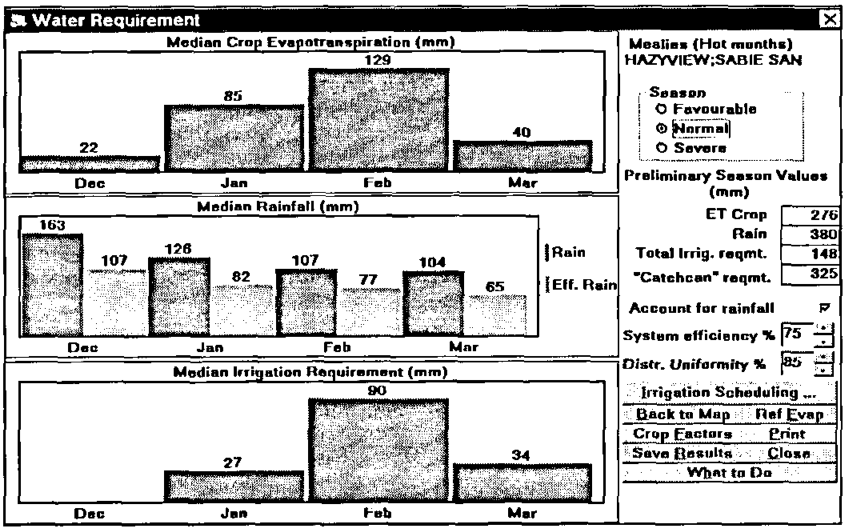
Geographical position is not the only factor to consider, it helps a great deal if one knows where the station is located. Is it in the middle of an irrigated area or is it up on a hill some way away?

We have selected Hazyview.

This is the crop factor screen for green mealies planted in Hazyview on the 15th December.

The crop factors define the growth characteristics and water requirements of the crop. We will be considering a series of scenarios in order to determine if irrigation at this time of the year is warranted.

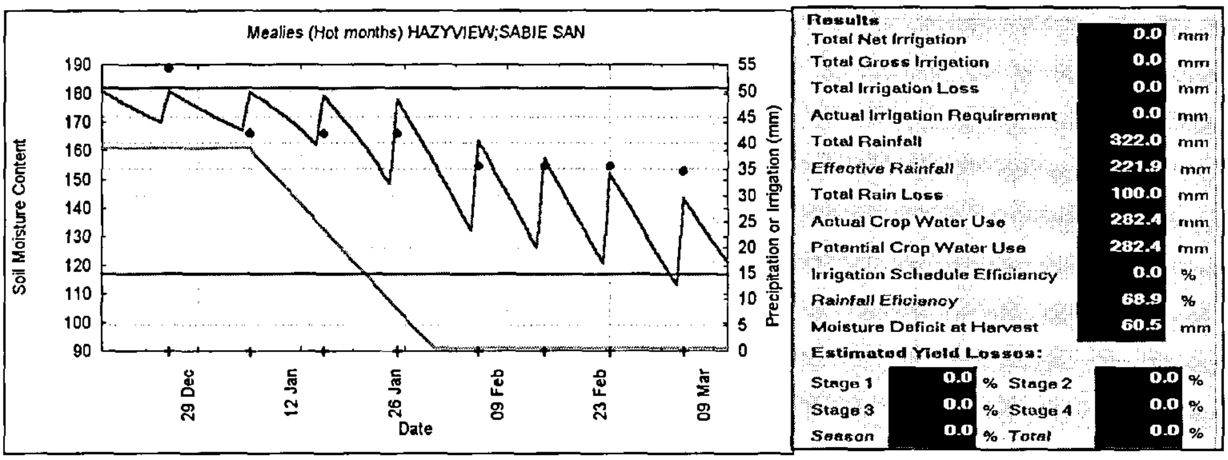




The water requirement screen provides the monthly values of ETcrop (evapotranspiration) in the top window, rainfall and effective rainfall in the middle screen, and irrigation requirements in the bottom screen.

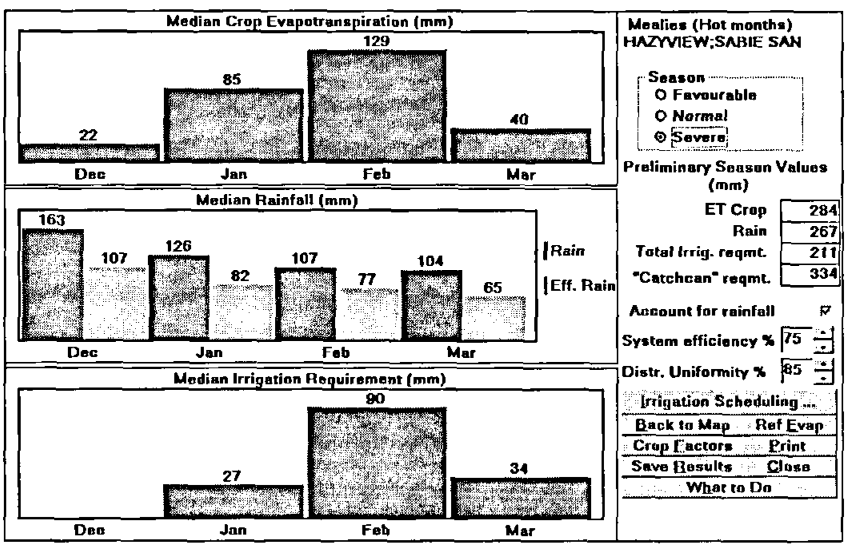
Allowance is made for both system efficiency (losses from farm boundary to land surface) and distribution uniformity (the effect of water distribution and soil variation).

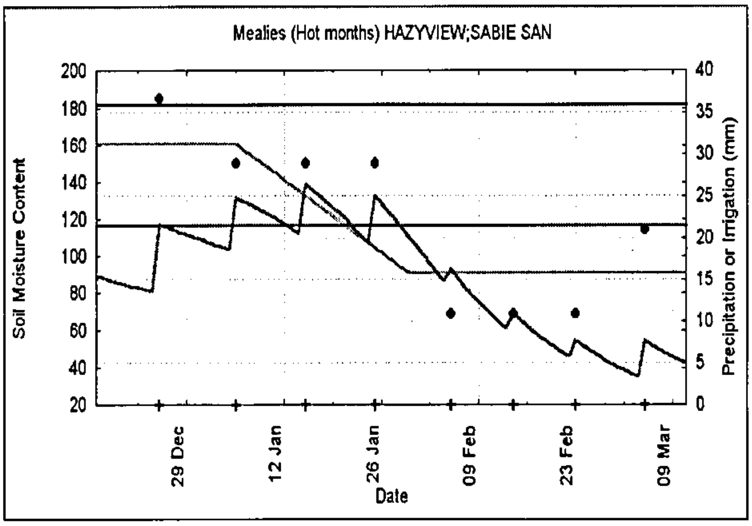
The crop water requirement screen above indicates that irrigation to the amount of 148 mm would be required in a normal year. But is this, in fact, the case? This is a high rainfall area and with a planting date in December the chances are good that the soil profile will be wet. The crop will be able to augment rain with the water stored in the profile and no irrigation will be required.



This situation is reflected in the table and graph above where the purple soil moisture content line remains safely between the red and blue limit lines.

What would the position be in an adverse year? Note that the 'severe' button has been activated. The irrigation requirements are now estimated for the severest year that can be expected once in five years. Nominal irrigation requirements are up from 148 mm to 211 mm largely because of reduced rain during the season.



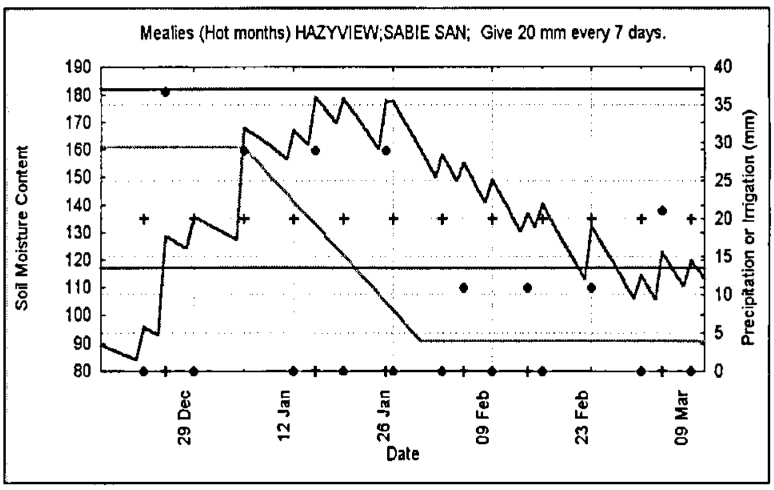


Results		
Total Net Irrigation	0.0	mm
Total Gross Irrigation	0.0	mm
Total Irrigation Loss	0.0	mm
Actual Irrigation Requirement	0.0	mm
Total Rainfall	177.9	mm
Effective Rainfall	177.9	mm
Total Rain Loss	0.0	mm
Actual Crop Water Use	226.3	mm
Potential Crop Water Use	284.5	mm
Irrigation Schedule Efficiency	0.0	%
Rainfall Efficiency	100.0	%
Moisture Deficit at Harvest	139.4	mm

Estimated Yield Losses:			
Stage 1	4.7 %	Stage 2	0.0 %
Stage 3	38.0 %	Stage 4	23.6 %
Season	25.6 %	Total	66.2 %

The initial soil water content above has now been reduced to half-full (not unlikely in a dry year) and rain alone is then not adequate in a severe year. Note how the purple soil moisture content line has dropped far below limits and the table shows major yield losses.

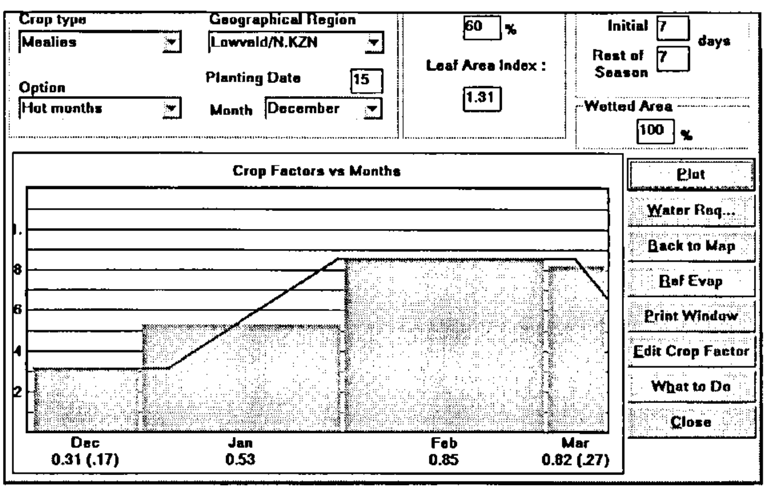
To provide for the above circumstances, irrigation is introduced below at the rate of 20 mm per week throughout the growing season, as shown below. Excess irrigation in the early phases is stored in the profile and sees the crop through a dry February. **It appears that, for this crop in the summer months, standby supplementary irrigation of 20 mm per week would be good insurance.**



Results		
Total Net Irrigation	153.0	mm
Total Gross Irrigation	240.0	mm
Total Irrigation Loss	9.5	mm
Actual Irrigation Requirement	143.5	mm
Total Rainfall	177.9	mm
Effective Rainfall	161.8	mm
Total Rain Loss	16.1	mm
Actual Crop Water Use	282.8	mm
Potential Crop Water Use	284.5	mm
Irrigation Schedule Efficiency	93.8	%
Rainfall Efficiency	90.9	%
Moisture Deficit at Harvest	68.5	mm

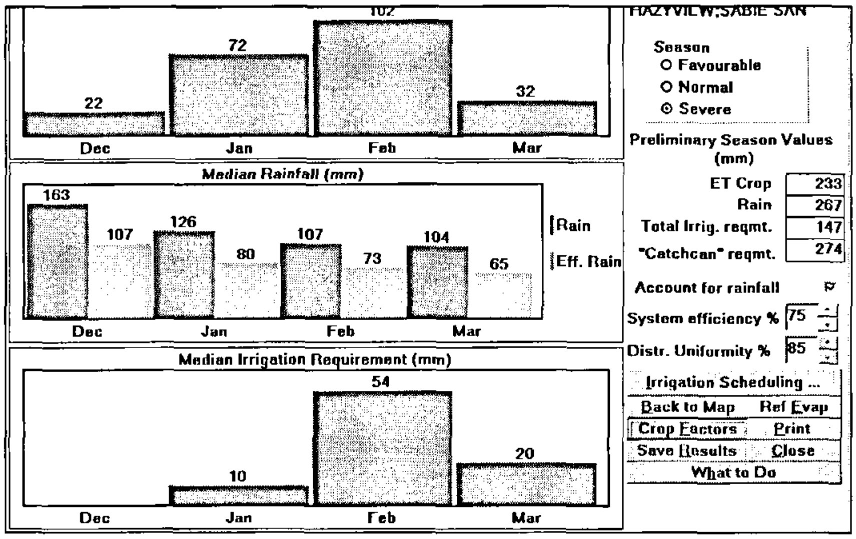
Estimated Yield Losses:			
Stage 1	2.3 %	Stage 2	0.0 %
Stage 3	0.0 %	Stage 4	0.0 %
Season	0.7 %	Total	2.3 %

We have assumed that the crop will be grown to normal commercial standards with a high planting density and heavy fertilisation. Many small and emerging farmers operating in an uncertain environment prefer a less intensive approach. This can be approximated by reducing canopy cover and attendent leaf area index to values more in line with dry land practice. Effectively this amounts to a 60% cover at peak and has a significant impact on crop factors.

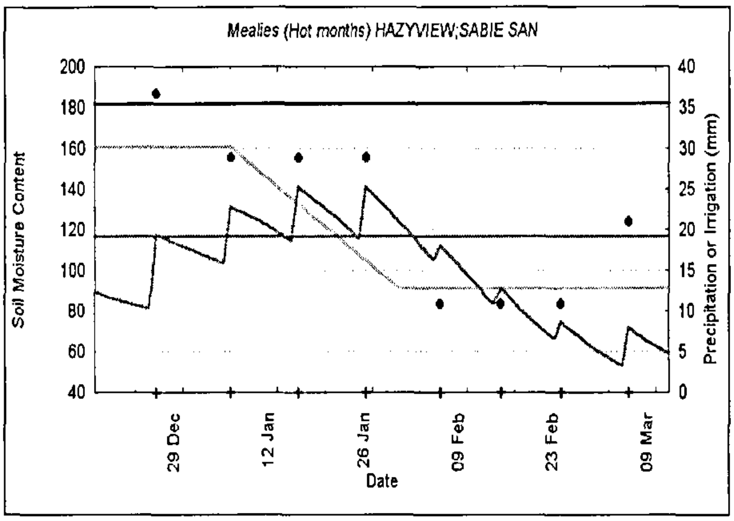


The lower planting density has resulted in a reduction in the crop factors and consequently in ETcrop and irrigation requirement.

It is now possible to assess whether irrigation is necessary in a severe year with a half-full profile at the start of the season.

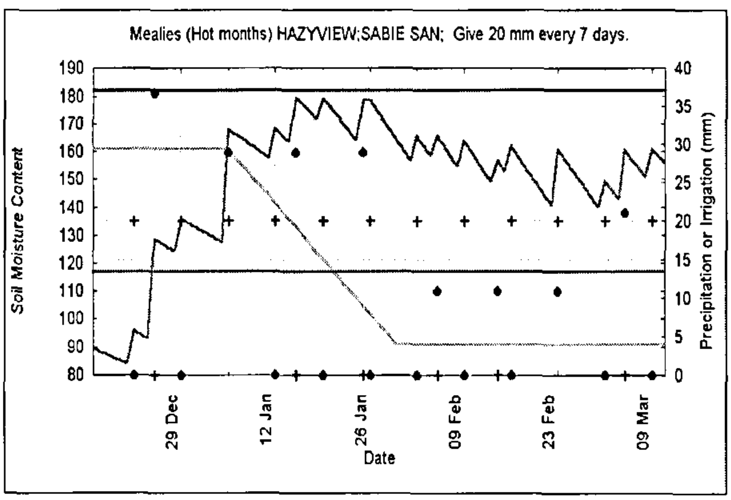


The next two screens make it clear that, despite the reduced planting density, supplemental irrigation is desirable.



Results		
Total Net Irrigation	0.0	mm
Total Gross Irrigation	0.0	mm
Total Irrigation Loss	0.0	mm
Actual Irrigation Requirement	0.0	mm
Total Rainfall	177.9	mm
Effective Rainfall	177.9	mm
Total Rain Loss	0.0	mm
Actual Crop Water Use	209.7	mm
Potential Crop Water Use	233.1	mm
Irrigation Schedule Efficiency	0.0	%
Rainfall Efficiency	100.0	%
Moisture Deficit at Harvest	122.8	mm

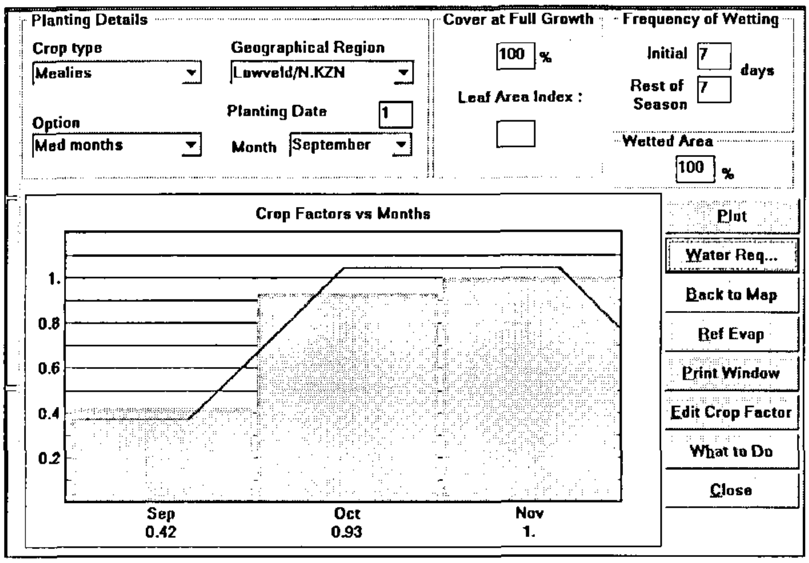
Estimated Yield Losses:			
Stage 1	4.7 %	Stage 2	0.0 %
Stage 3	16.8 %	Stage 4	14.2 %
Season	12.6 %	Total	35.6 %



Results		
Total Net Irrigation	153.0	mm
Total Gross Irrigation	240.0	mm
Total Irrigation Loss	12.2	mm
Actual Irrigation Requirement	140.8	mm
Total Rainfall	177.9	mm
Effective Rainfall	155.6	mm
Total Rain Loss	22.3	mm
Actual Crop Water Use	231.5	mm
Potential Crop Water Use	233.1	mm
Irrigation Schedule Efficiency	92.0	%
Rainfall Efficiency	87.5	%
Moisture Deficit at Harvest	26.1	mm

Estimated Yield Losses:			
Stage 1	2.3 %	Stage 2	0.0 %
Stage 3	0.0 %	Stage 4	0.0 %
Season	0.9 %	Total	2.3 %

Irrigation at 20 mm gross per week is more than adequate. The profile fills during the first part of the season and remains at this level until the cobs are picked. **This irrigation level would have been adequate even with a crop planted and fertilised to provide top yields, although we have seen earlier that the situation could become marginal towards the end of the season.**

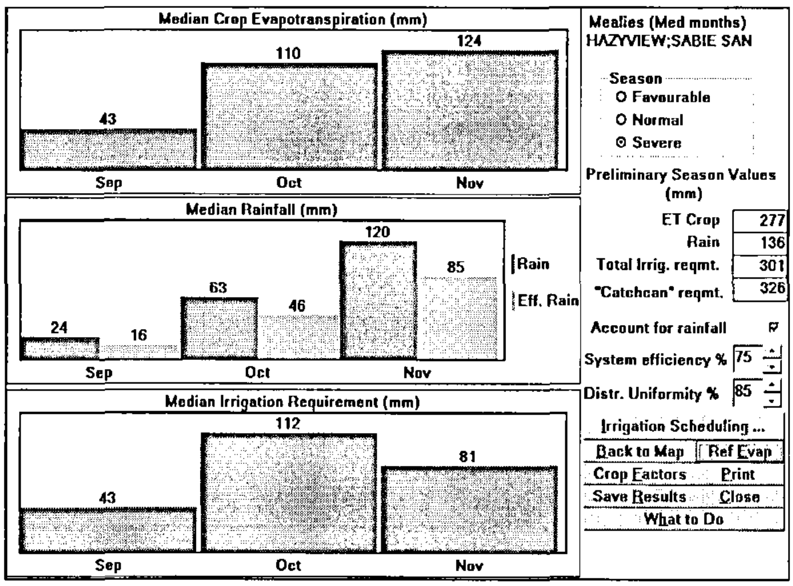


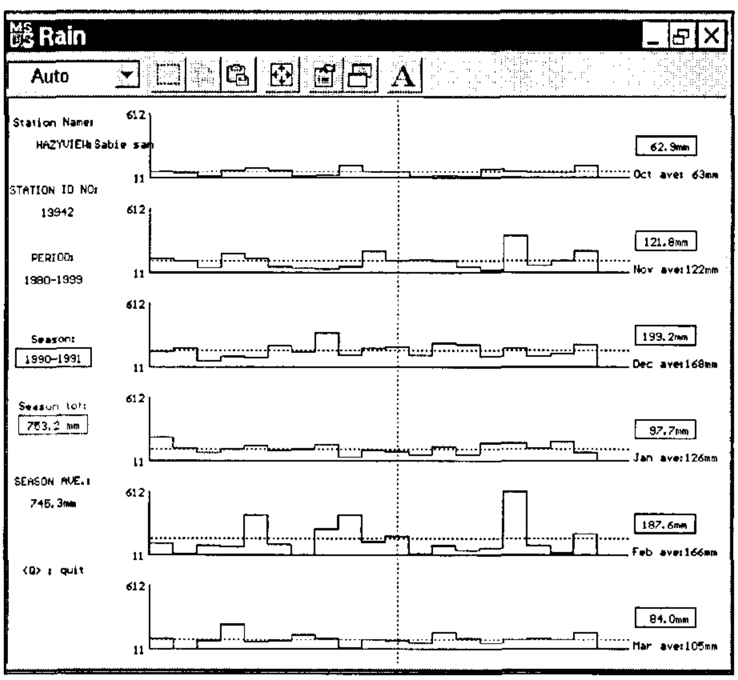
We have been considering the conventional planting date in December that is in the middle of the rainy season. Better prices can be achieved if the cobs become available in November. This implies a September planting date before the rains come while October has a high evaporative demand.

The irrigation demands in this period can be critical in scheme planning and design.

The screen reflects irrigation requirements for the one in five severe year. There is not a great difference between normal and severe years in this case because it is early in the rainy season.

The dragline efficiency factors are retained unaltered but in times of stress when there is not sufficient water all the water entering the soil is used and the distribution uniformity factor can be increased to 95%. Of course, system efficiency could be reduced!

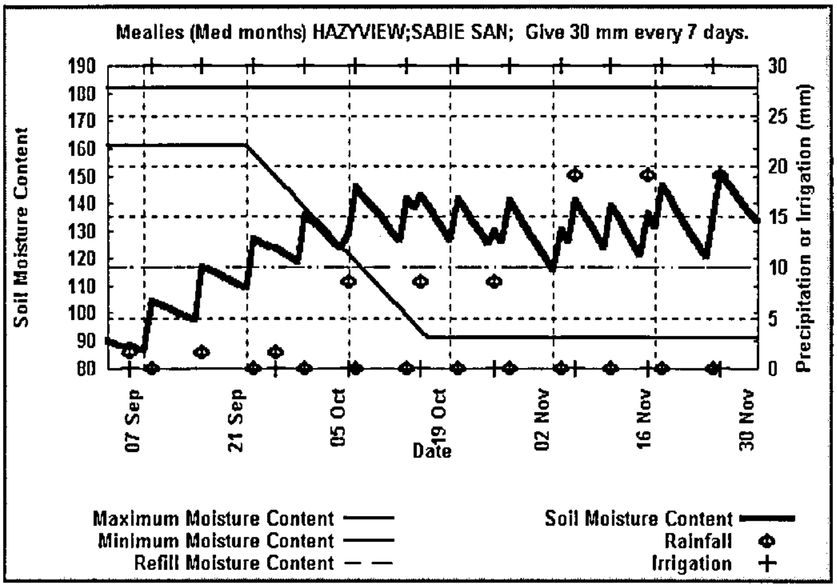


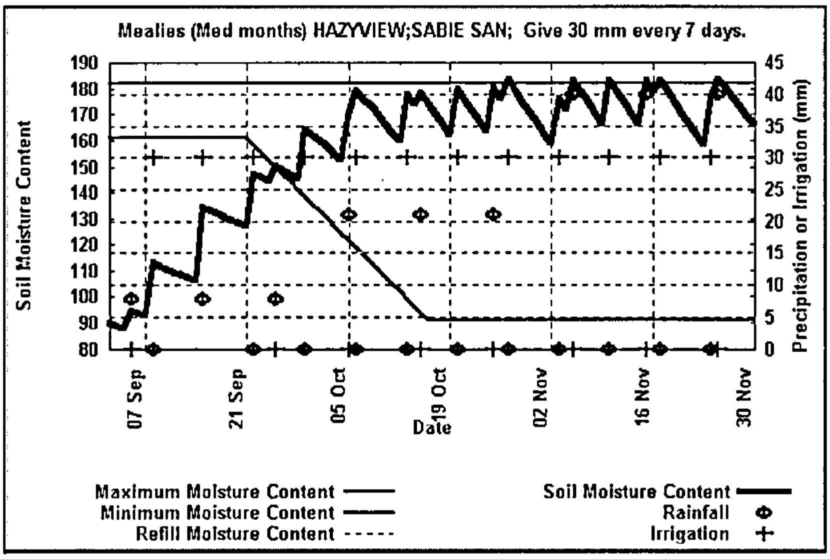


At this stage it is a good thing to check the rainfall pattern. The monthly rainfall pattern for the area is reasonably consistent and a series of dry months is unlikely.

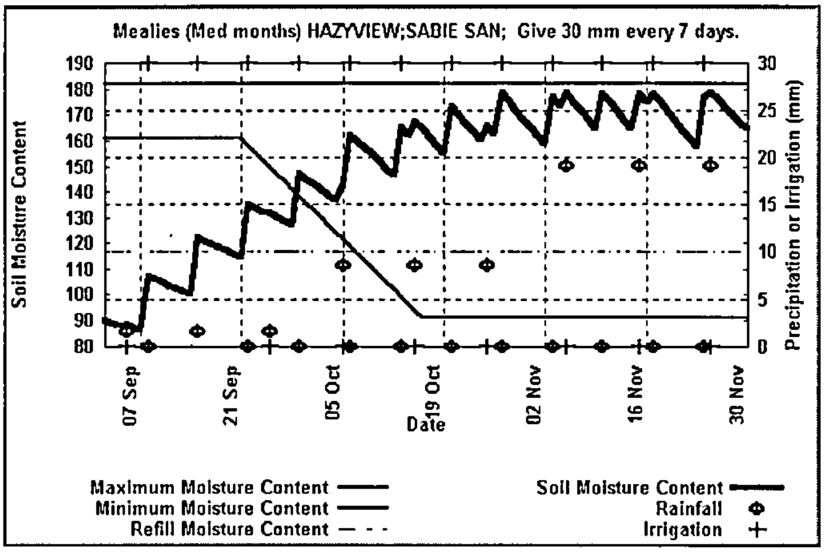
A diagram of this nature facilitates discussion with local people and augments conventional statistical present-ations.

This is for a severe year with a full plant population and high evaporative demand. Weekly irrigations of 30 mm ensure that there is no yield reduction but the profile is far from full.





If one considers what the position would be in a normal year the 30 mm per week irrigations effectively ensure optimum yields and a full profile at the end of the season.



Once again this is a severe year but the plant population is reduced and the canopy cover is now only 60 %. The crop has been ensured.

SAPWAT makes it possible to carry out rapid sensitivity tests to arrive at simplified management and design options. An irrigation of 20 mm per week is adequate for the December planted crop because it develops in the cool months. The key months are September and October, when 30 mm is recommended.

Chapter 5

WATER SUPPLY AND MANAGEMENT

See also ***Irrigation Design Manual*** (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

5.1 INTRODUCTION 5-1
5.1.1 The importance of water supply management 5-1
5.2 OBSERVATIONS DERIVED FROM THE FIELDWORK 5-2
5.2.1 Introduction 5-2
5.2.2 Independent water supply 5-2
5.2.3 Shared water supply 5-3
5.2.4 Management and payment systems 5-3
5.2.5 Considerations for water measurement and payment 5-4
5.2.6 Water supply system capacity requirements 5-7
5.2.7 Gravity-fed or pumped supply? 5-7
5.2.8 Water distribution management 5-7
5.2.9 Other users 5-8
5.2.10 Pumped water supply for groups of farmers 5-8
5.3 THE CONCEPT OF INDIGENOUS IRRIGATION SCHEMES 5-9
5.3.1 Introduction 5-9
5.3.2 Characteristics of indigenous systems 5-10
5.3.3 Need for a new approach? 5-10
5.4 WATER SUPPLY AND IRRIGATION SCHEDULES 5-11
5.4.1 Introduction 5-11
5.4.2 Water supply and water distribution 5-11
5.4.3 Managing the irrigation schedule 5-12
5.5 DEVELOPING A WATER SUPPLY SCHEDULE IN PRACTICE 5-15
5.5.1 Application to larger schemes 5-18
5.6 WATER DELIVERY CONTROL, FLEXIBILITY AND RELIABILITY 5-19
5.6.1 The role of water delivery in ensuring efficient irrigation 5-19

5.6.2 Water delivery networks 5-20
5.6.3 Reliability 5-20
5.6.4 Transferring modern and appropriate technology 5-21
5.7 IRRIGATION EFFICIENCY 5-22
5.8 PUMPING 5-22
5.8.1 Introduction 5-22
5.8.2 Surface pumping 5-23
5.8.3 Borehole pumps 5-24
5.8.4 Scheme pumping stations 5-24
5.9 CONCLUSIONS AND RECOMMENDATIONS 5-24

TABLES

Table 5.4.3.3: Possibilities for group size and unit flow 5-13
Table 5.4.3.6: Selection of possible intervals 5-14
Table 5.4.3.7: Selection of possible unit flows 5-15
Table 5.5a: Plot holders schedule for weekly irrigation turns 5-16
Table 5.5b: Printout of SACFLOOD, showing inputs and outputs 5-18

5.1 INTRODUCTION

5.1.1 THE IMPORTANCE OF WATER SUPPLY MANAGEMENT

Unexpectedly, this is one of the most important chapters in this report. Throughout this investigation, a major objective has been to identify the reasons for the general failure of irrigation in the context of development. The hope was that, once these reasons had been identified, viable recommendations for remedial action could be devised. It now appears that the management of water delivery to an irrigation scheme for small-scale farmers could be a key to the failures of the past, and that there may be no satisfactory short-term solutions.

The present occupiers of irrigation schemes are adamant that, unless infrastructure is restored and adequate water delivery assured, they cannot consider assuming responsibility for the management and maintenance of the schemes. Proposals for rehabilitation and hand-over emphasise 'sustainability', 'extension' and 'training', without going into detail. The assumption is that, with 'bottom-up' farmer management and upgraded skills, sustainability will automatically be achieved. There is evidence to suggest, however, that, for almost all these existing schemes, effective management of water delivery is, if not impossible, very difficult – *and, without it, sustainable irrigation is unattainable. The schemes failed in the past and, unless their water* delivery systems change, there is no reason to believe they can be successful in the future.

Innovative thinking is therefore essential if the assets of infrastructure, natural resources and experience are to be gainfully exploited. Restoring the *status quo* does not seem to be enough.

The issues surrounding water supply and management are complex. This is recognised internationally and the subject is covered in several publications that were reviewed for this report. Comprehensive extracts from these key publications are included in this chapter. The extracts have been edited and adapted in order to facilitate the development of meaningful recommendations.

The chapter consists of seven sections, each representing a different perspective:

- **Observations derived from the fieldwork.** These were largely developed by Ms Marna de Lange and derived from the interim report to the steering committee in 1996 (Section 5.2).
- **The concept of indigenous irrigation schemes**. This is taken from a paper presented by Slabber (1992)(Section 5.3).
- **Water supply and irrigation schedules**. This is divided into two sections. The first (Section 5.4.2), deals with small schemes and draws on the procedures developed by the Department of Agriculture, Republic of Kenya.(1990) The second (Section 5.4.3), is applicable to larger schemes and discusses the design methods published in the FAO Irrigation and Drainage Paper No 24 (Doorenbos and Pruitt, 1977).
- **Water delivery control, flexibility and reliability**. This is from a chapter on international aspects, which was published in 1990 in an American Society of Agricultural Engineers monograph on irrigation management and which has valuable comments on development (Burt and Plusquellec) (Section 5.6).
- **Applying a water supply schedule in practice**. It is difficult to appreciate just what is entailed in organising water delivery amongst a group of farmers served by one lateral. In order to quantify the situation, C P Crosby (1998) developed a computer simulation routine that can also be applied in design (Section 5.5).
- **Irrigation efficiency**. FAO No 24 clarifies the impact of various factors on scheme efficiency and design (Doorenbos and Pruitt, 1977). (Section 5.7).
- **Pumping**. Pumping is important both on schemes and on individual farms. Serious problems were disclosed in the course of the investigation. (Section 5.8)

5.2 OBSERVATIONS DERIVED FROM THE FIELDWORK

5.2.1 INTRODUCTION

The development of water supply infrastructure may include some or all of the following elements:

- development of the water source;
- a conveyance system to transfer water to storage;
- storage; and
- a distribution system to carry water to the edge of each farmer's farm or field. (The farmer-operated irrigation system takes care of the distribution of the water from the edge of the farm over the crops in the field so this is not included in the water supply infrastructure.)

The water source may be a river, borehole or large dam.

One of the main factors determining the nature of the water supply infrastructure to be developed is the decision whether or not to supply water under pressure at the field edge. To a large extent, this decision determines whether canals or pipelines will be used for conveyance and distribution systems. Generally, it also has an influence on whether or not the water will be mechanically pumped.

The capacity and the reliability of the water source throughout the irrigation season must be in balance with the amount of water needed on the irrigation project. The storage capacity (ie, the size of the dam), if any, should ensure that enough water is available to the project at the right time.

5.2.2 INDEPENDENT WATER SUPPLY

The requirements are well-known for planning and designing water supply infrastructure for a single large commercial farmer: The water supply must be sufficient to 'get through' all the lands on a rotational basis in peak season before crops are damaged by water stress (ie, by drought).

The requirements of a small independent farmer are much the same. However, as technical support is often less accessible to a small farmer in a remote area (without electricity, without easy access to spare parts and fuel, and without easy communication by telephone), the importance of robust, easy to maintain technology increases. Many small-scale independent farmers have shown ingenuity and achieved success:

Farmer A. This farmer worked for a number of years in Johannesburg to be able to afford the infrastructure he needed to start off his irrigation enterprise. He is currently farming 40 hectares of dryland maize and 5 hectares under irrigation, and he is doing very well. He pumps directly from the river with a diesel engine and has both long-furrow and sprinkler irrigation. Because his irrigation costs are one of his main expenditures, he prefers to use the flood irrigation method mainly, as he needs less pressure for this and therefore uses less diesel.

His cabbages are sold directly to hawkers who fetch them from the fields so there are no transport costs involved. His peanuts and tobacco are processed on the farm and then packaged and sold on the taxi ranks.

For an independent water supply, such as to an estate or an individual farmer, the choice of water supply technology depends mainly on the topography, the type of water source and the type of irrigation.

Farmer B. This farmer currently owns two centre pivots and cultivates mainly potatoes for the national fresh produce markets, obtaining his cropping advice from the Potato Board. He started small and built his farming enterprise gradually. He tries to assist his neighbours with advice, but is very disappointed by the lack of support from the Department of Agriculture's extension service. He does not want to purchase his own transport at this stage, because he feels he will 'let someone else make a bit of money out of that.' He prefers centre pivot irrigation, because it simplifies his management. He is very concerned about the consistent dropping of the water table in his area, and tries to spare his own boreholes, rather than over-pump. He is afraid, though, that his neighbours' pumping strategies may affect his own situation.

Estates and large-scale farmers often prefer the types of irrigation which require pumped supply, for irrigation management reasons, while an independent small-scale farmer may start his enterprise using furrow-basins with a gravity-fed supply, for cost reasons (because that is all he can afford). He may intend to expand later to more sophisticated types of irrigation. Farmer C showed how this could be achieved.

Farmer C. This farmer currently irrigates 50 hectares of tomatoes. He started off using only furrow-basin irrigation but, as he expanded, he converted some of his fields to drip irrigation to simplify management. He is thinking of buying his own transport as the transport companies in his area are not very reliable and all his produce is transported to the Johannesburg, Pretoria and Durban markets. He is currently trying sprinkler irrigation on a small field.

In all instances, system cost, ease of use and required levels of maintenance have to be in balance with the level of sophistication and management of the enterprise as a whole.

5.2.3 SHARED WATER SUPPLY

Shared water supply is normally considered when independent supply to each farmer is too expensive or impractical. Irrigation boards and farmer-managed irrigation schemes fall into this category. Planning and designing shared water supply adds a new dimension to the analysis required. It is important to consider the management implications of a shared system in the water supply design, because a shared system includes a number of individuals, each with different crops, with varying water requirements throughout the season! Merely designing a rotational supply to the entire area, as for an independent farmer, usually falls far short of small-farmer water management requirements.

Developing a shared water supply requires more elaborate planning, to provide for equitable and manageable distribution between a number of users. The farmers and the technical advisor, working as a team, must base the water supply design on thorough participatory exploration of the implications for management and use.

In summary, when developing shared water supply for small-farmer managed projects, the challenge lies in designing a system which:

- allows easy, sustainable management of equitable water distribution, especially during periods of drought or water shortage;
- provides for manageable water payment arrangements and reliable water measurement, should the payment system render measurement unavoidable;
- judiciously balances development costs with running and maintenance costs, according to financial and operational circumstances, while keeping overall costs as low as possible, to increase viability (this also requires critical re-evaluation of the realistic capacity requirements of the system); and
- achieves attainable maintenance requirements and minimal dependence on technical support services.

5.2.4 MANAGEMENT AND PAYMENT SYSTEMS

Experience shows that the management of small-farmer schemes, just like that of irrigation boards, must be based on consensus between farmers on the rules for the scheme. Many unsuccessful small-farmer schemes have been developed for central management, and an external management body is still managing a number of these, with little input by farmers. In contrast, much of the success of community gardens is attributed to the independence of the farmers' group in managing their own affairs - including water supply. Much is to be learnt from the success community gardens have had in constitutionalising agreed penalties for typical transgressions. The designer must make sure that he develops infrastructure that lends itself to management by farmers. The following examples of community gardens illustrate this:

Community Garden 1. This garden started off with help from the government in creating the water supply infrastructure but is fully independent and is managed by an elected committee. The constitution drawn up by the gardening group determines that any participant whose land lies fallow will lose the right to work it. Gardeners take turns to travel by bus and taxi to a neighbouring town to buy seeds and other inputs. They are very happy with the extension advice that they are receiving from the Department of

Agriculture. One gardener has started a small nursery to supply seedlings to the other community gardeners, as well as fruit trees to neighbouring farmers. All produce is marketed to the surrounding villages.

Community Garden 2. Like most successful community gardens, this garden group manages itself through an elected committee. They have drawn up a proper constitution whereby common concerns are governed, with agreed penalties for transgressions. One of the realities facing a woman in their area is that she may be summoned at any time by her husband to join him in Johannesburg, which means that she is forced to abandon her garden plot for an indefinite period. Agreed and stipulated in the garden constitution, she forfeits her rights to her plot after a month, unless she can make private arrangements with someone to cultivate the plot on her behalf until her return.

At the request of the garden group, the constitution was read and signed by the local chief, to make it legally binding.

For successful farmer-managed projects, the rules must first be established by mutual agreement between the users, but then there must be strict discipline in applying those rules to ensure that the system does not break down. The approach must build trust amongst users and induce incentives for water use efficiency and equitability. The water supply design can contribute to sustaining discipline. For instance, by designing water distribution so that everybody can always physically see what everybody else is doing, there is social pressure on the individual to comply with the rules he has helped to draw up. Compare the case studies below of Scheme 1 and Community Garden 3, which show the difference between scheduling for farmers in a large area, and scheduling for those in a small area:

Scheme 1. This is a typical furrow-basin scheme. Water supply is via a canal system, with sluice off-takes, each serving a block of irrigation farms. Blocks may cover 15-25 hectares, while farms are divided into 0.1-hectare plots, each farmer typically having one to ten plots (that is between 0.1 and 1.0 hectare of farmland.) The scheme consists of various blocks, making up a total area of over 1 000 hectares.

Like most flood irrigation schemes for small-farmer developments in South Africa, this one started off using controlled wild flooding, and has since developed into a furrow-basin system. Farmers and extension officers have found these furrow basins much more efficient in water use and far more manageable.

As on most of these schemes, water supply scheduling is currently on a rotational basis; that is, each alternate block receives the full stream for one day or one night in a fixed schedule. Every alternate block has sufficient storage capacity in a balancing dam to hold one night's flow, so that farmers who receive the stream overnight can still irrigate during the day, an important prerequisite with flood irrigation.

However, on a scheme of 1 000 hectares, the distance between the first and the last block may be more than 20 km. It is inevitable that some farmers may find it impossible to irrigate when it is their turn and farmers frequently take water out of turn. This is an insurmountable problem to farmers downstream, who normally do not have transport so that, by the time they have gone upstream to find the culprit(s) and have returned, several others may have started using the water, or the day may be gone. This arrangement leaves very little flexibility for farmers or blocks receiving a day-stream, because they pass up on their opportunity to irrigate until the next time which may be seven days later.

The researchers are of the opinion that continuous proportional distribution of water would be a more manageable arrangement. Farmers within a block (who should normally be not further than 500 m apart) could then arrange and rearrange their scheduling much more easily. This becomes particularly important in times of water scarcity.

Community Garden 3. This is an 8-hectare garden with a furrow irrigation system. Irrigation scheduling is rotational but farmers exchange shifts with each other whenever they find it impractical to irrigate in their usual turns.

5.2.5 CONSIDERATIONS FOR WATER MEASUREMENT AND PAYMENT

"Whisky is for drinking; water is for fighting" goes an age-old Irish saying. This is true to this day. One can also say with some conviction that 'farmers will steal water!'

Success in achieving an equitable and sustainable system seems to hinge, among other things, on the combination of whether:

- Water is received on a fixed schedule or per weekly order;
- Water supply is gravity-fed or pumped;
- Water payment is in the form of a fixed yearly payment or payment-on-order or payment-per-measured-usage;
- Water supply is farmer-managed or externally managed.

From field observations, the following was found:

Farmers on large-scale, farmer-managed, gravity-fed supply schemes (Loskop, Hereford) order water on a weekly basis. This appears to work but not without problems. Payment is in the form of a fixed yearly amount per hectare under irrigation and has to be paid, whether the farmer decides to irrigate or not. Collectively though, farmers can influence the way in which the water supply management is arranged. Scheme 2 is a good example.

Scheme 2. This is a typical flood irrigation scheme serving white farmers on farms of ten to twenty hectares. It has a canal system with a sluice off-take to each individual farm. Lands were originally developed for flood irrigation (gravity) below the canal. Many farmers have created storage dams, mainly to utilise night water (and storm water, which is considered a bonus) and have developed lands above the canal, irrigated by means of pumps from the storage dams.

The water source is a dam and each farmer puts in an **order** on Thursday for his needs for the following week. Water is released from the dam according to this order and a water bailiff is responsible for setting the sluices to the correct levels. This system works fairly well. Water distribution is administered by the Department of Water Affairs (other similar schemes have water distribution managed by an irrigation board). Farmers are well organised and handle disputes through an elected committee.

However, the diversion structures are not very good and diversion varies with the canal level. Farmers capitalise on this by placing obstructions in the canal to raise the water level at their sluices, thus taking off more water. Some farmers pump directly from the canal, thus increasing the volume of water they are extracting.

On similar schemes where the water source is a perennial river, farmers typically use a **fixed rotational schedule** ('beurtstelsel'). A water bailiff sets each farmer's sluice to the correct level and keeps the keys to the locks on the sluices.

Ordering water on a pumped, large-scale small-farmer development has led to endless problems of under-payment and central management tricks to keep the system operational. This is clearly illustrated in the case of Scheme 3.

Scheme 3. This scheme provides water under pressure to each farm. The water source is a large dam on a major river, and a canal system conveys the water to pumping stations, each station serving a block of 10-hectare farms. Any number of farmers in a block may irrigate simultaneously.

The rules of the scheme are that farmers place their order on a Thursday for water during the following week. Water is released down the canal daily, in quantities based on the cumulative order. There is an eight-hour delay from the dam to the scheme. Payment is according to the order placed for water. The reality now is that some farmers order water; water is released; and pumps are switched on according to the order. Very soon, the pump operator finds that the pressure drops, as farmers who have not ordered water start irrigating. Knowing that those farmers who have placed their order will be irate if they have inadequate pressure, the pump operator switches on more pumps. Soon, he realises the level of the canal is dropping too rapidly and that more water is needed. He contacts the scheme manager and explains the situation. The manager phones the official at the dam for an urgent additional release.

In one season, only one quarter of the water released from the dam was ordered and thus paid for. This is obviously not an economic proposition for the people who supply the water. In the past, water meters were installed to try to solve this problem but they were sabotaged.

There seems to be a general lack of meaningful communication between the scheme management and the farmers on this scheme. Farmers have no representation in the scheme; scheme management has good intentions but any 'plans' drawn up by them continue to be perceived as top-down interference, because the farmers are not actively involved in analysing scheme problems and proposing solutions. The farmers do not feel they own the system so they try to use water without paying for it.

For pumped systems, a payment-on-order system like this one is very difficult to manage and control, as it is so easy to sabotage water meters. On a large scheme, the pump attendant's brief is usually to switch on more pumps as soon as the pressure drops, which makes it possible for an individual farmer to obtain irrigation water without ordering, and therefore without paying. Clearly, if the scheme is managed by an outside organisation (like government), farmers will be tempted to take turns in ordering, just to get the pumps started.

The gravity-fed systems we visited in communal land tenure areas were on a fixed yearly water charge, which seemed to be satisfactory from the farmers' point of view. Two examples are Schemes 4 and 5, which were very low-cost.

Scheme 4. This is a surface irrigation scheme, divided into three blocks and served by a canal. Unlike the furrow-basin types of surface irrigation schemes, this scheme has many off-takes from the main canal within one block. Water shortages have led to a situation where, although the first block is still being cultivated, there is only some dryland cropping on the third block.

All along the route of the water, above the canal, and especially on some small areas below the canal, close to the weir intake at the river, refugees have made small survival gardens, which they irrigate by bucket from the canal. The local community tolerates this as the water supply long ago became inadequate for the last two blocks, so that the refugees can hardly be blamed for the shortages.

Scheme 5. This is a furrow-basin scheme with rotational water supply but no storage capacity for night water. The scheme is situated in an arid area and frequently suffers water shortages, despite which farmers seem to survive and produce good crops.

Many of the farmers are women. In times of drought, they sometimes try to irrigate at night but find this very dangerous. Occasionally, they have had to lie down flat in the fields to hide until hostile men have passed. They often experience crop losses as a result of theft.

In all cases, however, farmers experienced problems where there was a fixed water supply schedule, which rotated on a block-of-farms basis, rather than between-farms-in-a-block. (For gravity systems, the recommendation is to keep the area in which farmers have to co-operate as small as possible, so that social control comes into play. Larger distances require reliable transport or telephone communication between farmers or by their bailiff). On schemes where there was a fixed water supply schedule that rotated between blocks of farms, farmers seemed to have no influence on water supply management. Firstly, the infrastructure limited flexibility and, secondly, government appointed the bailiff.

A pumped supply scheme on a fixed yearly charge was acceptable. Due to drought, water was in short supply and on a fixed schedule of a limited number of hours every three days – a short enough cycle to allow farmers sufficient flexibility. It is unclear how much influence farmers have over management decisions, although an active system of farmers' committees is in evidence.

Scheme 6. This is a scheme of 1 500 hectares, roughly organised into three blocks of 500 hectares each. Each block is served from a central pumping station containing a number of pumps and, although the pressure supplied by the pumps is designed for sprinklers, the irrigation technology used varies widely from furrow-basin irrigation, to sprinkler irrigation, to micro. One farmer even operates a centre pivot. The centralised pumping for a variety of irrigation methods makes running costs high because the pressure produced for sprinkler irrigation is far in excess of that required for flood, micro and drip irrigation.

Farmers each have between three and fifteen hectares of irrigation land and the range of crops varies greatly. There is total freedom of crop choice, and each farmer or informal group of farmers handles marketing independently. Some farmers grow exotic crops for export under contract to Indian tradesmen in Durban, over 1 000 km away.

Water for irrigation is supplied on a fixed schedule for a number of hours every third day. Payment is in the form of a fixed yearly rate.

The level of the dam has been very low for a number of years so that water restrictions are a necessity and the outlook is not very bright. Yet the farmers are not discouraged; they are committed and happy to be farming, despite the difficulties. There is no resentment, no malice and no mistrust, such as can generally be found on centrally managed schemes.

The level of understanding of basic irrigation principles is very good on this scheme and the extension support is also of a remarkably high level and greatly appreciated by the farmers.

We could find no support for the argument that farmers used water more sparingly when they were paying on a *pro rata* basis.

5.2.6 WATER SUPPLY SYSTEM CAPACITY REQUIREMENTS

On a large scheme, it is often too expensive to supply enough pumping capacity so that all farmers can irrigate simultaneously. However, Clemmens (1987) argues that, statistically, the probable percentage of farmers irrigating at the same time on a continuous flow system decreases as the number of farmers on a scheme increases. This means that it may be safe to design a scheme for 200 farmers at as low as 60% of the full capacity requirements for peak season, with associated cost savings in infrastructure development. Field observations confirmed that, in practice, many existing schemes seem to have spare pumping capacity. Care should therefore be taken not to over-design, as the capital, running and maintenance costs of infrastructure have so much influence on the affordability and sustainability of small-farmer irrigation projects.

Another cost factor is over-provision for scheme expansion, especially with regard to mechanical equipment. We found apparent over-design of both installed pumping capacity and of room for pumps in the pump station building. Also, the building design and materials used for scheme pumping stations tends to be over-elaborating and expensive, looking much more like a municipal project in a suburban area than a farm structure.

The cost of standby pumps for down times can seldom be justified in farming and they are hardly ever found on large commercial farms.

5.2.7 GRAVITY-FED OR PUMPED SUPPLY?

One of the major questions a designer faces is whether the water supply should be pumped or gravity-fed.

Gravity-fed systems normally comprise a dam across a river or a weir, to turn water into a canal system that feeds flood irrigation fields along the river. No electricity or other power source is needed to run the system.

The water has to be pumped where the topography does not lend itself to a gravity-fed arrangement, for instance, if the irrigable lands are much higher than the river level, or when the farmer prefers using pressurised irrigation like sprinkler, or when the water source is a borehole.

Generally speaking, schemes managed by small-farmers should have gravity-fed water supply systems. Although they may in some cases be more expensive to implement, the running costs and maintenance requirements are very low.

In South Africa, there appears to be a dearth of knowledge about gravity water distribution structures, possibly because, for the past three decades, the emphasis has been on modern systems such as sprinkler, micro, drip and centre pivots. However, with Africa opening up to us, this gap in our knowledge can be rapidly filled by learning from the experiences in other African countries, particularly Kenya and Zimbabwe.

5.2.8 WATER DISTRIBUTION MANAGEMENT

Water distribution management is easier in a small area, where all participants can easily observe all activities, and social pressure helps to keep them in line. When the distances between farms become larger, management and even control by the farmers becomes more difficult, especially where farmers or their water bailiffs do not have transport to act quickly when a problem occurs. During periods of water shortages, such as drought or excessive losses due to leaking canals, these management difficulties increase.

A 'fixed schedule' water supply arrangement is very difficult to manage for the individual farmer, especially if there is little leeway for flexibility or exchanges of 'turns' with neighbouring farmers. A farmer finding himself under obligation to attend a funeral on the day of his turn for irrigation may have to take water out of his turn later in the week to prevent crop failure. This leads to a breakdown in trust and the beginning of a vicious circle.

The most effective system encountered is equal daily division of water between blocks that are small enough to allow flexibility among close neighbours. This takes advantage of social pressure to ensure compliance to group rules by individuals whose actions can be observed by everyone in their block. With this approach, significant savings in infrastructure are also possible, as water is divided proportionally among the blocks along the canal, so that the flow rate in the canal, and therefore the canal dimensions, can become progressively smaller along the route. Some storage capacity at each block may increase the flexibility further.

5.2.9 OTHER USERS

There are important implications of canal systems to bear in mind. The distance from the intake structure in the river to the first farm may be several kilometres because the canal follows the contour. Water 'theft' is therefore often a problem. It is recommended that all current and potential water users along the canal route are included in the planning process, and that the design makes provision for these users from the start. Where the river has been the traditional domestic water source for villages in an area and the canal brings water closer, naturally, the canal will be used rather than continuing to make the longer trip to the river. This should be provided for. Small-scale vegetable production by housewives may also have to be provided for and, in so doing, the benefits of the development will be spread to a larger portion of the community.

5.2.10 PUMPED WATER SUPPLY FOR GROUPS OF FARMERS

A situation often found on small-farmer irrigation schemes, is a centralised pumping station, with one or several pumps serving a group of farmers. Sharing common pumping infrastructure is often the only affordable way to supply water under pressure to small farmers who use sprinkler or mechanised irrigation, but this arrangement has inherent problems.

The number of farmers sharing a single pumping station may vary from two to two hundred. Management and design requirements differ according to the variation in number of farmers, type of irrigation, scheduling arrangements and size of area served. Normally, the fewer the participants, the better the chances of success but the management and water distribution design can counteract this. For example, compare Community Garden 4 with Scheme 7:

Community Garden 4. A relatively large group of seventy farmers in a 3-hectare community garden have no problem in managing their pumping (daytime, continuous) and irrigation scheduling (rotational, weekly). This is because the type of irrigation (furrows), and the small area within which farmers have to co-operate, allow enough flexibility for farmers to exchange an irrigation shift with a neighbour when necessary. The group were assisted at the outset in discussion of management possibilities and agreed upon rules of operation and penalties for transgression. The area is small enough that it is nearly impossible for any member of the group to cheat without being seen by other farmers.

On the other hand, a group of only four farmers sharing a pump on 40 hectares (10 hectares each) found themselves in dispute, because one person failed to co-operate, even though the pumping capacity is adequate to supply all four farmers simultaneously.

Scheme 7: This group of four farmers is doing very well – they are making money! They share a pump to draw water from a perennial river, each irrigating 10 hectares of sugar cane. They have dragline irrigation designed for 12-hour stand times, but have found it impractical to move sprinklers according to this schedule. They are compensating by moving their sprinklers in shifts of eight hours (day-time) and sixteen hours (night-time), making sure that roughly the same area that receives an eight-hour application in one cycle will receive sixteen hours in the next, although this has not been accurately managed. According to the farmers, there is 'some run-off and ponding but not too bad' after a sixteen-hour application.

However, their sprinklers were not very well maintained, with considerable wear on the nozzles. The farmers did not know how to specify correct sizes to a dealer. Although their cane growth was rather uneven, they had not considered that this could be as a result of their uneven water distribution. They were very eager to learn!

Three of the four farmers are experiencing some difficulty with the fourth farmer in the group, who often neglects to move his pipes in step with the others. In off-peak season, by the time these three farmers have completed their irrigation, the pump has to be kept running to enable the fourth farmer to complete his irrigation and, since the electricity account is split four ways, the three are directly affected by the negligence of the fourth. However, because they are all friends, the three find it very difficult to confront the fourth with the problem.

Each of these three farmers aspires towards independent pumping. (Interestingly, one of their neighbours, a farmer who is currently running his own pump, feels that it would suit him better to share a pump with others, as he believes this would work out cheaper.)

All these farmers were having difficulty in finding reliable and knowledgeable pump operators.

On a large scheme, it is often too expensive to supply enough pumping capacity so that all farmers can irrigate simultaneously but this is statistically unnecessary (Clemmens, 1987). However, an important requirement is to develop a system that has sufficient built-in flexibility to supply, simultaneously and economically, any number of users, from only a few farmers at a time, up to the agreed maximum number of farmers. A range of pumps of different sizes (instead of one large pump or a few with identical capacity), used in different combinations to cater for variance in flow requirements, is a novel way to achieve optimum power usage. An important requirement is that the pump attendant is well trained to understand and operate the station at optimum levels, otherwise the advantages of the design are lost.

5.3 THE CONCEPT OF INDIGENOUS IRRIGATION SCHEMES

5.3.1 INTRODUCTION

Adequate and consistent water supply and effective management are probably the most important factors in determining the sustainability of small-scale irrigation farming enterprises. This has not always been appreciated.

An important issue is the major difference in approach between commercial farmers and small-scale farmers, admitting that all farmers do have commercial motives but recognising that there are other, different motivations. This situation is well spelt out by Slabber (1992) as a consequence of research on indigenous village irrigation systems in Bolivia, Senegal, Mexico and the southern Andean region of Peru. Indigenous irrigation schemes there have been developed by the communities to suit their immediate requirements and the systems themselves have developed over time in accordance with the natural resources and materials available to the farmers. In South Africa, we lack genuine 'indigenous' irrigation schemes. Irrigation was introduced from 'outside' and to this day is heavily influenced by 'colonial' practices.

The conclusions reached by Slabber (1992) on water distribution policy throw new light on why so much has gone wrong with small-scale farmer irrigation schemes in Africa. In the communal land tenure areas, the main focus of our study, we have to consider a wide range of situations and farmers. These range from newcomers, particularly in the case of land reform settlements, through to commercial farmers who can compete with the best in the country. Between these two extremes are intermediate situations that must be considered on their own merits. It is dangerous to confuse the influences of irrigation practices that grew up from the 'inside' with those which were introduced from the 'outside' because it could lead to applying rules of thumb out of context

5.3.2 CHARACTERISTICS OF INDIGENOUS SYSTEMS

Slabber (1992) reports that, in terms of irrigation water distribution, the main characteristics of indigenous systems are:

- Water distribution principles are as complex as the nature of local society;
- These principles are dynamic and change over time;
- Irrigation units within the system are often based on social groups and units, and not, as is the case in Western theory, on physical data;
- Each season, farmers decide which crops to grow and in what area. This also depends on water availability;
- Rules for water distribution often vary during the growing season; for example, free access early in the season and rotation later on;
- In many systems, farmers are allowed to irrigate until they are finished, thus allowing for differences in topography, soils and crops between plots.

Irrigation engineers rightly see irrigation as water delivery to crops, and the irrigation system does need to have sufficient capacity to provide water to plots. However, apart from such physical factors, case studies of indigenous systems reveal other factors that should be taken into account by engineers. The difference between Western and indigenous principles is not a confrontation between two technical solutions but between two arrays of logic, of interests, of strategies and of production systems. Western principles disregard the complexity of local society reflected in complex water distribution principles; Western principles assume a static situation, as opposed to the dynamic situation found on indigenous systems.

5.3.3 NEED FOR A NEW APPROACH?

Slabber (1992) believes that University training in irrigation science tends to aim at physical generalisation. Internationally, university and other training of irrigation engineers is strongly targeted towards employment by governments and national and international agencies. Consequently, both training and employment often serve government interests rather than farmers' interests.

The approaches adopted by irrigation engineers cannot be generalised however. Fortunately, a new generation of irrigation engineers is emerging who are critical of Western concepts and acknowledge the social dimensions of irrigation development.

Slabber (1992) is of the opinion that the basic Western irrigation technology, particularly in Europe, is derived from experience with commercial irrigated agriculture in the colonies. The colonial context in which irrigation technology and approaches evolved was characterised by domination of the local population, and by resource mobilisation for external interests rather than for the rural societies concerned.

The legacy of the colonial-formed industrial concept of irrigation schemes can still be traced in present irrigation planning and design procedures. Thus, in irrigation water distribution, the central principle is that irrigation water is only intended to supply water to plants in a situation in which water is scarce. Coupled with this is the notion that water is distributed between plots and not between people. Present planning and design procedures also have a technology dimension, so that the colonial paradigm, as derived, for example, from sugarcane irrigation overseas, has not remained unchanged over the years.

The main questions to be considered when planning irrigated agriculture, which can be worked out socially in different ways, include:

- Is irrigation water distribution to be between plots or people?
- Is water application to be based on the requirements of crops or people?
- To what degree is land ownership linked with the right to water?
- How is the irrigable area calculated?
- Is irrigation water to be applied throughout the growing season?
- What is the ratio of irrigable area to canal length?

- What is the layout of plots?
- *What is the ratio of subsistence to market production?*
- What are the irrigated, non-irrigated and off-farm production and activities?
- Is the irrigation system to be managed by existing or new institutions?

These are questions that can be answered in the course of the participatory approach to irrigation planning and this emphasises the need to apply qualitative research techniques.

5.4 WATER SUPPLY AND IRRIGATION SCHEDULES

5.4.1 INTRODUCTION

The efficient distribution of water within an irrigation scheme is of particular importance in the case of small-scale farmer schemes. The small size of individual holdings and the large number of participants compound management problems.

> The Irrigation and Drainage Branch of the Kenya Ministry of Agriculture published a manual on scheme design for smallholder irrigation (Republic of Kenya, 1990). The manual is based on practice and is well presented. It is recommended that it be drawn to the attention of all developers of small-scale farmer irrigation projects in South Africa because there are few procedures adapted to deal with the small-scale farmer situation. The section that follows has been adapted, with appreciation, from this publication.

5.4.2 WATER SUPPLY AND WATER DISTRIBUTION

Water supply is 'the delivery of water to the whole irrigation scheme'. Water distribution is the distribution of the total flow of water:

- Within the scheme to the different areas;
- Within each area to the different groups; and
- Within each group to the different farmers.

The method of water distribution within the scheme and to the groups has consequences for the dimensions of the canals, structures and pipelines and overall efficiency.

5.4.2.1 Scheme water supply

> The main canal or pipeline supplies the total scheme design flow to the scheme. The supply to the scheme can either be continuous (if farmers irrigate day and night) or intermittent (if farmers irrigate only during the day). In the case of an intermittent water supply, the flow in the main canal may be maintained day and night. Irrigation will be restricted to daylight and the flow outside the irrigation period will either have to be stored in a night dam or returned to the river through the drainage system.

5.4.2.2 In-scheme water distribution

In general, certainly in the larger schemes, the scheme area will be sub-divided. Each sub-area will have a number of farmers, referred to as a 'group of farmers'. The water supply to the different groups may be **proportional** or **rotational**. If the flow to the groups is proportional, each group gets continuously a part of the total flow, proportional to the size of the group. If all the groups have the same number of farmers, the group flow equals the scheme flow divided by the number of groups. If groups receive water in rotation, some groups receive water, while the other groups do not. It is possible to direct the whole scheme flow to each group in turn.

The disadvantages of rotational water supply are:

- Canals and structures have to be larger than with proportional flow to be able to carry the flow;
- Velocities increase if the flow in canals increases. The slopes of the canals may have to be reduced to prevent erosion and more drop structures may be required;
- Check structures, in combination with farm inlet structures or siphons, are required to divide the water between the farmers because more farmers irrigate at the same time;
- As the distribution structure needs movable gates, maintenance is more difficult and costly.

The advantage of rotational water supply is that, with larger flow, the seepage in the feeders is less, compared to simultaneous partial flow in small group feeders, once the canal is filled and the soil is saturated. With rotation however, the feeder is not used for some time and the feeder bed dries out. Initial losses at re-filling may thus be high, particularly in cracking clay soils, while badly closing gates may cause additional losses. In sandy soils with high seepage, rotational distribution may be reconsidered.

The advantages of proportional supply [in-scheme] are:

- Group feeders have a reduced flow and, consequently, can have a reduced cross-section. The longitudinal slope may be steeper.
- The inlets/division boxes can be fixed, ie, permanent structures without adjustable parts, dividing the available water proportionately to the existing groups;
- Within the group, the flow is restricted and guided to one farmer at a time. No special structures or siphons are required, as the farmer can guide the water to his farm by breaching the canal bank. This method is acceptable in most cases;
- The groups work independently from each other, allowing more flexibility. Shorter irrigation intervals may be required for young plants whose root systems have not yet developed, and for shallow-rooted crops, and farmers within a group can easily set up or change their own timetables.
- In schemes with a central management, a rotational flow distribution over different blocks is often preferred, as supervision is easier. In small schemes, with emphasis on management by the farmers themselves, proportional group flow is advisable.

> A problem is that small-scale farmer irrigation schemes designed for proportional supply to groups have degenerated to rotational supply, with no modifications having been made to the canals or control structures. This is a recipe for disaster.

5.4.2.3 In-group water distribution

Within the group, water must be supplied to the individual farmer. The scheme design should be based on proportional group flow and each farmer in the group should receive his water in rotation. How the farmers organise the water distribution within the group does not affect the scheme design.

If the intakes are close together, the organisation is easier. If irrigation takes place on both sides of the feeder, the length in the canal is reduced and the individual farms are located in a more compact group. The reduction in canal length reduces the seepage losses considerably.

5.4.3 MANAGING THE IRRIGATION SCHEDULE

The irrigation schedule is a timetable presenting the date and time individual farmers may irrigate. It is based on the irrigation interval (the number of days between two consecutive irrigations) and the duration of each irrigation application. The application duration depends on the amount of irrigation the farmer wants to apply and the flow of water at the farmer's disposal. This flow of water, the unit flow, is shared by a group of farmers, who take turns in irrigating their farms (rotation).

5.4.3.1 The group

The group is defined as 'those people having a common, independent water supply'. There is, for example, only one inlet structure. A group should preferably be an organic entity, that is, it should not extend beyond the members of a clan and/or extended family.

Experience shows that groups consisting of ten to thirty members may work well and, to facilitate communication and internal group control, the block should be as compact as possible. When farmers have high priority activities outside the scheme (ie, when they are part-time farmers), groups of ten are preferable, as they may find organising for irrigation difficult.

> In South Africa, there may be a group of twenty to thirty farmers with 1.3-hectare 'farms' on one concrete feeder canal but each farm is divided into 0.1-hectare beds, each with a turnout from the canal. For all practical purposes this implies that there are 20 x 13 = 260 turnouts that have to be managed from one water supply source. The position is even worse when the 0.1-hectare beds are regarded as individual foodplots, each with a 'owner'.

5.4.3.2 Unit flow

Unit flow is defined as 'the quantity of water that can be efficiently handled by an individual farmer'. This flow may vary from two litres per second for continuous irrigation of short furrows, to about 40 ℓ/s under non-erosive conditions in large individual basins. However, international practice is to aim at a unit flow of 10 to 15 ℓ/s.

> In South Africa, with short-furrow irrigation, the manageable flow rate is less than 5 ℓ/s. The original designs catered for 'wild flooding' of wheat, and flow rates were higher. The low flow rates presently utilised make management difficult. In Kenya, where small basins are utilised without the short furrows, considerably higher flow rates are applied but soils and circumstances are very different.

5.4.3.3 Selection of possibilities for group size and unit flow

The following example will make the required calculations more clear.

- Scheme data:

  Number of farmers: 48, each with a holding of 0.4 ha.

  A flow of 60 ℓ/sec is available at farm level. Daylight irrigation only (ie, eight hours).

Table 5.4.3.3: Possibilities for group size and unit flow

Number of groups	Number of farmers per group	Unit flow (ℓ/s)
2	24	30
3	16	20
4	12	15
6	8	10

If the scheme flow is proportionally divided over the different groups in the scheme, practical possibilities are:

- The number of farmers per group and the unit flow are within the limits set (ten to thirty farmers and 10 to 20 ℓ/s respectively)
- If two groups are chosen, there are 24 farmers per group, but the unit flow is 30 ℓ/sec, which is considered too high.
- If six groups are chosen, there are only eight farmers per group, which is considered too few.

5.4.3.4 The irrigation interval

For the establishment of a practical irrigation interval, the following considerations are valid:

- **The irrigation interval should not exceed the maximum allowable irrigation interval**, which depends on the storage capacity in the root zone and the daily rate of water use by the plants. There may, however, be alternative scheduling strategies such as part replacement of water deficits – see Chapter 4.
- **The interval should not be too long**, preferably not over seven to eight days, as too long an interval may harm crops in the early growth stages.
- **The interval should also not be too short**, preferably not less than four to five days, as this will increase the workload of the farmers. Frequent small irrigation applications reduces the water application efficiency in surface irrigation, while intervals that are too short increase the chance that the root system will not develop properly.

5.4.3.5 The application duration

The following criteria may apply:

- The **minimum duration** is two to three hours, with a preference for the higher value.
- The **maximum duration** is ten to twelve hours but, practically, a duration of five to six hours is preferred.
- The water application duration should be **a whole part of the daily irrigation cycle**, ie, 1/1, 1/2, 1/3 or 1/4.

For example: Daily irrigation cycle: 12 hours – water application duration: two hours (1/6), three hours (1/4), four hours (1/3) or six hours (1/2).

If groups within a scheme differ in size, they will not have the same combination of unit flow, application duration and irrigation interval. It is probably best, in that case, to keep the application duration of all groups the same and to vary the intervals and unit flows. However, as the application duration is a whole part of the daily irrigation cycle, this leaves few options for variations. The farmers may perceive a difference in unit flow as receiving unequal amounts of water. On the other hand, farmers with a longer irrigation interval may think that they get less water because they have to wait longer between two irrigations (which is not true, as their unit flows are larger). It is advisable to discuss this issue with the farmers, especially the group leaders, to get their opinion.

5.4.3.6 Selection of possible intervals

The appropriate irrigation interval can be calculated for the size of the irrigation group, if the daily irrigation cycle is known.

The number of farmers in the group, divided by the number of farmers that can irrigate in one day, is equal to the length of the irrigation interval in days.

For example: With a daily irrigation cycle of 12 hours, the possible water application periods are 2, 3, 4 or 6 hours. The number of farmers that can irrigate in one day will be respectively 6, 4, 3 and 2.

Table 5.4.3.6: Selection of possible intervals

Irrigation duration (hours)	Number of farmers irrigating per day	Interval days	Remarks
2	6	2.7	Too short
3	4	4	Too short
4	3	5.3	Acceptable
6	2	8	Acceptable

Intervals less than 4.5 days have been rejected as too short, leaving the intervals of 5.3 and 8 days as possible options in this example.

5.4.3.7 Selection of possible unit flows

The first step is to determine the number of holdings per area and the area design flow at farm level, ie, at farm inlet.

The design flow at farm level (with a 10-hour daily cycle) is approximately 66 ℓ/sec. If there is a 12-hour daily irrigation cycle, the design flow at farm level is reduced to 55 ℓ/sec.

Table 5.4.3.7: Selection of possible unit flows

Number of groups (N)	Number of farmers in group	Unit flow 66 ℓ/sec	Unit flow 55 ℓ/sec
1	54	66	55
2	27	33	27.5
3	18	22	18.3
4	(14) 13.5	16.5	13.8
5	(11) 10.8	13.2	11
6	9	11	9.2
7	(8) 7.7	9.4	7.9

Practical number of groups : 4, 5 (10 hours' irrigation/day)
3, 4, 5 (12 hours' irrigation/day)

If the farmers have high-priority activities outside the scheme, the designer should adopt five groups. If the farmers can devote their full time to their farms, the designer should adopt four groups so that the group size and the unit flow would be closest to the average recommended values (ten to thirty farmers and 10 to 20 ℓ/s respectively).

The recommended unit flow of 10 to 20 ℓ/s determines the acceptable range of group size on a scheme. One group of ten farmers (the minimum derived from organisational reasons) on a ten-hour daily cycle and a design flow of 66 ℓ/s in a scheme with a total of 54 farmers would have an acceptable unit flow of:

(10/54) x 66 = 12.2 ℓ/sec.

The maximum allowable unit flow of 20 ℓ/sec gives a maximum allowable group size of:

(20/66) x 54 = 16.3

The acceptable range of group size is thus 10 to 16 on this scheme of 54 farmers.

5.5 DEVELOPING A WATER SUPPLY SCHEDULE IN PRACTICE

The calculation of realistic irrigation schedules for rotational supply to groups of farmers on typical small-scale farmer irrigation schemes in accordance with the principles discussed in Section 5.4.3 is not common practice in South Africa. In order to facilitate this process when designing for rehabilitation, a handy computer program called SACFLOOD was developed for this project. While farm sizes are normally uniform, SACFLOOD has the facility to cater for varying farm sizes. See Table 5.5b for a typical printout.

In the past, flood irrigation scheme layouts had a main canal feeding a series of small concrete-lined secondary distribution canals. The plots served by these canals were commonly 'farms' of 1.286 hectares that were divided into 0.1-hectare plots or beds approximately 10 m wide and 100 m long. These plots utilise either ordinary long furrows or short furrows, and are irrigated from the secondary canal with some form of turnout for each plot. It is normal practice to irrigate a single furrow at a time, with the acceptable flow rate being about 5.5 ℓ/s (see also Chapter 7: *Short-furrow Irrigation*).

On some schemes, some or all the plots were allocated to 'owners' and were designated as 0.1-hectare 'foodplots'. A conservative approach would be to size the secondary canal so as to provide for ten 1.3-hectare farms, a total area of 13 hectares, at peak periods. The main canal would be designed and operated on a proportional flow basis so that water would be freely available in the secondary canal on irrigation days. The farmers and plot holders forming the group would then be responsible for arranging for irrigation turns on a rotational basis.

Consider the foodplot situation where there are 130 owners on the lateral. (This is an over-simplification because there may be participants who operate several plots, but that does not have a major impact on management.) The task is to evaluate how irrigation turns, times and sequences can be worked out.

- Irrigation requirement is 46 mm/week in summer and 23 mm/week in winter;
- In an emergency, irrigation on seven days a week;
- Irrigation turn once every seven days;
- Irrigation hours in summer 06:00 to 19:00 (13 hours); irrigation hours in winter 08:00 to 17:00 (9 hours) or 08:00 to 15:00 (7 hours).

As a first approximation, 46 mm can be applied to 0.1 hectare in two hours with manageable stream strength of 6.4 ℓ/s. A plot holder is able to apply sufficient water for a week in this time. Unknowns are the capacity of the secondary canal, whether all 130 farmers are to be accommodated, and the impact of reducing the number of irrigation days and/or varying applications.

The program SACFLOOD rounds off the number of farmers who have to irrigate at the same time, and rounds off the length of time they will be irrigating to the nearest hour, so that there is an exact numerical balance in the schedule. Note that, when the weekly requirement drops from 46 mm to 23 mm, the duration of the turn halves from two hours to one hour. If the weekly requirement had been 35 mm, then the time to irrigate the plot would have been 1.5 hours at the same flow rate (6.4 ℓ/sec). To simplify the schedule, the time was increased to two hours and the flow rate decreased proportionality to 4.9 ℓ/s (see Row 11 in Table 5.5a).

The target minimum flow rate was 5.5 ℓ/s and this established the 6.4 ℓ/s flow rate in the schedule. If it is possible to double the flow rate, then the position changes significantly (Compare Rows 4 and 12 in Table 5.5a): Nine hours a day becomes a practical irrigation period, without having to increase the capacity of the secondary distribution canal. The importance of increasing the stream size that can be conveniently handled by the irrigator will be discussed in Chapter 7, *Short-furrow Irrigation*.

Although schedules of this nature can be developed as an exercise, it is doubtful whether they can ever be applied in practice. In this case, 130 separate plots all served by the one secondary canal are involved. Even if they were grouped into farms of ten plots each, the task of the irrigators would be a nightmare if they attempted to achieve an organised efficient operation.

The usual way of diverting the water from the canal is to impede the flow at the low points in the channel sides that are the turnouts into the plots. This is a hit-and-miss affair if water has to be allowed through to serve other farmers downstream. Originally, orifice plates were provided to regulate the flow to the downstream users but they have long fallen into disuse. The use of calibrated spiles or siphons would improve the position but they are hardly practical.

Where water can be diverted into a tertiary canal supplying water on each 1.3-hectare farm to each of the thirteen 0.1-hectare plots, control is facilitated because external negotiations on turns and their timing will be limited to the ten farmers. The SACFLOOD printout for the ten farms irrigating seven days a week can be compared with Row 1 of Table 5.5a. Farmer #1 requires 27 hours to irrigate his thirteen 0.1-hectare plots, very close to the two hours each specified in the table. The secondary canal capacities are close, 18.5 ℓ/s and 19.2 ℓ/s, because of the rounding off that has been done by the program.

It is obvious that effective controls of water delivery, even in the secondary supply canals, would be very difficult. It is unrealistic to expect that farmers will be in a position to keep to prescribed schedules or that the supply in the main canal will always be satisfactory. It is important, however, to ensure that, while it may be difficult, it must always be possible.

The program can be used to simulate any situation where rotational flow is utilised in the distribution. It is of particular value for evaluating existing designs to see if they are 'possible' and to assess the impact of modifications.

Table 5.5a: Plot holders schedule for weekly irrigation turns

DAY	Weekly water requirement		Irrigation		Irrigation turns	Flow rate to plot		Secondary canal capacity
1	5980	46	13	7	3	2	6.4	19.2
2			13	6	4	2	6.4	25.6
3			13	4	6	2	6.4	38.3
4			**9**	**6**	**6**	**2**	**6.4**	**38.3**
5	2990	23	9	6	3	1	6.4	19.2
6			9	4	4	1	6.4	25.6
7			9	3	6	1	6.4	38.3
8			7	6	4	1	6.4	25.6
9			7	4	5	1	6.4	31.9
10			7	3	7	1	6.4	44.7
11	4550	35	9	6	4	2	4.9	19.4
12	**5980**	**46**	**9**	**6**	**2**	**1**	**11.7**	**23.3**

Table 5.5b: Printout of SACFLOOD, showing inputs and outputs

Irrigating for 13 hours per day
Weekly irrigation requirement is 46.0 mm
There are 10 farmers using the canal
7 days per week are used for irrigation
The group requires 5980.0 m^3/week
3 farmers need to irrigate simultaneously, at an average flow rate of 6.2 ℓ/s, hence the canal should be designed for 18.5 ℓ/s
Farmer # 1 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 2 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 3 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 4 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 5 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 6 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 7 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 8 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 9 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer #10 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Total of active farmer hours is 270.0
Compared to a potential of 273.0
Which implies that 66.4 m^3 of water is not used

5.5.1 APPLICATION TO LARGER SCHEMES

FAO Irrigation and Drainage Paper No 24, *Guidelines for predicting crop water requirements* (Doorenbos and Pruitt, 1977) remains the definitive document, not only for predicting crop water requirements, but also for estimating the capacity and management of irrigation conveyance systems. It is important that consultants and planners concerned with the design and redesign of significant irrigation schemes take note of this publication. This section draws on the aspects of Chapter 2 of FAO 24, 'Project Design,' which deal with operational options, and provides sufficient detail to stimulate interest and debate.

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Farmer # 4 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 5 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 6 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 7 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
Farmer # 8 (size 1.3 ha) needs 27.0 hours at 6.2 ℓ/s
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5.5.1.1 Design and operation of a supply system

Following the preparation of a detailed field and canal layout, the criteria on which the canal system will operate must be developed. The methods of operating the supply system can be broadly delineated as continuous, rotational and supply on demand.

With the continuous method of supply, the system is constantly in operation and the supply is adjusted to the changing irrigation requirements over the season. The method is mainly used where the main canals supply areas of 50 ha or more. Only in the case of some monocultures such as rice, pastures and orchards is the continuous supply sometimes maintained up to the field level.

The rotational method of supply is most commonly used for surface irrigation, where a fixed supply is normally selected and changes in irrigation requirements are met by adjusting the duration and interval of supply. Supply schedules have to be prepared in advance. The method is not well adapted to a diversified cropping pattern or sudden large changes in supply requirements.

The supply on demand method of supply, for optimal operation, requires high investments in canal structures and a high level of management. It is primarily restricted to closed conduit pressure systems such as sprinkler irrigation or small projects (smaller than 50 ha), where there is adequate control of the water source, such as pump irrigation from streams or wells. Within certain limitations, the method, also called the free demand or random supply method, allows the user of water to take irrigation water when desired.

The FAO 24 design procedure is a manual one and is based on a number of 'indicators'.

- the supply requirement factor, fi = Vi / Vmax, which, for a given period i, is the ratio between the average daily supply requirements during the period i (Vi in m^3/day) and the average maximum daily supply requirements during the peak water use period (Vmax in m^3/day);
- the supply factor, fs = Qi/Qmax, which, for a given period i, is the ratio between the required stream size during the period i (Qi in m^3/sec) and the maximum possible stream size or canal capacity (Qmax in m^3/sec);
- the supply duration factor, ft = T/I, which is the ratio between supply duration (T in days) and the supply interval (I in days);
- the design factor, α = 86 400 Qmax / Vmax, which is the ratio between the maximum possible stream size or canal capacity (Qmax in m^3/sec) and the average maximum daily supply requirement during the peak water use period (Vmax in m^3/day) on which the design is based.

This method is recommended for large schemes but will not be discussed here in detail because to master it requires working through a series of examples.

5.6 WATER DELIVERY CONTROL, FLEXIBILITY AND RELIABILITY

In *Management of farm irrigation systems*, a monograph published by the American Society of Agricultural Engineers, Burt and Plusquellec (1990) contributed a chapter on "Water delivery control". They present viewpoints applicable to advanced irrigation systems and technology but, surprisingly, their comments can be applied directly to small-scale farmer irrigation in South Africa.

This section, based on extracts from their paper, deals with the complexities of irrigation water supply management that can impose almost impossible constraints on all but the most advanced and efficiently managed irrigation schemes.

5.6.1 THE ROLE OF WATER DELIVERY IN ENSURING EFFICIENT IRRIGATION

Water delivery systems transport the lifeblood of an irrigation project, and the selection and management of water delivery systems affects agronomic and social aspects of projects. The control strategy must be compatible with the flexibility of the ultimate water supply and with the social, political, geographical and economical conditions under which it will be used. The strategy of water delivery, the desired delivery schedule requiring interfacing, and the seat of decision-making must be carefully examined before initial selection or modification of the water delivery system. If water deliveries to the farm are inflexible, unreliable or unpredictable, the attainment of high on-farm irrigation efficiencies is restricted.

Water must be provided in a timely and reliable manner so that it may be efficiently used for crop production. Therefore the primary justification for updating infrastructure and improving control are the following:

- to assure a reliable water supply to farmers; that is, that water arrives when it is supposed to and in the proper quantities and flow rates;
- to assure a flexible water supply to farmers;
- to reduce restrictions on the capacity of the farmer to attain high on-farm irrigation efficiency; and
- to eliminate social conflict, which always occurs if the water supply is unreliable.

Improved reliability and flexibility of water deliveries to the farm result in both improved on-farm use and less spillage and loss in the conveyance system. These two factors definitely decrease the volume of water required at the source for the same crop yield and, in some cases, contribute to a decreased flow requirement at the project source, even though the water supply is available on a more flexible basis to farmers. This is the opposite of what many irrigation engineers believe. The common perception is that increased flexibility means that larger design capacity is needed at the source because more people will want to receive water at the same time. In fact though, individual farm irrigation requirements balance out as the number of outlets increase. It is, however, almost always necessary to increase the design capacity of short canals and the downstream, tail end sections of pipelines and canals in order to offer a more flexible schedule.

5.6.2 WATER DELIVERY NETWORKS

Irrigation delivery networks have several levels of operation. For purposes of explanation, consider a system of three levels, which are:

Primary canal. This is the main canal [or supply canal] that originates at the source.

Secondary canals. The primary canal supplies these canals. Their total length may be 2–10 times the length of the primary canal.

Tertiary canals and pipelines. The tertiary part of the network contains turnouts to large individual fields, or to groups of fields. [These are also called field canals.]

The reliability at each level should be the same. However, the flexibility of water delivery to each level may be different. The flexibility of water delivery at any level is generally restricted by the flexibility of the next higher level. Therefore, it is of paramount importance that on-farm irrigation designers and managers open communications with the engineers who operate and design the primary canals.

The schedules may vary at the different level; for example, a tertiary canal operated on a rotation schedule may receive water on an arranged basis from a secondary canal supplied by a primary canal with a demand schedule. Ideally, the most flexible schedule should be used all the way to the farm turnout. In general, the reliability of farm turnout deliveries increases as the flexibility of the network levels increases.

5.6.3 RELIABILITY

There is a basic truth that must be clearly understood for every irrigation project: Water is the economic lifeblood of the farmers. If it is provided in an uncertain and unreliable fashion, anarchy quickly develops as individual farmers try to prevent their personal economical destruction.

The list of unsatisfactory if not horrible performance of major irrigation developments is quite long. A number of studies have been initiated to determine the causes (GAO, 1983). Initial causes were thought to be the lack of farmer motivation, poor design of water user organisations, lack of water measurement on-farm, and lack of knowledge of good irrigation practices. All these are contributing factors, but it is now understood that unreliable water deliveries are often the major cause of poor performance, and unreliability often causes these other factors to emerge (Plusquellec and Wickham, 1985).

Farmers cannot be organised successfully unless they have confidence in the purpose of the organisation. Water that arrives in an uncertain and unreliable manner puts the organisation leaders in a very difficult position and the organisation soon fails. Unreliable water deliveries are like rainfall, in that they arrive at unusual times and deliveries are out of the control of the users, and farmers sometimes want to pay the same for unreliable irrigation water as for rainfall – ie, nothing. Farmers are also unwilling to invest (either in tertiary delivery system maintenance or in on-farm irrigation hardware) unless the irrigation supply is reliable.

A water user organisation on any level must develop a sense of ownership and control over the water. At that point, farmers will be willing to invest time and money. It is interesting to note that farmers who are able to develop their own reliable groundwater supplies consistently invest heavily in expensive pumps, fuel, and on-farm irrigation systems. Those same farmers, whether they are in India or in the San Joaquin Valley of California, are opposed to even small increases in water charges when inexpensive water is supplied by an irrigation district/agency on an unreliable basis. The lack of reliability and flexibility of the surface supplies may be the basis for their reluctance to pay more, and they may be willing to pay more if the delivery is reliable and flexible.

To this point, 'reliability' has meant that water will indeed be delivered when it is promised. There are, however, additional aspects of 'reliability', including:

- flows through a turnout remain constant if they have been set to remain constant. This is discussed later; and
- flows and water levels in the supply canals are controlled well enough that the canal banks/structures are not damaged (Damage would require shutting down the canal for repair).

5.6.4 TRANSFERRING MODERN AND APPROPRIATE TECHNOLOGY

A single 60-hectare field in the western US may be equivalent in area to thirty to a hundred individual fields in other parts of the world but the numbers of turnouts and people to communicate with are vastly different. Water may be available to the large US field on a limited-rate demand schedule, but it is not available to each spot of the field on that schedule. With a few exceptions, the large 60-hectare field will not be irrigated all at once. The farmer will irrigate a few hectares per 'set' and possibly take a week or two to move the water across the field. For the single large field, there will be a single flow meter rather than a flow meter for each set.

Water projects and farming in the western US have evolved over more than a century. Initially, many farmers were quite poor, logistical support was almost non-existent, and water laws were undeveloped. A clear advantage that most US projects had was a sense of ownership of the water by the farmers, and active participation in water user organisations. Another advantage in the US was the relative youth of the farms.

Technology that is transferred should take advantage of the great engineering and social lessons that have been learned. Over the last one hundred years in the US and abroad, a great deal has been learned about how to form water user organisations and the necessary legal structures to maintain them. The impacts of over-irrigation on the environment, the concepts of plant-soil-water relationships, the theory that allows designers to estimate canal capacities based upon the level of reliability and flexibility desired are well understood. The actual hydraulic engineering, materials availability, and construction processes involved have been proved in practice.

- Appropriate technology' means that this knowledge base is combined with local conditions to develop an optimum management/design plan.
- Appropriate technology' means that designers know how to implement an irrigation plan in phases in such a way that users do not become bankrupt.

  Using an economic analysis, it may appear that, over twenty years, considering all the costs and benefits, a certain type of water delivery system is 'most economical', even though it has a high initial cost. Whether or not it is actually the 'most economical' or the least likely to render its users bankrupt depends upon the availability of funding. In the US, a major reason for the present legal form of the public irrigation district laws is the provision of a financial structure for operation and maintenance. Public irrigation districts can legally draw upon a wide range of taxes, bonds, and assessments to provide long-term funding for both construction and maintenance. US economic analysts, therefore, generally assume that capital and credit are available. However, this may not be true for an individual farmer with a cash-flow problem, or in a nation saddled with a large foreign debt.

In cases (or countries) where there is a lack of credit or initial cash for construction and maintenance, it is imperative that the water delivery system be designed for the eventual implementation of more economical components. As wealth is developed in an area due to irrigation development, as electricity becomes more available and reliable, and as logistical support improves, the system can be readily modified if the original design was planned for future modifications. This is a very sensitive item: the classical economic analysis, which has been in favour of low initial costs and a high operation and maintenance budget, has been the reason why so many projects in the developing world have not been sustainable.

5.7 IRRIGATION EFFICIENCY

To account for losses of water incurred during conveyance and application to the field, an efficiency factor should be included when calculating the project irrigation requirements. Project efficiency is normally subdivided into three stages, each of which is affected by a different set of conditions:

- Conveyance efficiency (Ec): ratio between water received at the inlet to a block of fields and that released at the project headworks;
- Field canal efficiency (Eb): ratio between water received at the field inlet and that received at the inlet of the block of fields;
- Field application efficiency (Ea): ratio between water directly available to the crop and that received at the field inlet;
- Project efficiency (Ep): ratio between water made directly available to the crop and that released at the headworks; or Ep = Ea * Eb * Ec.

Conveyance and field canal efficiency are sometimes combined as distribution efficiency (Ed), where Ed = Ec * Eb. Field canal and application efficiency are sometimes combined as farm efficiency (Ef), where Ef = Eb * Ea.

Factors affecting conveyance efficiency (Ec) are, amongst others, the size of the irrigated acreage, the size of the rotational unit, the number and types of crops requiring adjustments in the supply, the canal lining, and the technical and managerial facilities of water control. Field canal efficiency (Eb) is primarily affected by the method and control of operation, the type of soils in respect of seepage losses, the length of field canals, and the size of the irrigation block. As can be expected, the distribution efficiency (Ed) is particularly sensitive to the quality of technical as well as organisational operation procedures (Ed = Ec * Eb). Farm efficiency (Ef) is much dictated by the operation of the main supply system in meeting the actual field supply requirements, as well as by the irrigation skill of the farmers.

Water losses can be high during field application. Low application efficiency (Ea) occurs when the rate of water applied exceeds the infiltration rate and the excess is lost by runoff; or when the depth of water applied exceeds the storage capacity of the root zone, so that the excess is lost by deep drainage. This is why, with surface irrigation, field layout and land grading is most essential. Uneven distribution of water causes drainage losses in one part and possibly under-irrigation in another part of the field, resulting in very low application efficiency. Ea may also vary during the growing season, with highest efficiencies during peak water use periods.

In the planning stage, efficiency values for the various stages of water distribution and application are estimated on the basis of experience. When they are estimated too high, water deficiencies occur and either selective irrigation and/or improvement in operational and technical control (lining, additional structures, etc) is required. When efficiency values are estimated too low, the irrigation area is reduced and the system is therefore over-designed, and probably wasteful irrigation is practised. However, over-estimation is more common.

EXAMPLE:

Given:

150 ha scheme, irrigation blocks of 10 ha with unlined canals, furrow irrigation, adequate management.

Calculation: Ep = Ed * Ea = 0.65 * 0.65 = 0.4

5.8 PUMPING

5.8.1 INTRODUCTION

Pumping is an important aspect of the delivery of irrigation water, both for individual farms and for schemes. Pumping is particularly important in the case of small-scale independent farmers because there are few areas in South Africa where direct abstraction from rivers is a viable proposition. Unfortunately, the situation and circumstances of irrigation in the communal land tenure areas is a major constraint. The schemes are located at considerable distances from the centres where service is available, and there is a shortage of trained maintenance personnel. Probably the commonest complaints from farmers on schemes concern the water shortages and the delays arising from mechanical breakdowns that take a long time to repair.

The increasing use of irrigation methods dependent on pressure has increased the requirement for pumped systems, despite the problems of their high capital investment and maintenance.

Pumping is important for independent farmers and community garden projects whose water is taken from rivers and boreholes. The limited size typical of these projects, coupled to their isolation and lack of suitable backup facilities, results in very specific problems, which need to be addressed when projects of this nature are being considered.

5.8.2 SURFACE PUMPING

Whenever one speaks of pumping, it must be understood that pumps and their power units have to be considered as a unit for this process.

Pumping from rivers is common in the case of small independent farmers and community gardens. Mostly the pumps are centrifugal pumps, which can be driven by electric motors but are more usually driven by diesel engines of considerable antiquity. When the water is used for flood irrigation, the pressure required is relatively low but, if sprinkler irrigation is used, the pressure should be suitable for the application.

Water is pumped out of the river through a suction pipe, and sound pump installation practice must be followed. As with all centrifugal pump installations, the height of the pump above the water, and the diameter and fit of the suction pipe are important.

Sand in the water is a problem because sand passing through the pump causes excessive wear, not only to the pump itself, but also to the sprinklers. It is possible to reduce the amount of sand drawn into a pump by ensuring that the intake is not on the sandy bottom of the river and is not in a position where the sand is continuously disturbed. It is also important to select pumps that are suitable for handling water with a high sand content. High-speed pumps should be avoided.

Local farmers have shown ingenuity in improving river pumping, particularly when the level of flow in the river is very low and it becomes difficult to obtain sufficient depth for the suction pipe. They have gone as far as constructing concrete sumps sunk into the riverbed. However, further investigation is required to find cost-effective and practical means of reducing the sand load passing through the pump.

Few farmers appreciate the problems that can arise if there are leaks in the suction pipes, where air can be introduced. One frequently sees makeshift and ineffective attempts to prevent this kind of leakage.

Leaks in the delivery mains are much more visible than those on the suction end, and are therefore more likely to receive the attention they deserve. Water and pressure is lost and fuel costs are increased - but such leakage is all too common, often because inferior piping has been acquired.

Farmers acquire second-hand pumps on sales or buy them from other farmers. The pump specifications are seldom suited to the application and this can result in operation problems and, very often, excessive pumping costs arising from high fuel requirements. The survey found small farmers who had bought pumps and engines off the shelf from retailers or co-operatives, paying no attention to their technical suitability.

Few independent farmers or community gardens have electricity, which means that most of their pumps are driven by diesel engines. Many of these engines are vintage models still providing good service but, obviously, the better the service backup, the lower the cost to the community and the farmer. In community gardens, small fire-fighting petrol pumping units are sometimes utilised. They have the advantage that they are portable and so can be carried home at night in areas where vandalism or theft is a major problem. They are also much cheaper than conventional diesel pumping units. Unfortunately, these engines are not designed or built for continuous operation. They require frequent overhaul, are liable to break down, and have a limited life.

Pumping is a field where small farmers need more technical advice and support, and one where a great deal more attention should be given to training of the farmers and the extension officers, and also of technicians who are advising the farmers. The basic principles of good practice are not difficult to follow but, at the moment, there is virtually nowhere that the small farmer can turn for technical assistance. He only becomes aware of deficiencies when he finds that the pumping unit cannot meet requirements.

Another major difficulty is that the pump has to be located below flood level in order to avoid suction problems and, when a flood occurs, the pump and engine can be washed away. This can be a crushing blow to a small farmer, who seldom has insurance on his equipment. There are units available that are mounted on a chassis in such a way that they can be pulled up the bank if there is any suspicion that a flood may occur, but the number of such rigs in use is limited. Guidelines are needed on specifications for achieving the necessary pump and engine mobility so that they can be moved out of the danger zone.

Despite the difficulties encountered by small farmers, there are many hundreds or even thousands of home made pumping schemes throughout the country and they serve their owners very well. There should be more investigation into detailed applications and specifications in order to improve overall pumping effectiveness. Technical support is probably a major priority.

5.8.3 BOREHOLE PUMPS

Borehole water is not cheap water. Unfortunately, the availability of river water or canal water is limited and a great deal of private irrigation in South Africa, both by large commercial farmers and by small farmers, is from boreholes. The drilling of the borehole is expensive and this is a factor that we dare not ignore. In addition to the costs of drilling and equipping the borehole, the great depth from which the water often has to be pumped makes the water expensive.

A borehole pump requires professional installation by a knowledgeable and experienced person with suitable equipment. Service facilities are of major importance and breakdowns at critical times of the year can endanger crops under irrigation.

Three types of pump are suited to supplying the quantities of water required for irrigation purposes. Turbine pumps are expensive and normally would only be installed on a communal scheme requiring high capacity. Submersible pumps are relatively cheap but require electric power and are vulnerable to lightning strikes. Rotor pumps are less cheap but can be powered by a diesel engine.

5.8.4 SCHEME PUMPING STATIONS

Pumped water supplies are subject to much the same constraints as those experienced with canal flow which were described in Section 5.6. The major problem is to develop systems suited to a relatively large number of individual participants in a scheme. The large number of participants creates management difficulties and means that the equipment has to be flexible enough to cater for seasonal and other changes in cropping requirements. In many cases, this results in over-design.

Consultants well versed in water supply installations normally design pump stations because the normal requirements warrant this. However, the specific needs of small-scale farmer irrigation are different to the normal requirements. In any case, the construction and operation of high capacity electric powered pump stations in the rural areas, far from commercial infrastructure and subject to regular power cuts, has proved to be problematical in many cases. This report will therefore not go into detail on the design of pump stations.

5.9 CONCLUSIONS AND RECOMMENDATIONS

An evaluation of both the situation on the ground in South Africa and the literature confirms that the importance of water supply in ensuring effective irrigation has not received sufficient attention in the past. The realisation that, in many cases, it would be quite wrong to restore infrastructure to its original condition is sobering. This is particularly true in the case of small-scale farmer irrigation projects.

It was not expected that the basic operational principles stressed for schemes in advanced countries would be applicable to small-scale farmer projects in South Africa. However, Burt and Plusquellec (1990) summarise the position when they say: "Appropriate technology' means that this (the international) knowledge-base is combined with local conditions to develop an optimum management/design plan.'

'Appropriate technology' also means that designers know how to implement an irrigation plan in phases in such a way that users do not become bankrupt.

There is a need for a study that will spell out the basics of 'appropriate technology' in respect of water supply and management for small-scale farmer irrigation projects

'Designing for management' in the case of irrigation implies a new approach to water supply infrastructure planning and development.

Chapter 6

PRESSURISED SYSTEMS FOR SMALL-SCALE FARMER IRRIGATION

See also *Irrigation Design Manual* (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

6.1 INTRODUCTION 6-1

6.2 APPLICATION OF PRESSURISED SYSTEMS IN SMALL-SCALE FARMER IRRIGATION 6-1

- 6.2.1 Maintenance and cost limitations 6-1
- 6.2.2 Production levels 6-2
- 6.2.3 Appropriate systems for changing circumstances 6-2
- 6.2.4 Vandalism and theft 6-2
- 6.2.5 Awareness of irrigation applications 6-3

6.3 PRESSURISED SYSTEMS IN PRACTICE IN SMALL-FARMER IRRIGATION 6-4

- 6.3.1 Sprinkler irrigation 6-4
- 6.3.2 Centre pivots 6-6
- 6.3.3 Drip irrigation 6-8
- 6.3.4 Piped furrows 6-8
- 6.3.5 Micro irrigation 6-9
- 6.3.6 The floppy sprinkler/giant micro system 6-9

6.4 SPRINKLER CHARACTERISTICS: DESIGN AND MANAGEMENT 6-9

- 6.4.1 Introduction 6-9
- 6.4.2 SAPSPRNK 6-10
- 6.4.3 Distribution uniformity 6-13

6.5 DESIGN NORMS AND INNOVATIVE POSSIBILITIES 6-15

- 6.5.1 Delivery rates 6-15
- 6.5.2 Extended lateral spacing 6-16
- 6.5.3 Irrigating with a single lateral 6-17
- 6.5.4 Sprinkler irrigation contractors 6-17
- 6.5.5 A change in approach 6-17
- 6.5.6 Designing small sprinkler layouts 6-18

6.1 INTRODUCTION

In practice, all irrigation systems, except flood (surface flow) systems, use water under pressure. They include conventional sprinkler systems, micro and drip installations and mechanised systems such as centre pivots. Our field surveys have shown that quick-coupling and dragline sprinkler systems are commonly used on small-farmer schemes and on independent farms. Some centre pivots are in operation, and the more specialised farmers operate micro and drip, but they are in the minority.

Most aspiring small-farmer irrigators regard sprinkler irrigation as being the norm to which they are entitled. The method appeals because sprinkler irrigation can be used with a minimum of land preparation, application quantities can be simply controlled, sandy soils are not a major problem, and the sprinklers need not be tended all day. The pipes are moved once or twice - and that is all there is to it!

6.2 APPLICATION OF PRESSURISED SYSTEMS IN SMALL-SCALE FARMER IRRIGATION

Pressurised irrigation systems are not new amongst small-scale farmers in South Africa. They are used on the major schemes in the Eastern Cape, which include Tyifu, Kaskamma, Xonxa (which is one of the few examples of the use of centre pivots) and Ncora. In the Northwest Province, Taung (with both sprinkler and centre pivots) is probably the major scheme in the country under sprinkler irrigation. The large irrigation scheme in the Northern Province, the Arabie-Olifants, was largely converted from flood irrigation to sprinkler irrigation in the early nineteen-eighties, while the Mid-Letaba scheme is a sprinkler scheme, although there are other pressurised systems.

In KwaZulu/Natal, the sugar farms where small-scale farmers are engaged, as well as the Makhatini scheme, are largely sprinkler irrigated. In recent years, there have been a number of major schemes launched in Mpumalanga for sugarcane and banana production, which are almost exclusively irrigated by dragline sprinkler.

In addition to these schemes, there are a very considerable number of small, independent farmers in the communal land tenure areas who have their own small sprinkler irrigation systems. In contradistinction to sprinkler, the other forms of pressurised irrigation have to date had only limited application. There are, however, indications that there is increasing interest in drip irrigation and, in the case of schemes and individual farmers operating orchards, there has been successful exposure to micro irrigation.

Pressurised irrigation systems are, of course, commonplace on the large commercial farms outside of the communal land tenure areas. In most cases, these systems are operated in the field by labourers who have developed considerable experience of this form of irrigation. It is not claimed that all is well on these farms with the irrigation systems because both the water use efficiency and maintenance could be improved. However, there is no reason at all, other things being equal, why pressurised irrigation should not be successfully applied by small-scale farmers, particularly if they have built up experience and management skills on commercial farms.

6.2.1 MAINTENANCE AND COST LIMITATIONS

The major problem with pressurised irrigation, both on schemes and on individual farms in the communal land tenure areas, is that motors and pumps must be maintained. This applies to schemes operated and managed by development corporations and the Departments of Agriculture in the provinces, as well as to individual farms. This is possibly because of the location of these schemes far from the major commercial centres where the service facilities are concentrated, and the consequent lack of profitability for irrigation equipment dealers when they have to operate in these areas.

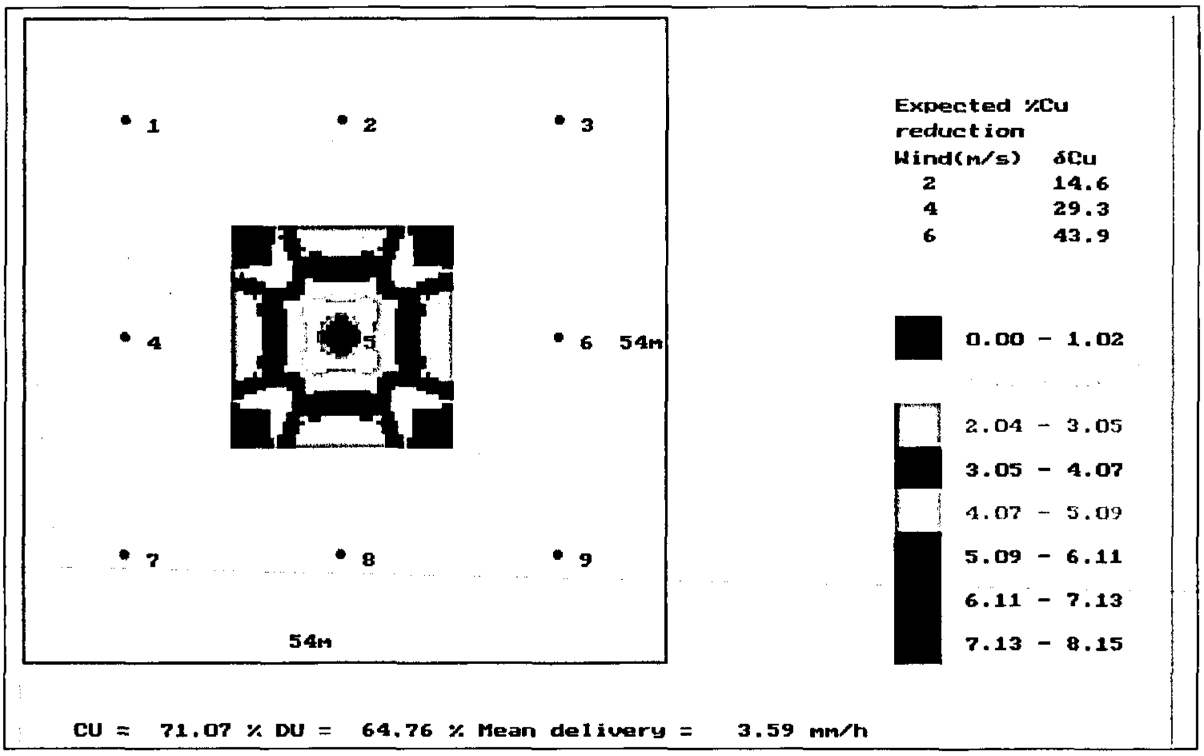
The capital and operating cost of pressurised schemes is a concern. For the major schemes that were developed in the past, the State, for all practical purposes, financed the infrastructure and equipment. The tendency was to 'automate' to compensate for the possible lack of management skills on the part of the farmers and operators. In addition, the State generally, directly or indirectly, accepted

6.5.7 Designing moderately-sized sprinkler layouts 6-20
6.5.8 The case study layout 6-20
6.6 UPTAKE OF TECHNOLOGY 6-27
6.6.1 The influence of technical factors 6-27
6.7 CONCLUSIONS AND RECOMMENDATIONS 6-30

FIGURES AND TABLES

Figure 6.4.2.2a: Delivery pattern in mm/h 6-11
Figure 6.4.2.2b: Distribution patterns – Sprinkler I is rectangular, Sprinkler II is triangular, and Sprinkler III is undefined 6-12
Table 6.4.3.2: Sensitivity to pressure changes 6-13
Table 6.4.3.3: Effect of operational faults on sprinkler distribution 6-14
Table 6.4.3.4: Sprinkler spacing and arrangement 6-14
Table 6.4.3.5: The value of Du and Cu for missing or faulty sprinklers 6-15
Table 6.5.5.1: Design and planning procedures 6-18
Figure 6.5.6.1: Selecting a pump 6-19
Figure 6.5.8: Case Study – 18-hectare sprinkle 6-21
Figure 6.5.8.3a: Pressure control variations and tolerances 6-22
Figure 6.5.8.3b: Pressure control variations and tolerances 6-23
Figure 6.5.8.3c: Pressure control variations and tolerances 6-23
Figure 6.5.8.3d: Pressure control variations and tolerances 6-23
Table 6.5.8.4a: Influence of the position of the main on dimensions of piping and total operating costs 6-25
Table 6.5.8.4b: Comparative total operating costs of central mains without pressure control and 10% and 20% pressure tolerance 6-25
Table 6.5.8.5: Influence of halving pumping hours on pumping main design. (Central main, 80 mm diameter laterals, no pressure control) 6-26
Table 6.6.1: Keller's factors and categories 6-28
Table 6.6.1.1a: Factors influencing the appropriateness of different irrigation systems 6-29
Table 6.6.1.1b: Ranking of system types reflecting suitability for smallholders 6-30

Figure 6.4.2.2a: Delivery pattern in mm/h



The sprinklers can be manipulated to simulate a wide range of circumstances.

- A Changes all sprinklers.
- C Changes the spacing of the sprinklers and the laterals.
- E Sprinklers can be selected from the menu.
- G Graphs individual sprinkler delivery distribution.
- H Sets the stand time in hours for individual and combinations of sprinklers.
- L Enables a lateral to be moved.
- M Moves any designated sprinkler to a new position.
- P Changes the pressure of all sprinklers.
- R Resets the spacing of the sprinklers and the laterals to a default value.
- T Toggles the spacing between a rectangular and triangular spacing.

Conventional sprinkler calculations are based on a permanent-set layout, where all the sprinklers operate at the same time. However, in practice, with movable laterals or draglines, conditions do not comply with the conventional sprinkler calculations. This has a significant influence on the actual infiltration capacity of the soil, as well as on spray and evaporation losses, which means that the conventional sprinkler calculations are inaccurate. It is possible for SAPSPRNK to simulate specific conditions and produce accurate calculations. Figure 6.4.2.2b illustrates the distribution pattern of a single isolated sprinkler such as in dragline applications. Figure 6.4.2.2c illustrates the distribution pattern of a single lateral and adjacent laterals have been 'moved out of the picture'.

Figure 6.4.2.2d depicts three typical distribution patterns, triangular, rectangular and undefined. The impact of working pressure is obvious. Depending on overlap, satisfactory Cu's and Du's can be achieved in all three cases, but triangular and rectangular patterns can have special applications.

responsibility for the maintenance of systems. Despite this the schemes have failed (Bembridge, 1997).

In the past, there was a tendency to load the capital investment in order to reduce operational costs because it was more satisfactory to service the initial loan than to have to supply funds out of annual budgets to cater for operating and running costs. This is obviously not a sustainable situation and it is important that, in the future, the farmers are in a position to repay the loans, if the more sophisticated pressurised systems are used, and are acquired and operated with conventional financial arrangements. Any change in loan or funding policy should be reflected in design approaches.

One of the difficulties experienced by independent farmers, particularly in the communal areas, is the difficulty of obtaining skilled advice on equipment selection and design, as well as the difficulty of obtaining the equipment itself. Only too often, equipment is acquired on sales, second-hand, or is bought from a co-operative branch or dealer without due consultation having taken place. This can lead to serious difficulties so there is a need for greater technical support.

6.2.2 PRODUCTION LEVELS

The first basic factor that must be taken into account when considering the possibility of using irrigation under pressure is that it must enable production to be at a level that provides sufficient income to be able to pay for the irrigation system and its operation and maintenance. It is therefore irresponsible to even consider irrigation under pressure for a community, if they are not able to produce effectively and efficiently, and do not have the means to market the products they produce.

The available natural resources are extremely important in estimating production levels because most of the other limiting factors can be overcome. There is very little one can do, however, to circumvent unsatisfactory climate, soils or water quality and supply. This is as true of food plots and community gardens as it is of large schemes, and there is ample evidence to indicate that, in the past, this has not received sufficient attention.

It is appreciated that communities wish to have the amenity of pressurised irrigation and that, politically or administratively, it may be very difficult to avoid acceding to their requests. It is important, however, that politicians and administrators appreciate the consequences if inadequate attention is given to the feasibility of growing good quality crops under the prevailing circumstances.

6.2.3 APPROPRIATE SYSTEMS FOR CHANGING CIRCUMSTANCES

If the natural resources and the market potential pass the criteria outlined in Chapter 2, which deals with feasibility studies, then there is no reason for not using water under pressure for small-scale farmer irrigation schemes. There is, however, the proviso that the scheme selected must be designed, manufactured, installed and managed to be appropriate for the circumstances under which it is going to be used. These circumstances are not necessarily the same as those on established and successful commercial farms. Ultimately, there will probably be little difference, but this development of irrigation, the most complex of all forms of crop production, needs to be approached on an evolutionary basis.

On the well-established commercial farms, the irrigation technology used has become accepted, and design and management are based on well informed rule-of-thumb. There is a danger in this, however, when the circumstances change. And this is now becoming apparent in South Africa, where water is becoming scarcer and more expensive, profit margins are declining on many products, and farmers must improve the efficiency of their irrigation systems in order to survive. There can be no doubt that accepted rules will have to be modified to cater for the new circumstances. In the same way, planners must take the need for increased efficiency into consideration and designers who are concerned with the rejuvenation and reconstruction of failed irrigation schemes and the creation of a new irrigation sector. It is also necessary to mobilise the best available knowledge and product.

6.2.4 VANDALISM AND THEFT

An unfortunate fact of everyday existence is the danger of vandalism and theft of equipment in the deep rural areas. This is a factor that can determine whether or not irrigation under pressure should be considered now, and what measures can be taken to reduce the risks involved. Hopefully, this is a passing phase and, for this reason, the materials and methods which are vulnerable, but which technically would be appropriate, are not excluded from consideration in this chapter.

6.2.5 AWARENESS OF IRRIGATION APPLICATIONS

One of the practical problems of irrigation management is that soil is not 'transparent'. One cannot see what is happening under the ground, so it is difficult to develop an awareness of the way in which irrigation water is being distributed and used by the plant. One of the major advantages of sprinkler irrigation, which it shares with short furrow flood irrigation, is that the farmer at least knows how much water he has applied to the land and has the assurance that it is fairly uniformly distributed across the land. He still does not know, however, whether he is giving too much or too little water, or how that water is behaving out of sight beneath his feet. In the case of sprinkle irrigation, this can be related judgementally to the effects of natural rain.

The specific aspects of systems of irrigation under pressure, which are applicable to small-scale farming and which are be discussed in this chapter, are outlined briefly in the following paragraphs.

6.2.5.1 Sprinkler irrigation

The emphasis will be on:

- the operational problems encountered,
- the properties of sprinklers and how these can influence methods and efficiency,
- the present design norms and the case for their modification, and
- designing for non-standard applications and prospects for innovation.

The only variation on conventional sprinkler irrigation covered is centre pivots, as no other mechanical systems were encountered in the surveys.

6.2.5.2 Drip irrigation

Drip irrigation is an attractive approach that is becoming more and more applicable, not only for specialised horticultural agricultural crops, but also for field crops in the commercial farming sector. Drip irrigation does, however, have limitations, which will be discussed. It is one of the least 'transparent' irrigation methods and it is difficult to predict the behaviour of the wetted 'onion' in the root zone. Small-scale farmers consider it to be a logical and desirable method and there are various simplified systems that have been developed for garden type applications. Water quality and filtration are important.

6.2.5.3 Micro irrigation

Micro irrigation is largely used for fruit crops in commercial orchards, but can have additional specialist applications that should not be neglected.

6.2.5.4 Floppy sprinklers/giant micro

This South African development has considerable potential for small-scale irrigation provided production and returns can justify the relatively high cost of permanent-set applications. The floppy sprinkler is entirely plastic, which makes it unattractive to scrap metal thieves and it can be installed overhead, where it is less vulnerable to vandalism than conventional applicators.

6.2.5.5 Piped furrow irrigation

There are, in addition, systems that can best be described as 'piped' furrow irrigation, that are promising and have been initiated by individuals on a do-it-yourself basis. Conventional drip irrigation has a low, controlled application rate. This variation on the drip irrigation method uses permeable drainpipes or PVC laterals, with relatively large 'dripper' holes that have much the same effect as furrow irrigation, without the penalty of losses due to excessive penetration in light soils.

6.3 PRESSURISED SYSTEMS IN PRACTICE IN SMALL-FARMER IRRIGATION

6.3.1 SPRINKLER IRRIGATION

6.3.1.1 Stand times and sprinkler spacing

Sprinkler irrigation is familiar to most people because it has been used for many years, in one form or another, on garden lawns. The sprinkler waters a circle and, to obtain even coverage over the whole lawn, must be moved at regular intervals. If one forgets to move the sprinkler, that particular circle is over-watered. Even if one remembers to move the sprinkler, it is not easy to judge where the sprinkler should next be positioned so that the wetted circles overlap, to obtain even coverage. Any gardener will therefore appreciate how difficult it is for a small farmer to achieve uniform irrigation distribution.

Stand time, or how long sprinklers stay in one place, depends on sprinkler discharge rate and the amount of water that must be applied. Usually, small-farmer sprinkler irrigation systems are designed to operate in two equal shifts about ten hours long, with the pipes being moved in the early morning and late afternoon.

It is very difficult for many small farmers to comply with these designed stand times. One reason is that, in many cases, the village where the farmers live is some distance away from the fields and transport is seldom available so it is difficult for them to get to the lands twice a day. Also, a large proportion of the farmers or farm workers are women, with household duties that make it impossible for them to be away from home early or late in the day, when sprinklers should be moved. Inevitably, and for very good reason, their day shift ends up being short and the night shift long.

Sugar farmers visited in Mpumalanga have found a simple solution to this uneven stand time problem. They move the dragline sprinklers so that, if a particular spot in the land is irrigated for eight hours one week, it is irrigated for sixteen hours the next. This can work, if the shifting of the sprinklers is systematic and if the soil is deep enough to store the heavier application.

If a system has been designed to operate for twenty hours a day and the farmer can only operate during the day, it is impossible to meet crop needs. (With flood irrigation, farmers need to be in the fields for four to five hours continuously over the midday period, which is a time that may fit into their routine better. However, it is inconvenient to spend four or five hours every day 'leading' water. Sprinkler irrigation therefore has the attraction that the irrigator is not tied down for a long, continuous period.)

It is possible to design a system with stand times to suit the requirements of the farmers, eg, stand times are artificially extended by reducing the rate of application and increasing the number of sprinklers, but this usually has cost implications.

6.3.1.2 Moving sprinklers

Moving sprinklers is an uncomfortable, muddy chore, and can be heavy work. There can be big differences between design assumptions and practice because it is difficult to move pipes in high crops, such as maize. Sugar cane is particularly difficult: It is nearly impossible, if you are working with a dragline, to get the sprinkler correctly positioned. Sighting poles can be used, but not easily, and sometimes the operators, often children, who are moving the draglines, forget where the last position was or do not understand the importance of even water distribution. The consequences are visible in the cane growth.

An unusual situation is cited by De Lange (1994), in which draglines are shared by farmers on a scheme where the irrigation layout does not coincide with the farm boundaries. However, although farmers can help one another to move quick-coupling sprinkler laterals, sharing of equipment does not usually work in practice. After a few production seasons, farmers are generally determined to increase the number of draglines on the scheme, so that each farmer can control his own equipment.

6.3.1.3 Mechanical vulnerability

One of the problems of sprinkler irrigation is that the pipes and equipment lie exposed on top of the ground and everything can be easily borrowed or stolen. Deliberate damage by vandals is a reality. Also, because pipes are moved more than once a day and are often exposed to grazing animals, accidental mechanical damage is to be expected.

However, spare parts are seldom obtainable locally. Once something is damaged and the replacement part 'borrowed' from a neighbour, then a chain reaction starts and the whole system eventually breaks down. Few scheme farmers actually own the equipment they use and so they lack interest and commitment. Naturally, maintenance suffers. Independent farmers usually fare better. They certainly have the commitment and normally live near enough to the fields to keep an eye on things.

While a sprinkler system looks simple and effective, it has the disadvantage that wear and tear is not immediately visible. A sprinkler will continue to operate until the knocker falls off or jams. However, long before it reaches this stage, the sprinkler's efficiency may have deteriorated to such an extent that it has an adverse influence on costs and production. Undetected worn nozzles can double application rates. Like a leaking coupling or pipe, worn nozzles waste water and cause water logging, which leaches nutrients out of the soil. Pressure decreases accordingly and, to compensate, engines and motors drastically increase electricity costs.

Nevertheless, farmers in general do not pay attention to minor maintenance chores, such as replacing rubber washers and worn nozzles, and they leave repairs until it is too late. This happens not just on small farms; it happens only too often on many large commercial farms, true to an old agricultural engineering motto: *If it works, don't fix it.*

6.3.1.4 Suitability of soils

Infiltration rate, water-holding capacity and depth of soil are the main factors that determine suitability of soils for irrigation. Severe surface crusting of soils is a widespread problem throughout South Africa because surface sealing leads to low infiltration rates (often barely more than 2 mm/h). This has serious implications for sprinkler irrigation, with poor water infiltration leading to ponding or run-off. The susceptibility of a soil to crusting must be taken into consideration in sprinkler irrigation planning.

6.3.1.5 Water and equipment management

On irrigation schemes, water measurement, especially if there is an allocation or a charge for water, is a management problem. This is discussed in greater detail in Chapter 5, *Water Supply Infrastructure and Management.*

Sprinkler irrigation can be a management problem when there are severe water shortages, because sprinklers are designed to distribute water over the whole area. Smaller farmers can counter this problem by removing sprinklers from dragline hoses and concentrating the water in small beds or basins, to irrigate individual plants, thus reducing evaporation losses.

Water and equipment management problems are not usually easily solved, however. The level of management demanded by sprinkler irrigation should not be under-estimated. This is particularly true on schemes where farmers are dependent on shared water supply infrastructure. A pump station may be designed to service ten farms, under the supervision of a pump operator. Farmers typically apply a week in advance for the water they plan to use, but it can happen that a farmer is not able to irrigate at all during a particular cycle. A funeral can unexpectedly take as many as half of the participants in the scheme away from the farm, which means that their crop is not irrigated.

It also means that system pressure becomes too high, if the pump operator is not warned about the lower demand for water. This can upset sprinkler discharge and damage the system, if the pump operator does not notice the problem and react. Pump operators do not always understand the implications of pressure variations and many have indicated that they are frustrated by their lack of training.

Sprinklers are very dependent for efficient operation on maintenance of the correct pressures in the system. In the case of schemes, it is how the pumping station is designed to be operated, and the condition of the individual farmer's pump that determine what the correct pressures are. It is rare to find pumps operating at specified design pressures on any farm, including large commercial farms. Since incorrect pressure means higher electricity costs and less water means lower crop yields, this can have serious cost implications if it happens often.

The situation is further compounded by 'unauthorised', but very natural, modifications to systems. The most common is the addition of sprinklers and/or laterals in order to cover more ground, without making any changes to pump capacity or pipelines. Inevitably, system pressures vary and the designer's careful work, aimed at achieving high efficiencies and low operating costs, is negated because irregular pressures mean higher costs and greater wear.

6.3.1.6 General design and planning factors

It is not anticipated that there will be major deviations from existing procedures. Hopefully, however, there will be more innovation and flexibility, readiness to assess the needs and circumstances of the small farmer, and willingness to meet these requirements.

The main objective in the design of systems for conventional situations is efficiency. Uniform distribution of irrigation water over the land, effective power utilisation through selection of the correct pump, and a sound balance between capital investment and operating costs all receive attention.

All irrigation system design starts with crop water requirements. The proposed modified approach to estimating crop water requirements is outlined in Chapter 4.

Irrigation cycle length, the number of working hours per day, and the number of working days per week, coupled to stand times are the other fundamental inputs in irrigation system design. Over the years, conventions have developed which have become regarded as being 'good practice' but, every now and again, something happens to upset the *status quo*, such as the introduction of new electricity tariffs, which made night irrigation disproportionately advantageous - and a new set of rules becomes enshrined. **A similar shift in thinking is now required to cater for the varied situations of small farmers**. Innovation is needed to achieve more appropriate and affordable systems.

Meeting the needs of the small farmer cost-effectively requires new and more flexible standards that demand more initiative of designers. There is a need to build more versatility into designs, and a pump that can handle unauthorised extensions should be selected, rather than one that achieves the highest efficiency at what might well be a fictitious operating point. Higher variations in discharge than are usually considered acceptable along a lateral may be more than justified, if there is a significant cost saving and little yield loss.

A major advantage of sprinkler systems is that a farmer can start in a small way and expand the system as he learns how to use it and can afford it. If the farmer plans to do this, provision should be made at the planning stage.

6.3.2 CENTRE PIVOTS

Centre pivot sprinkler systems have become very popular and more than 15 000 are in operation in the RSA. The apparent simplicity of operation and the advantages are very attractive to all farmers, including small farmers, and there are several small-farmer schemes that utilise centre pivots.

However, centre pivots are designed to irrigate circles, generally ranging in size from 30 to 100 hectares in area. Smaller sizes are generally not a practical proposition because the cost per hectare is very high, although the larger sizes are not very much more expensive than conventional sprinkler systems. Centre pivots are mechanically complex and require skilled maintenance so that they can only be considered for small-farmer schemes under exceptional circumstances.

There are also specific management problems with pivot systems, such as infiltration restrictions of the soil and the high application intensities experienced at the outer end of the lateral, but these are not specifically a small-farmer issue and are not considered in detail here.

6.3.2.1 Management and production issues

Centre pivots have been used on a limited number of small farming schemes. For example, four farmers can share a 40-hectare pivot, so that each farmer irrigates a quarter segment, but smaller pivots and segments are evidently not practical. De Lange (1994) has described the various methods of utilisation.

It is possible to operate a centre pivot so that it can cater for the irrigation needs of each of the four farmers. The rate of application for each segment can be adjusted, and it is possible to move over a segment without irrigating, so there is flexibility. However, inevitably, difficulties arise. How does one divide up the electricity and water accounts, when the participants may have followed different irrigation patterns and there is as yet no means of metering the sectors individually?

The ploughing of the land and other contractor services require co-ordination between the four farmers and this tends to reduce their freedom of action. The farmers in the example believe they should own a tractor between them and this would solve many of their problems. In some cases, it has been the understanding that, if the pivot requires repair, it is the responsibility of the farmer over whose area it was operating when the breakdown occurred to organise and possibly pay for the repair. The arguments that can arise from this attitude can be imagined. There is very little that the individual farmer can do to rectify the things that go wrong with a centre pivot. In a remote area, a relatively minor fault, such as a flat tyre, stops the whole operation until repairs can be done and this can take several critical days.

The centre pivot also makes it difficult for an individual farmer to plant several crops at one time. On the larger schemes, farmers generally have to regiment themselves into planting the same crops at the same time.

6.3.2.2 *Financial issues*

In the case of the centre pivot size normally used on commercial farms (50 hectares), the costs per hectare are not too far out of line with conventional sprinkler systems. However, a pivot must be installed for the full area for which it is designed. This means that the farmer is committing himself to 50 hectares under irrigation. This has two implications: the first is that the total investment must be made at the outset because the development cannot be phased in over time, which is possible with most other irrigation systems. The second is that, should there be a decline in the water supply, the farmer cannot reduce his investment, even though he cannot irrigate the full area. One of the main reasons for failure with centre pivots has been that the water supply has dried up. This is particularly applicable to boreholes and direct pumping from rivers.

In order to ensure satisfactory returns from the system, it is necessary that the management and production of the full-irrigated area be adequate. **The high investment involved in centre pivot irrigation means that, unless the yields are well above average, the scheme would not be financially viable**. This implies that the other inputs, such as fertiliser, must be forthcoming, and that management, including disease and insect control and weeding, must be of a high standard.

Sometimes farmers do not actually irrigate, perhaps because of failure in water supply or electrical power. However, on schemes, farmers are committed to paying the basic charges for the centre pivots, even if for some reason or another they do not actually irrigate. This can put the farmers in a very difficult position and can even cost them the crop.

A further financial factor is that, because the pivot is an expensive piece of equipment, the farmers have a large debt to repay. Very few small farmers have an understanding of financial matters and find at the end of the season that they have made only a very small profit or even a loss, without being aware how this has come about. This breeds suspicion.

6.3.2.3 *Mechanical vulnerability and infrastructure*

Centre pivot irrigation is not feasible unless there is ESKOM power available. The pivot is a sophisticated machine with electrical controls and wearing parts, tyres and gearboxes, etc, so maintenance is important and, when breakdowns occur, they normally require specialist repairs. This means that, when the pivot is installed in remote areas, breakdowns can result in their being out of action for a considerable period – and, because they normally operate on relatively short cycles, this can very often lead to crop loss.

6.3.2.4 *Design and planning factors*

The conventional centre pivot, designed according to normal standards, has sufficient flexibility to make virtually any irrigation strategy possible. However, the agricultural and financial aspects of the investigations are of primary importance because the high initial capital investment means that low yields cannot be tolerated. This means that there can be no modification or relaxation of the normal design methods and inputs just because the pivot is going to be used by small farmers. There is no way in which the specifications of a centre pivot can be modified in order to get a lower cost unit, for example, if anticipated production will be less than usual, as can be done in some cases with conventional sprinkler systems.

It must be concluded from all the foregoing that centre pivot irrigation cannot be recommended for small farmers.

6.3.3 DRIP IRRIGATION

Drip irrigation is an expensive and management-intensive method of irrigation and is not normally considered suitable for small-farmer applications. However, there is no inherent reason why small-scale farmers should not use drip irrigation successfully. In fact, the logic of drip irrigation appeals to many of them because it applies the water to the plant where it is required. The two major drawbacks, however, are cost and clogging of emitters.

Cost should be seen in the context of how the system is used by small-scale farmers, who are very often prepared to move drip lines from one position to another between applications, thus considerably reducing the overall capital investment.

Filtration is a problem. Bacteriological growths in the pipes are also major problems, so that effective filtration and the chemical treatment of the water may be required. This could be a disqualification.

Water and soil quality is important because drip irrigation is possibly the least 'transparent' of the irrigation methods. It is virtually impossible to visualise or to predict the pattern of wetting below the surface and, very often, if the horizontal spread of the water is not as anticipated, water can be lost to deep percolation, without the irrigator's being aware of the situation. Over-irrigation, resulting in a perched water table, is not unknown.

Drip irrigation only becomes a feasible proposition for small-scale farmers when there is practical, site-specific experience and understanding of drip irrigation under the circumstances under which it is going to be used. Even amongst experienced commercial farmers, this knowledge is rarely available. Drip irrigation should therefore not be suggested to small farmers unless there is adequate precedent to support the recommendation.

Having said this, considerable success has been achieved in household gardens with small-scale drip irrigation in the Free State, using municipal treated water. The wagon-wheel and Malawi drip systems have also been successful, where water from a container is led into short dripper lines. Some are conventional dripper lines, while others are homemade ones, with holes drilled into a plastic pipe which has string threaded into it to retard the flow rate.

It should be noted that the whole purpose of drip irrigation is a very slow, controlled application of water. The do-it-yourself approach of drilling a series of holes in a plastic pipe and allowing the water to run through these holes into the ground therefore cannot be considered to be conventional drip irrigation. These DIY rigs really approximate to piped furrow irrigation, if they are on the surface.

6.3.4 PIPED FURROWS

Piped furrow irrigation on the surface can have merit because, in very sandy soils, furrow irrigation, even in relatively short furrows, like those used in community gardens, are not very satisfactory because of the very rapid infiltration rate into the soil. Allowing the water to flow through a plastic pipe with a series of holes along it is a very good way of applying the water in the furrows with good distribution and minimum losses due to deep percolation. This method is being developed by farmers themselves but has not as yet had any critical assessment.

A similar approach, which was well known many years ago in the United States, has recently gained favour in Australia. Water is run into a porous drainage pipe that is buried between rows. The water is run through at very little pressure, if any, and drains out along the length of the pipe to irrigate between the plants. This is another form of piped furrow irrigation.

The criticism has been raised, particularly in the case of the buried pipeline, that roots are likely to block the pipe and interfere with the even distribution of the water.

Sub-surface drip irrigation is gaining popularity amongst both commercial and small-scale sugar and cotton farmers. The dripper line is very often T-tape and, while this is a very efficient and water-saving method of irrigation, management is important and so this is not a method for the uninitiated.

6.3.5 MICRO IRRIGATION

Conventional micro irrigation systems are more applicable to orchards, where they are used in the normal way.

An interesting innovation was found during the survey where, in young orchards, the micro jets mounted on spaghetti tubing were used as mini sprinklers for inter-cropping between the trees.

6.3.6 THE FLOPPY SPRINKLER/GIANT MICRO SYSTEM

The 'floppy' is an award-winning South African development that is now increasing in popularity and application. The technical details will not be discussed here but an important feature is that it produces uniform droplets, which reduces mist formation. There is evidence to show that the losses due to wind drift and evaporation are lower than with conventional systems. The floppy does not have reactionary forces so lighter risers or even an overhead wire system can be used. The operating pressure is low, permitting the use of low-pressure piping. Water must be filtered but the aperture in this sprinkler is 3 mm so it only requires a rudimentary filter system.

Possibly the most important attribute is that, being constructed entirely of plastic materials and small-bore piping, it is not normally a target for thieves. Mounted at a considerable height on a wire network, it is also out of reach of casual vandals. This method has the additional advantage that there are no components at ground level that could interfere with farming practices.

However, this is not a low-cost system. Normally, installations are done on the basis of a permanent set. This means that all the floppies would be operating at the same time in a specific block, as is the case with micro irrigation. Installation costs are between R5 000 and R10 000 per hectare, about the same as for centre pivot and drip irrigation, but cheaper than for a permanent-set conventional sprinkler system. The use of irrigation systems of this nature is therefore dependent on the production of high return crops, in which case these costs are acceptable.

6.4 SPRINKLER CHARACTERISTICS: DESIGN AND MANAGEMENT

6.4.1 INTRODUCTION

The team was disturbed when they undertook their surveys of schemes with sprinkler irrigation to find that there was so much wrong. Management and maintenance of stand times, sprinkler layout, dragline positioning, replacement of worn nozzles, etc, left so much to be desired that doubts arose as to the advisability of using sprinkler irrigation on small-farmer schemes. (It must be emphasised that the deficiencies and problems disclosed by the surveys are by no means confined to small-farmer irrigation. They are surprisingly general, even on commercial farms, which are usually considered to be models of irrigation efficiency.)

It was, however, difficult to evaluate the consequences of the malpractices encountered, such as varying stand times, mixed sprinklers, dragline sprinklers incorrectly positioned, worn nozzles, etc. Some of the unanswered questions related to the relative importance of:

- Characteristics of the sprinkler itself,
- Pressure-sensitivity,
- Variations in stand times,
- Positioning of laterals and draglines,
- Defective or missing sprinklers, and
- Non-matching sprinklers.

Commercially available software packages for sprinkler selection, evaluation and system design were evaluated to ascertain if they could provide adequate answers to these questions, but they are meant for 'normal' situations and were not suitable for diagnostic purposes. When no suitable program could be found to simulate these field conditions, a program was developed to evaluate the consequences of these deviations from the original design intentions. The SAPSPRNK program (Crosby, 1997) was developed as part of the project as a diagnostic and design tool. It uses as one of the inputs the published results of tests on sprinklers undertaken by the Institute for Agricultural Engineering of the Agricultural Research Council.

6.4.2 SAPSPRNK

A single sprinkler is tested under wind-still conditions and the distribution pattern of the sprinkler can be integrated by SAPSPRNK into the distribution patterns applicable to the situations typified by the 'unanswered questions' above. SAPSPRNK can then combine the delivery patterns of a group of sprinklers so that changes to lateral position, etc, can be simulated and quantified.

The team was surprised to find that these results show that the quality of water distribution is quite reasonable, in spite of various malpractices. Sprinkler irrigation is remarkably robust in this respect. The probable reason for this is that the overall wetting pattern is built up by the multiple overlap of a number of sprinklers mounted on adjacent laterals, and that this overlap tends to smooth out the effects of malpractices.

This puts a new light on the advisability of using sprinkler irrigation for small-farmer applications. The greater insights attained with the help of SAPSPRNK emphasised, however, the need to assess the actual on-the-ground situation when developing sprinkler irrigation systems, and not to assume that what has become accepted as standard practice is necessarily always suitable. Further work needs to be done in this regard.

Not enough account has been taken of the importance and implications of the variations in characteristics between sprinklers. In the following section, SAPSPRNK is applied to quantify the answers to 'unanswered questions' and to develop innovative applications for sprinkler irrigation.

6.4.2.1 SAPSPRNK output

The determination of sprinkler uniformity in the field is done by placing catch cans out on a grid and computing two coefficients.

One is the Cu value (coefficient of uniformity), which is an internationally recognised statistical reflection of the uniformity of distribution of the irrigation water. The other coefficient is the Du value, which is the distribution uniformity, derived from the driest 25% of the area covered, and which is extensively used in the United States. This is the area that would show reduced yield as a result of water stress.

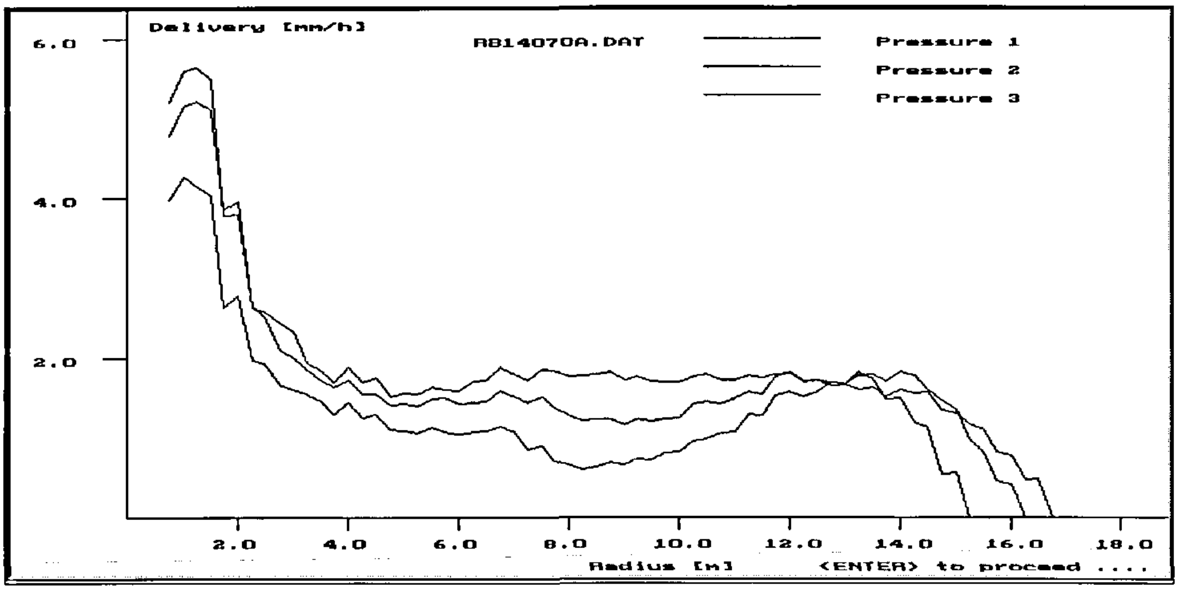
(The Institute for Agricultural Engineering is proposing to use the SAPSPRNK routine and publish the Du figures in their test reports, in addition to the Cu presently published.)

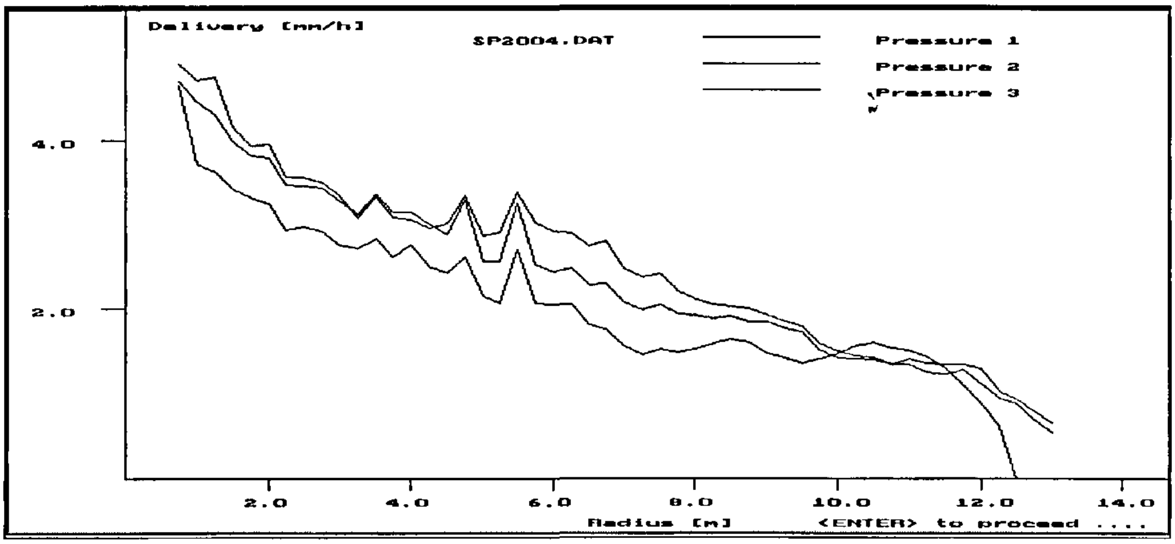
SAPSPRNK simulates the catch can method and a pattern of up sixty-four sprinklers can be accommodated. To eliminate edge effects, the uniformity of distribution is only calculated in a rectangular area within the field, with a margin left equal to the sprinkler spacing.

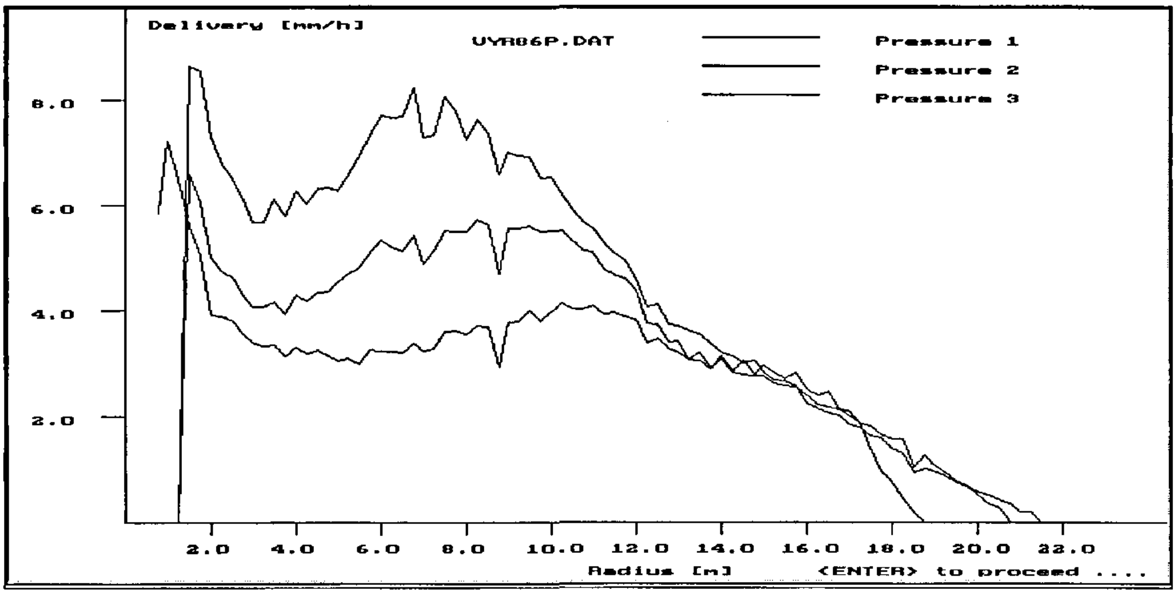
6.4.2.2 SAPSPRNK standard output screen

The standard output used to assess normal distribution uniformity is based on sixteen sprinklers (4 x 4). The delivery pattern in mm/h is presented graphically in Figure 6.4.2.2a. The statistical data tabulated is Cu, Du and mean delivery in mm/h.

Figure 6.4.2.2b: Distribution patterns – Sprinkler I is rectangular, Sprinkler II is triangular, and Sprinkler III is undefined







6.4.3 DISTRIBUTION UNIFORMITY

6.4.3.1 Sensitivity to operational defects and design assumptions

The pattern of the sprinkler distribution curve can also vary very widely. In some cases, it is triangular; in others, rectangular, and, in others, it tends to be a mix. This obviously has an influence on the effectiveness of the overlapping of the sprinklers, which changes with the spacing. Where conditions and pressures are likely to vary, it makes good sense to pick a sprinkler with a satisfactory (or tolerant) distribution curve, which does not vary greatly with pressure and enables reasonable distribution to be maintained in practice.

It is possible, with SAPSPRNK to simulate the various operational situations that are identified in the field. Three sprinklers known to be satisfactory were selected to illustrate the results obtained. See Figure 6.4.2.2d for the distribution pattern graphs of the three sprinklers.

Sprinkler I is not affected by pressure differences and has a very flat rectangular distribution pattern.

Sprinkler II is rather more pressure-sensitive and has a very uniform triangular pattern.

Sprinkler III is pressure-sensitive and has a pattern intermediate to II and I.

In each situation, the simulated Cu, Du and mean delivery rate in mm/h are tabulated for each sprinkler in the analyses that follow so that comparisons can be made of their reaction and an impression gained as to the acceptability of the results obtained.

Unless otherwise specified, the simulations assumed that sprinklers were spaced 12 m apart along the laterals, with the laterals being spaced at 15 m and, as is normal in design tables, the sprinklers were all operational at the same time. This is the permanent-set situation. Later runs were done at modified spacing.

6.4.3.2 Sensitivity to pressure changes

The sprinkler's sensitivity to pressure changes is of major importance. This is particularly true in the small-scale farmer context where it is highly likely that there are or will be variations, both in position in the field and, over time, in pressure. Consequently, other things being equal, it is desirable to select a sprinkler which is relatively insensitive to pressure variation. The distribution patterns of all three sprinklers were good (acceptable Cu > 85 %) at this spacing, at both the top and bottom of the pressure operating range. In all cases, there was a significant drop in the mean delivery rate at the lower pressure.

Table 6.4.3.2: Sensitivity to pressure changes

Sprinkler	I			II			III		
Pressure	**Cu**	**Du**	**mm/h**	**Cu**	**Du**	**mm/h**	**Cu**	**Du**	**Mm/h**
High	88%	79%	6.95	91%	86%	5.85	87%	77%	9.44
Low	84%	71%	5.44	86%	78%	4.58	84%	70%	7.24

6.4.3.3 Effect of operational faults on sprinkler distribution

In a high or a dense crop, it is not always easy to position the sprinklers at the end of their drag-hoses in precisely the right position. At first, it appeared that, with deviations of three or four metres, the consequences could be serious. But practice showed and was confirmed by simulations, that this is possibly not a serious problem. (In fact, there are cases where a degree of random spacing of draglines gives better Cu's and Du's than when they are positioned on the grid positions originally intended.) The probable reason for this is, again, the multiple overlap of sprinkler distribution patterns and the tendency for the delivery immediately adjacent to the sprinkler to be higher than average. The scatter arising from the somewhat random positioning of the draglines obviates this problem and may, in fact, have a beneficial effect.

In the simulation in Table 6.4.3.3, one of the four sprinklers in the 12 by 15 pattern was displaced 3 m south and 3 m west.

One of the laterals was moved 3 m away from the correct position, so that the distance between laterals was 18 m instead of 15 m.

In the simulation, the default stand time for a lateral position was twelve hours. This was changed in Table 6.4.3.3 so those adjacent laterals had stand times of eight and sixteen hours respectively. This was expected to be a serious vulnerability but, as a consequence of the multiple overlap in the sprinkler arrangement, it was not as serious as it seemed at first. It will be noted that, even when a lateral position has been missed (and the stand time is therefore zero), the area around the lateral still receives a significant amount of water. Possibly, specific strategies should be considered when designing in order to evaluate the consequences of variable stand times.

Table 6.4.3.3: Effect of operational faults on sprinkler distribution

Sprinkler	I			II			III		
Operational fault	**Cu**	**Du**	**mm/h**	**Cu**	**Du**	**mm/h**	**Cu**	**Du**	**Mm/h**
Normal position	88%	79%	6.95	91%	86%	5.85	87%	77%	9.44
Lateral 3 m displaced	84%	69%	6.58	85%	79%	5.49	82%	75%	8.88
Stand times 8 & 16 h	80%	71%	6.95	76%	65%	5.85	79%	65%	9.43
Dragline sprinkler 3 x 3 m displaced	86%	76%	6.93	88%	81%	5.81	80%	72%	8.76

6.4.3.4 *The influence of sprinkler spacing and arrangement*

The three sprinklers selected for the spacing and arrangement simulations each have very good but widely differing distribution pattern. The simulations reflected in Table 6.4.3.4 were done at the top of the operational pressure range but sprinklers I and II are exceptionally pressure stable and it can be assumed that much the same pattern would have been found at lower pressures. Sprinkler I has a flat, rectangular distribution pattern, while II has a triangular pattern. The versatility of all three sprinklers at spacings ranging from 12 x 15 through to 18 x 18 and 18 x 12 is surprising.

Table 6.4.3.4: Sprinkler spacing and arrangement

Sprinkler	I			II			III		
Spacing & Position	**Cu**	**Du**	**mm/h**	**Cu**	**Du**	**mm/h**	**Cu**	**Du**	**mm/h**
12 x 15 rectangular	88%	79%	6.95	91%	86%	5.85	87%	77%	9.44
12 x 15 triangular	84%	73%	6.77	92%	86%	5.82	87%	80%	9.34
15 x 15 rectangular	81%	71%	5.56	91%	87%	4.675	83%	78%	7.55
15 x 15 triangular	88%	86%	5.55	88%	79%	4.66	87%	76%	7.52
18 x 18 rectangular	77%	75%	3.86	86%	77%	3.23	87%	77%	5.26
18 x 18 triangular	75%	63%	3.86	89%	83%	3.23	81%	71%	5.24
18 x 12 rectangular	79%	63%	5.80	90%	84%	4.87	73%	60%	6.04
18 x 12 triangular	86%	84%	5.76	89%	82%	4.85	80%	71%	6.01
15 x 12 rectangular	88%	79%	6.94						
15 x 12 triangular	87%	80%	6.90						

6.4.3.5 *Missing or faulty sprinklers*

It is obviously an unsatisfactory state of affairs to have missing or faulty sprinklers but, again, there is far more tolerance than was originally expected. Naturally, the impact of missing or faulty sprinklers will vary with the number of inoperative sprinklers.

Table 6.4.3.5: The value of Du and Cu for missing or faulty sprinklers

Pattern and Spacing	Cu	Du	Inoperative Sprinklers
12 x 12 rectangular	84,43	85,14	0
12 x 12 rectangular	84,72	78,97	1
18 x 18 rectangular	82,35	75,14	0
18 x 18 rectangular	68,26	46,97	2

6.4.3.6 Non-matching sprinklers

It has been noticed that farmers sometimes purchase sprinklers as over-the-counter items, without any real trouble being taken to ensure that they match up with the existing sprinklers that are in use. This is obviously undesirable and much depends on the randomness with which these sprinklers are replaced. However, depending on operating circumstances, particularly pressure, there would appear to be a reasonable amount of tolerance here too.

6.4.3.7 Preliminary conclusions

It must be appreciated that these simulations are based on laboratory tests and do not take account of the influence of wind, which can be significant. What these simulations do provide is an indication of the relative importance of poor sprinkler selection or design and of defects arising from negligent management. The sprinklers used in the simulations were selected for above-average distribution characteristics and, had less successful sprinklers been used, with an indifferent initial uniformity pattern, the results would have been more prone to adverse consequences.

All in all, however, the tolerance disclosed by these simulations is encouraging because it appears that, even when 'things go wrong', distribution can still be reasonable. It will be seen in the next section, however, that more attention should be paid at the design stage to the appropriate selection of sprinklers.

6.5 DESIGN NORMS AND INNOVATIVE POSSIBILITIES

The availability of SAPSPRNK (Crosby, 1997) has made it possible to evaluate some non-standard practices and to answer some questions about new approaches to small-scale farmer irrigation.

- There are new, far-throwing, conventional sprinklers, as well as the floppy sprinkler, on the market, and neither has been fully exploited. How useful are they?
- Small-scale farmers sometimes irrigate a foodplot using a single lateral, ignoring the need for overlap to ensure reasonably uniform water distribution. Is this legitimate?
- The South African recommendations for minimum application rates are conservative. Are they well founded?

6.5.1 DELIVERY RATES

The currently accepted norm is not less than 5 mm/h for movable systems and 4 mm/h for permanent-set sprinklers. The reason for not going to lower delivery rates (or application rates) is the influence this can have on evaporative losses. On the other hand, most designers are reluctant to go to a rate above 6 mm/h for conventional systems although, in some countries, for example, India, twice this rate is preferred. It is accepted that these norms have been developed as a result of field experience, but it is not always possible to relate back to the origins of the values.

The main reason for limiting delivery rates in South Africa is probably so as not to exceed the infiltration capacity of the soil and consequent run off. Surface crusting is a major problem in South Africa and is related to clay mineralogy, particularly in areas with annual rainfall below 600 mm, and this could be the underlying reason for the conservative approach.

An additional reason for keeping the delivery rate below 6 mm/h is the very practical one of organising stand times and pipe moving at convenient times of the day. High delivery rates usually equate to short stand times, several moves and additional labour requirements. We have seen that this question of stand times and night irrigation can become a nightmare in the communal land tenure areas.

Delivery rate is not a simple concept. Test reports and design tables indicate delivery rates in mm/h at various sprinkler and lateral spacings. The rates are calculated by dividing the discharge from a single sprinkler by the area obtained by multiplying sprinkler spacing by lateral spacing. This is only valid for a permanent set, where all sprinklers are operating at the same time. The normal position with movable systems falls between the extremes just discussed. Water is applied the full length of a lateral and the distance between sprinklers influences the rate of delivery but the wetted width is twice the effective throw of the sprinkler.

A sprinkler that is a common choice for dragline systems has a discharge of 1.120 m^3/h at working pressure and, with 18 m x 18 m spacing (area 324 m^2), the delivery rate would be 3.5 mm/h, if this were a permanent-set system. In a dragline application, the sprinkler would be operating in isolation. The sprinkler has a throw of 15 m and would wet an area of 707 m^2, resulting in an average effective delivery rate of 1.58 mm/h.

What are the implications of this low application rate and to what extent do the present norms indirectly make allowance for the non-permanent set situation? We do not know, but there are many thousands of hectares being irrigated by dragline at this tempo.

Utilising the same popular sprinkler at an 18 m spacing along a lateral, the area covered by a single sprinkler is 18 x 30 = 540 m^2 and the delivery rate is 2.1 mm/h. In this case, the strip next to the one just irrigated, which must provide the necessary overlap to bring the total application up to design level, may be irrigated within hours, or days. This must have an influence on soil infiltration capacity and evaporation losses.

In order to achieve the norm of a minimum delivery rate of 5 mm/h, it would be necessary to reduce the sprinkler spacing to 12 m, if the lateral spacing of 18 m is maintained. This would bring the actual average delivery rate during operation to 3.1 mm/h. This particular sprinkler has a very flat, rectangular pattern, with the delivery rate being maintained over the full radius. In the case of a sprinkler with a triangular distribution pattern, the delivery at the end of the radius tapers off so that overlap is important. Evaporation and infiltration characteristics would obviously differ from those of the rectangular pattern sprinklers.

The introduction of new 'super sprinklers' with effective throws of over 20 m, and the need to cater for the specific requirements of small-scale irrigation farmers, emphasises the need for a better understanding of delivery tempos, and may warrant a revision of possibly over-simplified norms.

6.5.2 EXTENDED LATERAL SPACING

One of the difficulties encountered with conventional sprinkler irrigation is the length of time required to complete a cycle. Centre pivot irrigation 'gets around' in a much shorter period that has numerous management advantages and a strategy has been developed to shorten the irrigation cycle, approximating centre pivot cycle management. (Van der Hoven, 1998).

This strategy drastically reduces the overlap between laterals but takes account of the fact that the middle section between the laterals is liable to under-irrigation. (As we have seen, however, provided there is a reasonable soil water reserve in the soil profile, the strategy of utilising the reserve to cater for peaks is viable. In practice, the spatial variation in soil water content in an irrigated land is considerable, and this strategy is not as drastic as may appear.)

With a greater distance between laterals, the time taken to cover the land is proportionately reduced. The position of the laterals is modified on the next cycle and they are placed down the centre where there was previously under-irrigation. The approach undoubtedly warrants further investigation. The characteristics of the sprinkler and the delivery distribution pattern are important, emphasising the need to select sprinklers for specific applications.

6.5.3 IRRIGATING WITH A SINGLE LATERAL

It appears to be quite feasible to irrigate with a single sprinkler lateral on a small plot. This has been done in practice for many years. The design requirements have, however, received little attention. With some of the newly available sprinklers, it would appear to be possible to irrigate a strip thirty metres wide without any real need for overlap. The uniformity will be dependent on the spacing of the sprinklers and a sprinkler spacing of twelve metres can be adequate to ensure a reasonable distribution pattern. (This is adjudged under no-wind conditions, whereas wind can have both a positive and a negative influence on this distribution pattern.) However, the approach should be feasible.

This technique is applicable on long narrow plots such as those set out on the original flood irrigation schemes. In Chapter 4, *Managing Crop Water Requirements*, in the section dealing with scheduling and programming strategies, examples were given of filling the profile before planting, and then possibly carrying out a second irrigation at mid-season if drought conditions prevail. It is possible that a contractor using a tractor as a power source for a single lateral could do irrigation of this nature. In the next section, the possibility of utilising contractors for irrigation will be discussed in more detail.

6.5.4 SPRINKLER IRRIGATION CONTRACTORS

In Chapter 5, *Water Supply and Management*, it is noted that farmers require independence in their water management and that there is a limit to the number of farmers who can be expected to share a common water source effectively. One of the other major problems in the case of irrigation under pressure is the power source. Very few schemes have access to electric power and the same applies to groups of independent farmers.

The alternatives to electric power, diesel and petrol engines are expensive and require specialised maintenance. However, in the earlier days of irrigation, extensive use was made of tractor-mounted pumps and the possibility of tractor contractors' extending the scope of their activities in future by using their tractors as a power source for water pumping should be investigated in depth. Although mechanisation services also create problems and bottlenecks, the establishment of these contractors has been hampered by the seasonality of their workload, which is largely confined to land preparation and transport. They would therefore probably welcome the possibility that they should undertake irrigation as one of their services. This was referred to in the previous section in connection with single lateral applications.

Doubts have been expressed as to the financial viability of this suggestion. Further evaluation is needed because the capital cost would be spread over a number of activities, which could range from seedbed preparation through to transport and such activities as grinding and milling, as well as water pumping. Costing would have to be re-evaluated because costing is normally done on the basis of new equipment, not used equipment. However, we all know that there is an important place for used equipment in farm management, provided it can be brought into a reasonable state of mechanical reliability at moderate cost. Previous analyses have shown that tractor contractors with used equipment can be viable.

6.5.5 A CHANGE IN APPROACH

The procedures for designing schemes for small-scale farmers are, from the technical point of view, much the same as those applied in designing for larger-scale schemes and for commercial farmers. **What is required, however, is a change in approach** because the farmers' objectives are intrinsically different.

6.5.5.1 The pragmatic approach

The differences between the conventional approach to designing sprinkler systems and the pragmatic approach, which is more appropriate to small-scale farming, are outlined in the following table.

Table 6.5.5.1: Design and planning procedures

Factors	Conventional Design Approach	Appropriate Design Approach
Water	Supply **sufficient water** over full growing period to ensure **maximum production**	Estimate present or **probable water use** for small-scale **target yields** and **production methods**
Stress	Cater for **peak periods** to ensure **no stress**	Make full use of **profile water reserves** and accept **moderate stress**
Pipes / Sprinklers	Select pipe/sprinkler combination for high Cu and less than 20% pressure drop	Choose pipe/sprinkler combination best suited to **realistic operational conditions**
Pumps	Select pump for **best efficiency at operating point** (pressure/delivery)	Select pump for **versatility** in the event of **non-standard use, extensions and wear**
Costs	**Optimise** capital/operating costs	Aim at **lowest cost** (good enough)

Although design is preceded by discussion with the farmer or community, it is virtually impossible to predict how the situation will develop in the future. Inevitably, there will be moves to other crops, shifts in market, increased skill on the part of the farmers themselves, and so on. The maximum degree of flexibility and versatility and provision for unexpected possible modifications should therefore always be taken into account in the design.

In future, small-scale farmers will probably be expected to bear the bulk of the costs of their irrigation systems. There probably will be arrangements for bridging finance in the early period of development but ownership will be with the farmer, who will be expected to recoup any big costs that arise from the irrigation scheme. This will put a premium on aiming at the lowest capital and operational costs commensurate with the purposes for which the scheme is intended. The system, including water supply, must therefore be so designed that it is possible for it to be managed by ordinary, competent people, with support from 'outside' but with a minimum of intervention.

6.5.6 DESIGNING SMALL SPRINKLER LAYOUTS

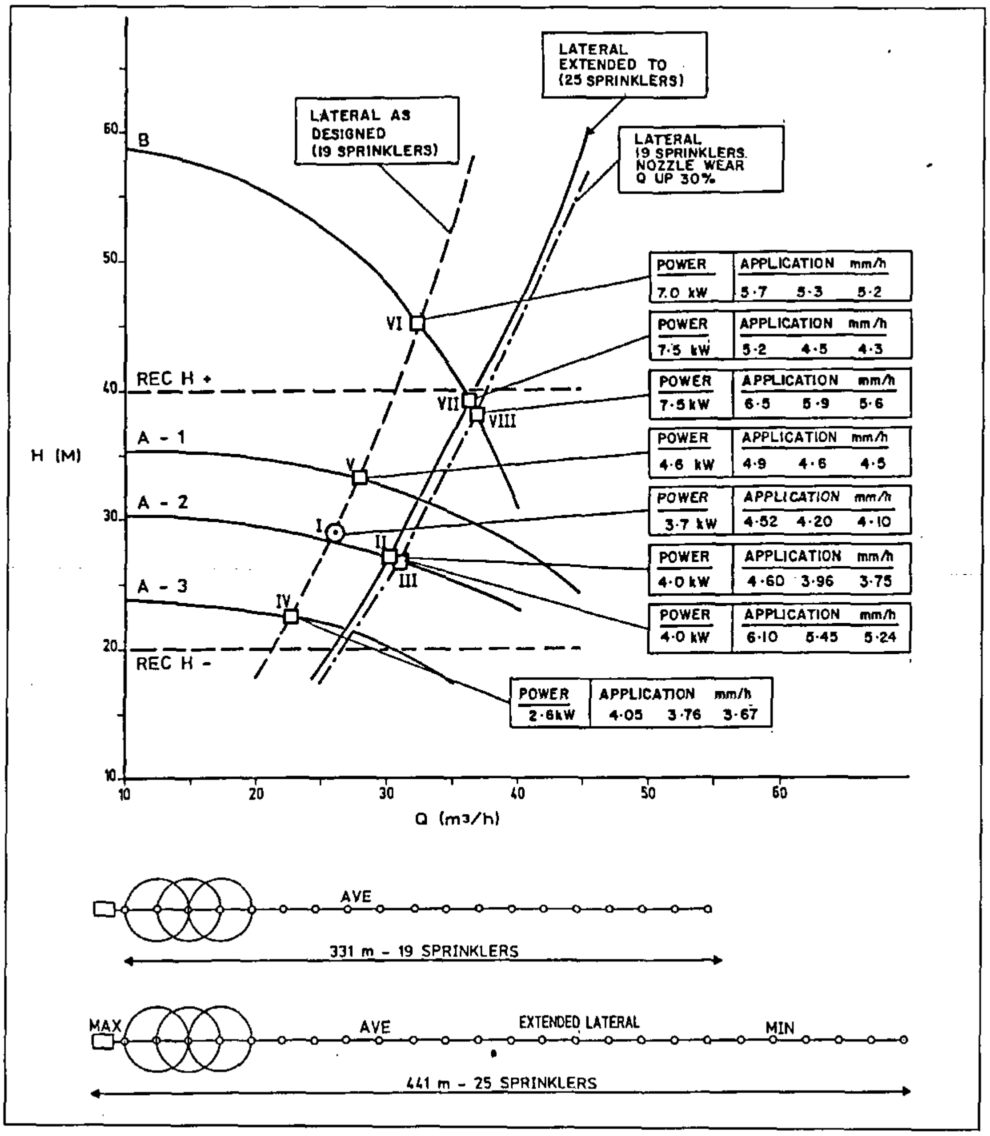
An example follows of the approach to a simple, appropriate design of a single, portable lateral. For simplicity's sake, it is delivering water from a pump positioned on a riverbank onto adjacent flat land. This is not an over-simplification of the more elementary application of sprinkle irrigation practised by small independent farmers using a portable pump and power unit.

6.5.6.1 The set-up

The requirements are to apply 25 mm in a nominal 6-hour stand time, in other words, an average application rate of 4.20 mm/h. The 331 m lateral with 19 sprinklers has been selected so that the pressure drop will be within the conventional 20% limit. The operating pressure head range of the sprinklers is from 20 m to 40 m, with a design head of 25 m. The pump delivery required will be 25 m^3/h.

All that remains to be done is to select a pump. Referring to Figure 6.5.6.1, it appears that pump A with impeller (2) is suitable. The operating point I in the graph is where the H-Q characteristic curves of the pump comply with the required head and discharge of the sprinkler lateral. The power requirement is 3.7 kW. Normally, the designer would go no further, provided the pump efficiency at this point was satisfactory.

Figure 6.5.6.1: Selecting a pump



6.5.6.2 *Checking on change*

Design should take into account the possibility of change: Will the pump still be satisfactory if the farmer decides to add on to the lateral, in the example up to 441 m and 25 sprinklers? The only way to check this is to plot the H-Q curves for the original lateral and the extended one. The new operating point is II on the extended lateral. Head is lower but the delivery is up. The pump characteristic is flat and the position is still very satisfactory. Average application rate is now 3.96 mm/h so that, to apply 25 mm as originally intended, the stand time is now only slightly up from 6 to 6.3 hours. Power requirement is up from 3.7 to 4.0 kW.

Nozzle wear is seldom noticed but, if this were to cause an increase of 30% in flow rate, operating point III shows that the power increase to 4.0 kW is again negligible. Application rate is now 5.45 mm/h and the stand time is down to 4.6 hours. If this rate of application is acceptable from the point of view of run-off, then the use of larger sprinkler nozzles could be considered.

6.5.6.3 *The influence of pump selection*

There are two additional scenarios illustrated in the Figure 6.5.6.1. Pump A with the (3) impeller is worth considering. Operating point IV shows that the application rate would be down to 3.76 mm/h, pushing the stand time up to 6.6 hours. In practical terms, this is probably not very serious but the impact on power requirement, down from 3.7 to 2.6 kW, is dramatic. The capacity of the electric motor, or, more typically, the petrol or diesel engine, is of great importance in the context of the small-scale irrigation farmer.

Unfortunately, only too often, small-scale farmers acquire equipment from sales or gifts and have nowhere to go for the sort of technical guidance that Figure 6.5.6.1 gives. For example, they would not know that Pump B, very close to pump A in the catalogue, is not suitable for the application. At operating point VI, the application rate is high. On the extended lateral, however, it is on target. In both cases, the power requirements are excessive, however, and this could provoke a whole series of problems.

6.5.6.4 Conclusions

The designer who selects pump A with impeller (2) cannot be faulted: He has met the specifications exactly. However, if he checked sensitivities and actually plotted pump and lateral or pumping main characteristic H-Q curves, his pump selection could make a major difference to a small-scale farmer. For the small-farmer, designing for the lowest possible power requirement may be a major consideration. There could be other factors that can make all the difference to the viability of the scheme. What is needed is the willingness to identify needs, together with the ability to come up with non-standard but practical and theoretically sound proposals.

6.5.7 DESIGNING MODERATELY-SIZED SPRINKLER LAYOUTS

Sprinkler irrigation using portable sub-mains and laterals was, for a considerable period, regarded as being the most satisfactory system for irrigation schemes. This was later, to a large degree, superseded by dragline systems. Both are now, however, under something of a cloud because of their vulnerability to theft.

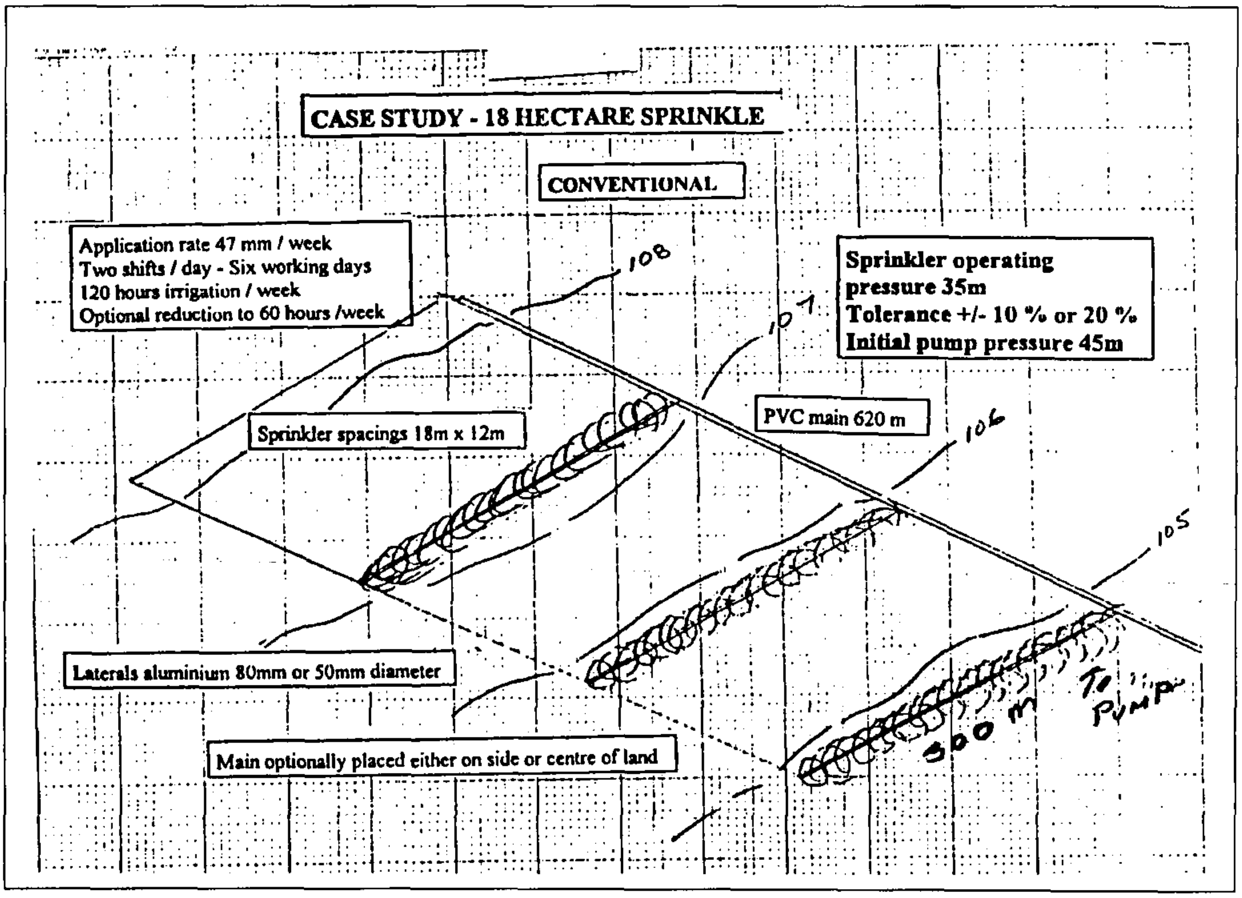
We have seen that sprinkler systems are now more tolerant of the circumstances under which irrigation takes place in the communal areas than was previously anticipated. This robustness is a plus factor but it is important that the initial designs and product selection be such that this property of sprinkler irrigation is fully exploited. In the future, with the rehabilitation of schemes and the introduction of new schemes, it will be important to ensure that the systems designed are appropriate to the particular circumstances under which the farmers will be operating, taking full account of cost and management requirements. Designers may therefore have to make greater input than is normally the case when designing relatively standardised systems for established commercial farmers.

6.5.8 THE CASE STUDY LAYOUT

In order to illustrate the important factors in developing a sprinkler irrigation design and to give some idea of sensitivities, a unit of 18 ha was selected as an example. A unit of this size is compact enough for integrated management but it includes the need for a fairly large power unit, pumping mains and several laterals. In Chapter 9, dealing with the redevelopment of existing schemes for occupation by small-scale irrigation farmers, this example will be used to illustrate how existing infrastructure can be incorporated into the revised design. In addition, an attempt was made to assess the degree to which some of the established norms for sprinkler design could and should be modified in the context of the small-farmer situation.

The layout of the land is shown in Figure 6.5.8. The land is 600 m long and 300 m wide. The highest point in the land is 3 m above the pump outlet. The required application rate is 47 mm per week with two shifts per day, six days a week, which amounts to 120 hours of irrigation per week. In order to evaluate the impact this has on the management and cost of the scheme, irrigating for sixty hours was included in the case study. Sprinkler operating pressure is 35 m and the initial pump pressure is 45 m, which allows for pressure losses in the main. In the first instance, the main runs up the side of the field and the laterals are 300 m long. As a second phase of the evaluation, the main was run up the centre of the land, shortening the laterals, which is of course the more economic approach to design and the one normally adopted.

Figure 6.5.8: Case Study – 18-hectare sprinkle



6.5.8.1 Pressure regulation and piping design

Piping design needs to take account of pressure variation, topography, pressure control methods and friction losses.

One of the major issues in sprinkler irrigation design is tolerance to pressure variation. In conventional design, this entails limiting to 20% the pressure difference between the sprinkler with the highest pressure and the one with the lowest pressure. For example, the pressure at the first sprinkler is set at 35 m plus 10% (38,5 m) and the last at 35 m minus 10% (31.5 m); ie, the pressure tolerance is ±10%. This ensures that the discharge difference of the sprinklers less than 10%.

Topography also obviously plays a major role in design for pressure normalisation. The moment the slope becomes excessive, it is necessary to provide some pressure control on the laterals. This can be a simple valve at each off-take, which can be manually set, provided a pressure gauge is available. Setting it is not a complicated procedure but, even on commercial farms, is seldom accurately undertaken and, in the case of small farmers could be a major difficulty, particularly as the chances of pressure gauges' being stolen, damaged or lost are very high. There are various types of pressure control or flow control valves or mechanisms that can be used to control the pressure automatically but these are relatively expensive and, of course, are vulnerable to damage. Under normal circumstances in the small-farmer applications, they would be avoided.

The main reason for an unacceptable pressure loss in the system under relatively flat conditions is friction in the main lines. The layout design is extremely important in developing an economic solution to the problem. However, one must distinguish between the variation in friction losses due to the drop along the laterals, and the losses in the main line and, possibly, sub-main lines that supply the laterals. In the case study, the friction losses in the 80 mm diameter pipes used for the 300 m laterals were low and could be discounted. However, pipes of 50 mm diameter are frequently preferred because they are lighter to move. The problem is that, with this length of lateral, there would be excessive pressure loss. The solution is to make the laterals shorter by running the main up the centre of the land.

6.5.8.2 *Balancing capital and energy costs*

In assessing the costs of the systems, it is necessary to distinguish between capital cost and energy or running costs. In order to make this distinction, the energy costs over fifteen years are capitalised and added to the initial cost of the equipment. These calculations are limited to piping costs and energy costs and do not include the cost of the pumps, pump-house and engines or motors. These costs should be calculated with caution as prices vary and the rate used to capitalise running costs can distort the position. However, the figures are included here to provide an indication of the factors that influence the relationship between capital and operational costs. They were calculated with the help of the WICARDI computer program. This program is extensively applied in South Africa for irrigation system design and includes an evaluation module that is less well known. It was this module that was used to develop the 'optimised' pipe designs and cost figures. It is a valuable tool that will facilitate the evaluation of irrigation schemes under consideration for redevelopment.

Four examples of the relative costs are given in Figures 6.5.8.3a to d. It will be noticed that, in the first example, Figure 6.5.8.3a, the capital cost is R64 626, ie, twice the energy costs of R31 860, giving a total cost of R96 486.

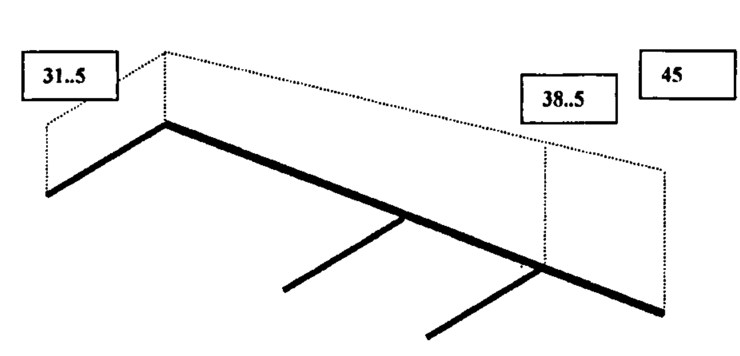
The introduction of pressure control, either manual or automatic, can make a dramatic difference to costs and this is shown in the third example, Figure 6.5.8.3c, where the total cost is reduced to R74 658. This is because the pressure control makes it possible to increase the pump pressure and reduce pipe sizes, thus reducing the capital investment, while the energy cost element only has a modest increase.

6.5.8.3 *The impact of relaxing the pressure variation tolerance*

While there is very good reason for stipulating a conventional ±10% range for pressure, one should also consider the position if one were to increase this tolerance to an unconventional ±20%. As we have seen, the uniformity of distribution along laterals will be satisfactory. The difference will be in the discharge variation between the lower lateral position and the upper lateral position. As will be shown later, provided the sprinkler is of a type that is not excessively sensitive to pressure differences, the differences in actual application between laterals are not excessive. There may be rather more water being applied at the lower lateral positions than at the upper ones but, in the light of the inevitable variations that are brought about by management, which have already been discussed, it is unlikely that these variations in water application can be disqualifying. For this reason, both where there is pressure control and where there is none, this unconventional tolerance of ±20% was assessed in terms of relative costs. Figure 6.5.8.3b shows that the increase to a ±20% range of pressure tolerance allows a greater head loss in the main so that pipe sizes can be reduced and capital investment in piping can therefore also be reduced. The fourth example, Figure 6.5.8.3d, shows that the increased range of pressure tolerance, combined with an increase in pump pressure, allows a reduction in lateral diameter from 80 mm to 50 mm, further reducing capital investment in piping.

Figure 6.5.8.3a: Pressure control variations and tolerances

NO PRESSURE CONTROL – CONVENTIONAL 10% TOLERANCE

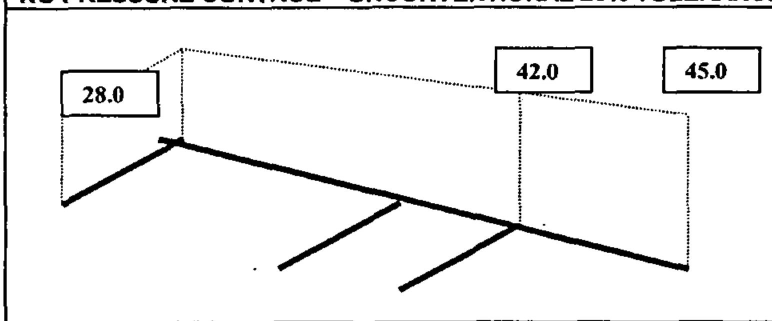


The design conforms to good practice, including the limitation of pressure variation to 20% [10%] between the sprinkler nearest the pump station and the one at the end of the lateral. This is a flat field but there is a height difference of 3 metres. No attempt is made to control pressure by valves or devices. The pressure at the first sprinkler is set at 35 m plus 10% (38,5 m) and the last at 35 minus 10% (31,5 m). Head loss is determined by pipe sizes, both main and laterals.

Pump pressure	Piping cost	Energy costs	Total costs	
45 m	R 64 626	R 31 860	R 96 486	

Figure 6.5.8.3b: Pressure control variations and tolerances

NO PRESSURE CONTROL – UNCONVENTIONAL 20% TOLERANCE

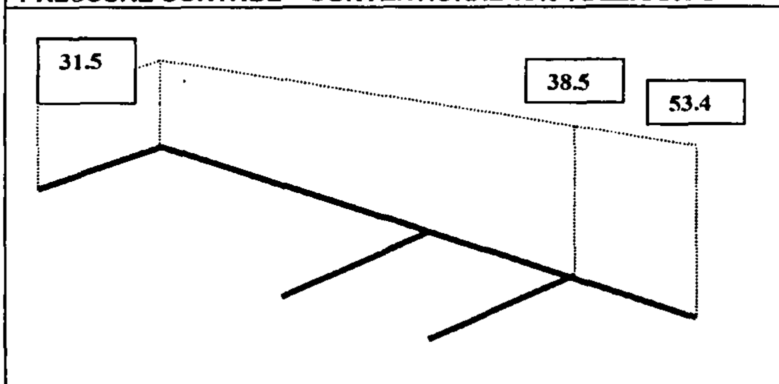


Would it make any difference if the pressure tolerance were increased to 20% plus and minus, when the pressure limits would then be 42 m and 28 m? The effect of this is to allow a greater head loss in the main so that pipe sizes can be reduced. Pump pressure remains unchanged and, with it, energy sue, but the capital investment in piping can be reduced from R64 626 to R42 325, a massive saving of R22 301.

Pump pressure	Piping cost	Energy costs	Total costs
45 m	R 42 325	R 31 860	R 74 185

Figure 6.5.8.3c: Pressure control variations and tolerances

PRESSURE CONTROL – CONVENTIONAL 10% TOLERANCE

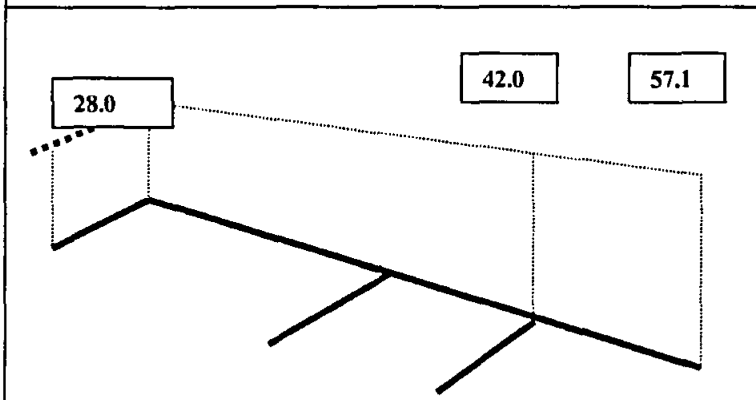


Here, the pressure limits of 38,5 and 31,5 m have been observed but pressure control has been introduced. Pump pressure can be increased, in this case to 53,4 m, but the pressure at the first sprinkler is controlled at 38,5 m by the hydrant valve. The increased head makes it possible to reduce pipe sizes but energy costs rise due to increased pump pressure. The total cost is much the same as in the previous example, but capital investment is lower and pressure tolerances conform to usual norms.

Pump pressure	Piping cost	Energy costs	Total costs
53,4 m	R 36 828	R 37 830	R 74 658

Figure 6.5.8.3d: Pressure control variations and tolerances

PRESSURE CONTROL – UNCONVENTIONAL 20% TOLERANCE



Pressure control makes it possible to increase pump pressure to allow a reduction in lateral diameter from 80 mm to 28 mm. This, combined with the acceptance of pressures ranging from 42 m to 28 m, makes possible a further major reduction in pipe costs. While the estimated 15-year total cost is only R2 000 down on the previous examples due to higher pressures and consequent higher energy costs, piping at R31 749 is less than half that of the original proposal and R5 000 lower than the next closest proposal.

Pump pressure	Piping cost	Energy costs	Total costs
57,1 m	R 31 749	R 40 450	R 72 199

It is interesting to note that, in the last three examples, Figures 6.5.8.3b to d, there is no significant difference in total costs. In other words, under the particular circumstances applicable here, virtually the same effect can be obtained by increasing the pressure tolerance or pressure drop along the main line, as would be obtained by using pressure control. If pressure control is used, there might be little point in increasing the tolerance from ±10% to ±20%.

6.5.8.4 The factors that influence the composition of the pumping main

Table 6.5.8.4a is based on the case study and illustrates four typical situations that influence the diameter and composition of the pumping main and, consequently, costs. The ±10% pressure tolerance applies across the board and, in the first case, there is no pressure control, the pumping main is routed along the edge of the land and the 80 mm diameter laterals are 300 m in length. In the second case, there is pressure control but the situation is otherwise the same. There is a significant drop in the capital cost and it is evident from the pipe sizes why this should be so. In the first case, the bulk of the pipes are either 200 mm or 250 mm in diameter. With pressure control, the pipes can be between 110 mm and 140 mm, a very considerable saving.

Columns 3 and 4 are similar to Columns 1 and 2 but have the pumping main running up the centre of the field with 150 m long, 80 mm diameter laterals. However, the third column, without pressure control, compares very favourably with the second column, which had pressure control. The pressure control introduced in the fourth column really brought very little significant improvement because of the negligible friction losses in the laterals. It is important to appreciate that layout can sometimes compensate for pressure control in this way, especially in small-farmer schemes where capital cost and maintenance factors are of major importance.

Table 6.5.8.4b illustrates that, with 80 mm laterals in use, there is little point in compromising the pressure tolerance. However, the matter is entirely different with 50 mm laterals. In this case, the overall cost has risen to nearly R96 000 but, if one accepts the ±20% pressure tolerance or installs pressure control, this is brought back down to R73 000.

There is probably no cost advantage in using the 50 mm diameter laterals but they are lighter and easier to handle and, particularly if the farmers are women, the smaller diameter is an advantage.

Table 6.5.8.4a: Influence of the position of the main on dimensions of piping and total operating costs

	1. NO PRESSURE CONTROL		2. PRESSURE CONTROL		3. NO PRESSURE CONTROL		4. PRESSURE CONTROL	
LAYOUT	MAIN AT SIDE OF FIELD				CENTRE MAIN AND SHORT LATERALS			
TOTAL COSTS		R96 486		R74 658		R76 571		R74 592
RUNNING		R31 860		R37 830		R31 860		R35 880
CAPITAL		R64 626		R36 828		R44 711		R38 712
PIPING	Length	Diameter	Length	Diameter	Length	Diameter	Length	Diameter
		110 mm	200 m	110 mm	40 m	90 mm	182 m	90 mm
		125 mm	200 m	125 mm	141 m	110 mm	199 m	110 mm
	35 m	160 mm	218 m	140 mm	17 m	125 mm	20 m	125 mm
	367 m	200 mm			200 m	140 mm	358 m	140 mm
	218 m	250 mm			358 m	160 mm		
	620 m		618 m		756 m		759 m	
Laterals	876 m	80 mm	882 m	80 mm	861 m	80 mm	861 m	80 mm
Sprinklers		75		75		75		75
Average pressure		35 m		35 m		35 m		35 m
Pressure difference		±10%		±10%		±10%		±10%

Table 6.5.8.4b: Comparative total operating costs of central mains without pressure control and 10% and 20% pressure tolerance

COSTS	.PRESSURE ±10% LATERAL 80 mm		PRESSURE ±20% LATERAL 80 mm		PRESSURE ±10% LATERAL 50 mm		PRESSURE ±20% LATERAL 50 mm	
TOTAL		R76 571		R72 258		R95 963		R72 780
RUNNING		R31 860		R31 860		R31 860		R31 860
CAPITAL		R44 711		R40 398		R64 103		R40 920
Piping	Diameter	Length	Diameter	Length	Diameter	Length	Diameter	Length
	90 mm	40 m	90 mm	181 m	90 mm		90 mm	181 m
	110 mm	141 m	110 mm	17 m	110 mm		110 mm	
	125 mm	17 m	125 mm	200 m	125 mm		125 mm	17 m
	140 mm	200 m	140 mm	277 m	140 mm	181 m	140 mm	73 m
	160 mm	358m	160 mm	81 m	160 mm	17 m	160 mm	485 m
	200 mm				200 mm	296 m		
	250 mm				250 mm	262 m		
		756m		756m		756 m		756 m
Sprinklers		75		75		75		75
Average pressure		35 m		35 m		35 m		35 m

6.5.8.5 The impact of operating hours

Table 6.5.8.5 illustrates the situation if it is necessary to halve the operating time to 60 hours per week. If the same amount of water is going to be applied in the cycle, it is necessary to double the number of sprinklers from 75 to 150 and to double the number of laterals. The cost has now increased to over R106 000. The reason for this is obvious when looking at the main line pipe sizes, where they are all above 115 mm in diameter. This can be reduced by relaxing the pressure difference tolerance but the costs are still high.

There is no simple solution to this problem of curtailing the pumping hours. One of the major problems that have arisen on existing schemes is that they were designed for the longer pumping hours. For various reasons, including crime and theft and generally unpleasant working conditions, this has had to be cut back to a shorter period, and the crops are simply not getting sufficient water. This is a major factor that has to be taken into consideration in the rehabilitation of existing schemes.

Table 6.5.8.5: Influence of halving pumping hours on pumping main design. (Central main, 80 mm diameter laterals, no pressure control)

PUMPING HOURS	**Full pumping hours 120 hours**		**Half pumping hours 60 hours**		**Half pumping hours 60 hours**	
Pressure tolerance	**±10%**		**±10%**		**±20%**	
TOTAL COSTS		R76 561		R106 089		R93 781
RUNNING		R31 860		R 37 940		R37 940
CAPITAL		R44 711		R 68 149		R55 841
PIPING	Diameter	Length	Diameter	Length	Diameter	Length
	90 mm	40 m				
	110 mm	141 m				
	125 mm	17 m			125 mm	182 m
	140 mm	200 m	140 mm	181 m		
	160 mm	258 m	160 mm	17 m	160 mm	216 m
	200 mm		200 mm	327 m	200 mm	359 m
	250 mm		250 mm	231 m		
Sprinklers		75		150		150
Lateral		882 m		1 752 m		1 752 m

6.5.8.6 *Electric vs diesel power*

The balance between capital investment and operating costs is particularly important when alternative power sources have to be considered or where incentive schemes such as RURAFLEX electricity tariffs distort the normal pattern. The rule of thumb methods of balancing costs are a good guide for any standardised situation. The initial assumption is that, for electric power and 'normal' tariff structures, a 1% friction head in pumping mains should be aimed at to ensure a good balance between capital and operating costs.

The use of diesel power has a significant influence, in that investment in larger pipes is warranted in order to reduce operating heads and energy costs. Using WICARDI, analyses were developed similar to the ones undertaken in previous sections, indicating the impact of using diesel instead of electric power.

Unfortunately, the WICARDI results do not give a complete optimisation and do not tell the whole story. The curtailment of irrigation hours on small-scale farmer irrigation schemes can also have a significant impact on the selection of pumping mains.

There is also an empirical equation published in the *Irrigation design manual* that was developed to enable pipe sizes to be adapted to the use of diesel as an alternative fuel. It was based on many years of records and is valid as a broad estimate for conventional situations.

In the case of small-scale irrigation, it is vital to achieve a realistic balance. Usually the situation will be anything but 'standard' and a more searching analysis is advisable. There are methods that are not generally in current use and deserve further development. One is in the form of a computer program (PUKA) developed by Eckard (1980) and the other is an algorithm developed by Reynders (1985).

6.6 UPTAKE OF TECHNOLOGY

This section is derived from Cornish (1997), who in turn drew much of his information from Keller (1990). It is a valuable reference to ranking technology options and indicates where we should be broadening our technology for small-scale irrigation.

6.6.1 THE INFLUENCE OF TECHNICAL FACTORS

In a review of modern irrigation technologies in developing countries, Keller (1990) suggests a number of technical factors relating to operation and maintenance, which determine whether a smallholder will take up a system successfully.

These factors are:

- divisibility,
- maintenance,
- risk,
- operational skill, and
- durability.

For each factor, several categories are identified and 'scored'. The scores allocated to each of the categories are indicated in the text – higher values reflect greater suitability for smallholders. Some element of weighting is built in against technologies that are non-divisible by allocating a score of zero rather than one to the Divisibility category. Scores for each factor are summed and the technologies ranked according to the total score (see Table 6.6.1).

The assignment of categories to technologies is based on subjective assessment and the resulting ranking should be used only as an approximate guide to the relative suitability of different technologies for smallholders. The ranking also does not take account of the operating or capital cost of equipment, but indicative values of capital cost per hectare are given in Table 6.6.1, based on large-scale installations in the United States.

Systems that are technically more appropriate for use by smallholders therefore include:

- piped distribution systems for surface irrigation,
- low technology sprinklers,
- pressurised bubbler, and
- dragline sprinklers.

These are relatively low-technology systems, easily adapted to small plots, easily maintained and requiring limited skills of the operator. With the exception of bubbler systems, they have low capital costs, which must be traded-off against the higher labour requirements to move equipment manually around the irrigated area.

The much higher capital cost of a pressurised bubbler system reflects the fact that this is a permanent-set system. However, bubbler systems for orchard crops are the only form of micro-irrigation technology that ranks highly on the basis of technical suitability. Of the other forms of micro-irrigation, mini-sprinklers or sprayers rank higher than drip and line source systems. This is because mini-sprinklers or sprayers have less risk of widespread system failure as a consequence of a key component's failing, and the equipment is less prone to damage through poor operating practice.

Large irrigation machines such as centre pivots, linear-move laterals and continuous-move rain-guns are at the bottom of the list. Their mechanical complexity and non-divisibility for small land holdings are normally regarded as making them unsuitable as a method of irrigation for smallholders.

Table 6.6.1: Keller's factors and categories

FACTOR	CATEGORIES	SCORE	
Divisibility The suitability of the technology for use on small and irregularly shaped land on plots of 0.2 to 5 ha.	Well-suited for use on any area and shape of plot. Implies that supply, distribution and field application equipment can be operated by an individual farmer:	Total	3
	Only applied with difficulty and/or high expenditure to small plots. Normally implies some group co-operation to control water supply or distribution between users:	Partial	2
	Technologies only suited for use on large and regular-shaped plots:	None	0
Maintenance Indicates the Complexity of the maintenance task and possible requirement for specialist Technicians to carry out maintenance.	Only basic skills, easily acquired by a 'traditional farmer', required to maintain the equipment:	Basic	4
	Can be maintained by the farmer, but requires skills associated with more entrepreneurial farmers growing high-value crops:	Grower	3
	Some specialist skills or equipment required:	Shop	2
	Specialist technicians with workshop facilities and equipment are needed for maintenance:	Agency	1
Risk Indicates the risk of serious yield reduction or crop loss as a consequence of equipment failure.	Risk of component failure is slight and problems can be easily rectified. Soil moisture storage normally provides an adequate buffer against a brief shutdown:	Low	3
	Failure of a component would only jeopardise the supply to a single outlet:	Medium	2
	Failure of a single component can result in complete shutdown of the system. (Applies to drip systems requiring micro-filtration and all continuous move systems):	High	1
Operational Skill Indicates the level of training and under-standing required of the operator to achieve good water application efficiencies and avoid damage to the equipment.	Few skills are required, easily acquired during a single season's operation:	Simple	3
	Considerable skill and care are required to operate the equipment effectively without damage:	Medium	2
	Needs good understanding of the system design and operating principles and/or extended field experience to achieve good application efficiency:	Master	1
	The user must acquire complex technical skills to operate and service the equipment:	Complex	1
Durability Indicates the likelihood of equipment breakdown during normal operation and susceptibility to damage as a result of improper handling or operation.	Systems with few or no moving parts, other than in the pump. Unlikely to breakdown:	Robust	4
	Systems not likely to suffer breakdown or damage through improper handling, but nonetheless requiring a minimum of spares for immediate repairs and periodic servicing:	Durable	3
	Systems that require careful operation and extensive workshop and spares backup to remain operational:	Vulnerable	2
	Systems highly prone to breakdown if subjected to inadequate maintenance or incorrect operation:	Fragile	1

6.6.1.1 Ranking

Tables 6.6.1.1a and b show the results of applying the scoring system for the factors and categories shown in Table 6.6.1.

Table 6.6.1.1a: Factors influencing the appropriateness of different irrigation systems

System Type	Divisibility	Maintenance	Risk	Operational Skill	Durability
SPRINKLER **Periodic move**					
Hand move	Total (3)	Shop (2)	Medium (2)	Medium (2)	Durable (3)
Drag hose	Total (3)	Basic (4)	Medium (2)	Simple (3)	Durable (3)
Low-tech sprinkler	Total (3)	Basic (4)	Low (3)	Simple (3)	Durable (3)
Perforated pipe	Total (3)	Shop (2)	High (1)	Simple (3)	Vulnerable (2)
End-tow	Partial (2)	Shop (2)	Medium (2)	Medium (2)	Durable (3)
Side-roll	None (0)	Shop (2)	High (1)	Medium (2)	Vulnerable (2)
Side move	None (0)	Agency (1)	High (1)	Complex (1)	Fragile (1)
Static gun	Partial (2)	Shop (2)	Medium (2)	Master (1)	Durable (3)
Boom sprinkler	None (0)	Shop (2)	High (1)	Master (1)	Vulnerable (2)
Solid set					
Portable	Total (3)	Shop (2)	Medium (2)	Simple (3)	Durable (3)
Permanent	Total (3)	Grower (3)	Medium (2)	Simple (3)	Durable (3)
Travelling gun	Partial (2)	Agency (1)	High (1)	Master (1)	Vulnerable (2)
Centre pivot	None (0)	Agency (1)	High (1)	Complex (1)	Vulnerable (2)
Linear move	None (0)	Agency (1)	High (1)	Complex (1)	Vulnerable (2)
MICRO-IRRIGATION					
Drip emitters	Total (3)	Grower (3)	High (1)	Complex (1)	Fragile (1)
Line source					
Re-usable	Total (3)	Grower (3)	High (1)	Complex (1)	Fragile (1)
Disposable	Total (3)	Grower (3)	High (1)	Complex (1)	Fragile (1)
Sprayers	Total (3)	Grower (3)	Medium (2)	Complex (1)	Durable (3)
Bubbler					
Pressurised	Total (3)	Grower (3)	Low (3)	Simple (3)	Robust (4)
Low pressure	Total (3)	Grower (3)	Low (3)	Master (1)	Vulnerable (2)
PIPED CONVEYANCE					
Piped distribution	Total (3)	Grower (3)	Low (3)	Simple (3)	Robust (4)

(After Keller and Bliesner, 1990)

Table 6.6.1.1b: Ranking of system types reflecting suitability for smallholders

System Type	Score	Crop Types	Initial Cost $US/ha
Piped distribution	16	All types	800
Low-tech gravity-fed sprinkler	16	All types	N/a
Pressurised bubbler	16	Orchard	3 000
Drag hose, sprinkler	15	All types	675
Permanent solid set sprinkler	14	Orchard, soft fruit	3 500
Portable solid set sprinkler	13	All types	3 250
Hand-move sprinkler laterals	12	All types	675
Micro-irrigation sprayers	12	Orchard, soft fruit and vegetables	3 500
Low-pressure bubbler	12	Orchard	3 000
Sprinkler, perforated pipe	11	Soft fruit and vegetables	800
Sprinkler, end-tow lateral	11	Cereal and row crops	950
Sprinkler, static rain gun	10	Cereal and row crops	N/a
Drip emitters	9	Wide row fruit/vegetables, orchard	3 500
Line source reusable	9	Wide row fruit/vegetables	5 000
Line source disposable	9	Wide row fruit/vegetables	3 000
Sprinkler, side-roll	7	Short cereals and row crops	1 100
Travelling rain gun	7	Cereal and row crops	1 200
Boom sprinkler	6	Cereal and row crops	N/a
Centre pivot	5	Cereal and row crops	1 500
Linear move	5	Cereal and row crops	1 300
Sprinkler, side-move	4	Cereal and row crops	1 350

Notes:
1. After Keller (1990). Costs are based on US experience and include mainlines and pumping plant with systems installed in large fields.
2. Maximum score = 17
3. Minimum score = 4

6.7 CONCLUSIONS AND RECOMMENDATIONS

There was a general swing to pressurised irrigation systems on small-scale farmer irrigation schemes in the 1980s, due to the problems experienced with flood irrigation at that time. The systems installed were conventional sprinkler systems with portable laterals, although there were exceptions, including a limited number of centre pivot installations. In later years, dragline systems became popular.

On the negative side, there have been problems, including over-regimentation of management, poor maintenance, vandalism and theft, the inherent difficulties associated with operating pumping installations in the deep rural areas, and malpractice in the field. There is a positive side, however, in that at least reasonable water distribution is achieved, and there is no reason to believe that present problems are insurmountable in the longer term.

Analysis has shown that sprinkler irrigation can be surprisingly tolerant, but that design for the specific circumstances encountered in small-scale farmer irrigation requires refinement and the need to apply basic principles. In time, a new set of 'standards' may emerge but designers need to be made aware of how to approach the present situation.

The importance of sprinkler distribution characteristics has come to the fore. This is far more involved than simply achieving a satisfactory Cu. Little attention has been given in the past to analysing the operation of sprinklers in isolation (dragline), along a lateral (conventional hand move), and when a segment of a field is irrigated at one time (permanent set). The impact on application rates and losses can be significant and, while analytical approaches are useful, more field testing is required.

Greater flexibility will be possible if the areas irrigated can be broken down into smaller management units.

The possibilities of pumping units based on tractors or the new generation of small Asian diesel engines should also be considered.

The filling of soil profiles prior to planting, using single non-overlapping laterals and the application of skip-a-position lateral spacing, depends on the selection of sprinklers with a flat, rectangular distribution characteristic. The development of a new generation of relatively low-cost, plastic sprinklers is a plus factor, while the full potential of the floppy sprinkler has not been fully exploited.

There is room for both micro and drip irrigation in specific circumstances.

Chapter 7

SHORT-FURROW IRRIGATION

See also ***Irrigation Design Manual*** (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

7.1 INTRODUCTION 7-1

7.1.1 Keeping track of irrigation applications 7-1

7.1.2 Variables in flood irrigation 7-1

7.1.3 Small-basin and short-furrow irrigation 7-2

7.2 SHORT-FURROW IRRIGATION IN PRACTICE 7-2

7.3 LAYING OUT SHORT-FURROW SCHEMES 7-4

7.3.1 On-farm layout 7-4

7.3.2 Farm shape and orientation 7-5

7.3.3 Layout of schemes 7-10

7.3.4 Guidelines for the design of infrastructure 7-14

7.4 LOSSES IN SUPPLY FURROWS 7-19

7.4.1 Introduction 7-19

7.4.2 Determining infiltration losses in supply furrows 7-19

7.4.3 Results of the experiments 7-21

7.4.4 Simulations of supply furrow losses 7-21

7.4.5 Estimating the experimental infiltration values 7-24

7.4.6 Dealing with supply furrow losses in practice 7-25

7.4.7 Tshiombo: A Case Study 7-26

7.4.8 Dingleydale and New Forest: A Case Study 7-27

7.5 DISTRIBUTION UNIFORMITY IN SHORT FURROWS 7-30

7.5.1 Factors that influence efficiency 7-30

7.6 RECOMMENDATIONS FOR DESIGN 7-31

7.6.1 Flow rate in supply furrows 7-31

7.6.2 Supply furrow length and layout 7-31

7.6.3 Supply furrow gradient 7-31

7.6.4 Recommended furrow width 7-31

7.6.5 Erosion prevention 7-31

7.6.6 Recommended design norms ... 7-32
7.7 CONCLUSIONS AND RECOMMENDATIONS ... 7-32

APPENDIX 7.A. DETERMINATION OF THE INFILTRATION CHARACTERISTICS OF THE SOIL ... 7-33

FIGURES AND TABLES

Figure 7.2: Layout of a short furrow scheme in South Africa ... 7-3
Figure 7.3: Typical layout of a short-furrow scheme in South Africa ... 7-4
Figure 7.3.1: Layout of a farm with basin irrigation ... 7-5
Figure 7.3.2: Layout of plots in a scheme area ... 7-6
Figure 7.3.2.1a: Plot layout with one-sided irrigation ... 7-7
Figure 7.3.2.1b: A group feeder split into two branches ... 7-8
Figure 7.3.2.2: Plot layout with two-sided irrigation ... 7-9
Table 7.3.3.1: Comparison of one- and two-sided irrigation (technical points) ... 7-10
Figure 7.3.3.1a: Layout in blocks ... 7-10
Figure 7.3.3.1b: Incorrect layout of a larger scheme – no blocks ... 7-11
Figure 7.3.3.1c: Correct layout of a larger scheme – blocks ... 7-11
Figure 7.3.3.1d: Less suitable layout of larger schemes – No real blocks ... 7-12
Figure 7.3.3.2: Comparison of different layouts ... 7-13
Figure 7.4.4a: Time taken to irrigate an experimental plot with eleven sets of short furrows ... 7-22
Figure 7.4.4b: Layout of experimental plot ... 7-22
Figure 7.4.4.1: Irrigation time – Comparison of experimental data with SIRMOD computer simulation ... 7-23
Table 7.4.5.1a: Example of FURROW printout for 10 m^3/h stream flow. ... 7-24
Table 7.4.5.1b: Example of FURROW prints out with 20 m^3/h stream flow ... 7-25
Table 7.4.7.3: Summary of simulated results ... 7-26
Figure 7.4.8: Typical layout of short furrow system in South Africa ... 7-27
Table 7.4.8.1: Summary of test data ... 7-28
Graph 7.4.8.1a: Infiltration Curves ... 7-29
Graph 7.4.8.1b: Measured and Simulated Advance front ... 7-29
Table 7.5.1.3: Possible Gross Applications (GA) mm at high Distribution Uniformity (DU) ... 7-30
Table 7.6.6: Short-furrow lengths and maximum advance times ... 7-32
Figure 7.A.2: A typical data sheet ... 7-35

7.1 INTRODUCTION

In the past, the majority of small-farmer irrigation schemes were based on flood irrigation and, in Chapter 5, *Water Supply and Management*, some of the particular problems relating to flood irrigation were discussed. These generally revolve around the issue of the sustainability of water supply, the quality of water, the problems of siltation when water is tapped from rivers, canal management, and the limitations on the flow rate that farmers can handle and that can be made available to them. Thus, although flood irrigation can play an important part in the future, it is important to understand the strengths and weaknesses of flood irrigation in the context of small-farmer irrigation.

In this report the concentration is on one particular form of flood irrigation, short-furrow irrigation. This is not to say that other forms of flood irrigation cannot be utilised but their design is covered in detail in the *Irrigation Design Manual* and in Kruger (1998).

7.1.1 KEEPING TRACK OF IRRIGATION APPLICATIONS

When discussing irrigation systems under pressure, it was remarked that sprinkler irrigation is "transparent", in that the farmer is aware of how much water he has applied and where it has been applied, although he still tends to lack information on what precisely is going on under the soil surface. Drip irrigation, on the other hand, is relatively non-transparent, in that, while the farmer has a sound idea as to how much water he or she is applying, he does not know how that water is being distributed below the soil surface. It may be tunnelling straight down and not spreading as desired. This can be a major complicating factor in irrigation management.

Flood irrigation can be transparent to a satisfactory degree or completely non-transparent, depending on the methods adopted and the circumstances under which they are applied.

7.1.2 VARIABLES IN FLOOD IRRIGATION

There are a number of variables that influence design and management that have to be considered in the case of conventional irrigation systems:

- the slope of the land,
- the rate at which water infiltrates,
- the stream flow,
- the rate at which the water advances over the surface,
- the length of the land, and
- the frequency with which water is made available.

All these factors can have a major influence on the distribution of the water in the soil profile. Not only can it vary drastically from one site to another, it can also vary on the same site, not only from season to season, but also within the season. The result is that most methods of flood irrigation can only be efficient if the production process as a whole is well managed.

Far from being a crude, primitive system that can be applied by relatively untrained and inexperienced people, conventional field-scale flood irrigation requires great experience and skill. There are just too many 'degrees of freedom' for the uninitiated. This is true for all farmers and that is why, when they become aware of the need to irrigate efficiently, there is a natural tendency to prefer pressure systems. Pressure systems cannot always be used, however, because initial costs and energy costs, pumps, engines, pipelines, mechanical maintenance and associated factors have to be taken into consideration.

The saving grace in areas where flood irrigation has been applied for many years is that, with experience, farmers have learned how much they can irrigate, what area they can irrigate under specific circumstances, and generally how to match the area irrigated to the quantity and rate of water supply. Under good management, the system tends to become self-correcting.

For most flood irrigation systems, it is essential that the land be well prepared and cultivated every season to ensure uniform gradients and to eliminate hollows, furrows and ridges which can distort the flow of water. Unfortunately, ensuring uniform gradients is extremely difficult for small-scale farmers, who continually have the problem of lack of power for tillage purposes.

7.1.3 SMALL-BASIN AND SHORT-FURROW IRRIGATION

There are, however, two irrigation methods that are not nearly as sensitive to these factors as the more conventional flood irrigation methods and it is for this reason that they deserve particular attention. Small-basin and short-furrow irrigation have proved their suitability for small-scale irrigation schemes in Africa, the former in Kenya (where it has been well-documented in official publications), and the latter in South Africa.

Basin irrigation is dealt with comprehensively in Chapter 15 of the *Irrigation Designers Handbook* and only the aspects peculiar to small-scale irrigation farmers will be dealt with here. There is great similarity in principle and layout between the small-basin and the short-furrow methods. The short-furrow method has the advantage that the water advances rapidly, ensuring even distribution in sandy soils with a high infiltration rate, while larger flow rates are required by the small-basin method.

7.2 SHORT-FURROW IRRIGATION IN PRACTICE

Short-furrow irrigation is very similar to basin irrigation. The short furrows divide the basin into narrow sub-basins, about 1 m wide and 10 m long.

The farmer prepares the land by first ploughing then disking the soil, before ridges are made to form a strip of six to eight furrows up to 150 m long, about 1 m wide and 200 mm deep. These long strips are subdivided into sets of basins approximately 10 m long, by constructing **cross furrows** with a hoe at right angles across the strip. Each set of basins should be as level as possible so that the water infiltrates evenly into the soil, ensuring uniformity of irrigation application.

The top furrow is used as a supply furrow to carry water to each of the cross furrows. Water is diverted into the supply furrow from a **secondary canal** (group feeder) by placing an obstacle in this canal just downstream of the supply furrow inlet. The flow rate into the supply furrow is regulated by the size of the obstacle, which can be a large stone, a sandbag or a metal plate. It should not completely stop the flow of water otherwise farmers further along the secondary canal cannot irrigate at the same time. This is an obvious vulnerability: If several farmers irrigate at the same time, it is unlikely to be possible to achieve equitable distribution. The fact that the water is turned out of the group feeder directly into the supply furrow is normal practice in South Africa but cannot be condoned. The matter of how many plots or small farms should be supplied from a common source was discussed in Chapter 5, *Water Supply and Management*, where from ten to twenty seemed to be a reasonable range. The current method, which lacks an intermediate farm feeder canal supplying the supply furrows, can result in up to 150 plots' sharing a common source.

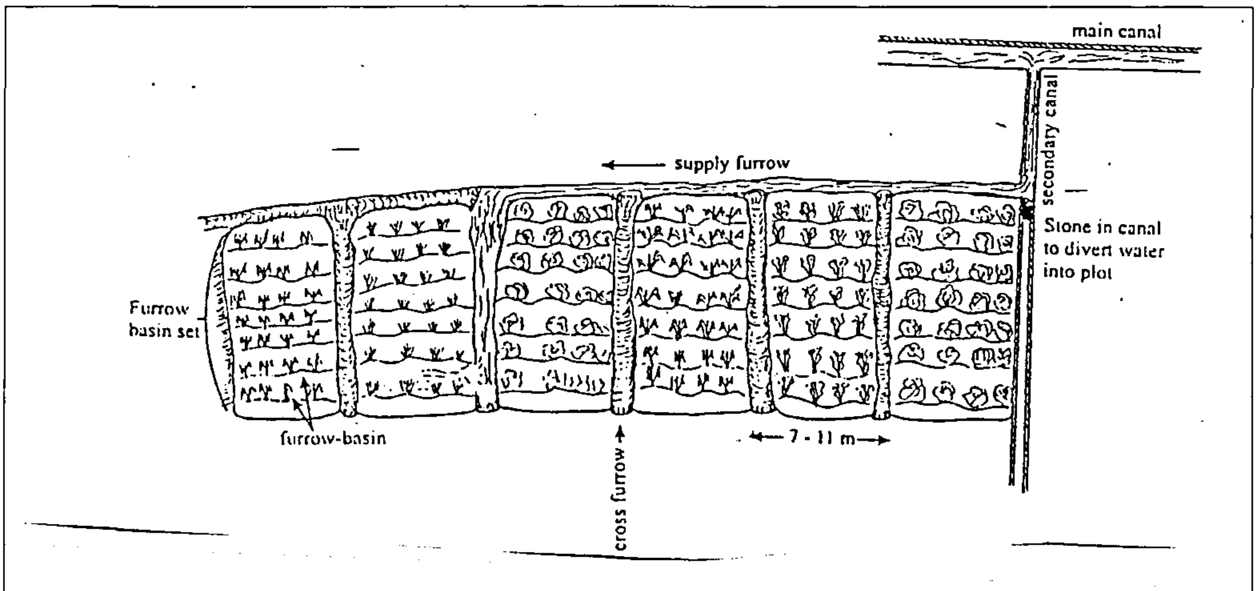
The secondary canal is fed from a main canal, which brings water to the top of the lands from a dam or river, sometimes quite far away. (Canals, unlike furrows, are lined to prevent water losses.) Thus, water is carried from the river to each short furrow via a main canal, a secondary canal, a supply furrow and a cross furrow. See Figure 7.2.

A common water supply management system would allocate water to each group of farms/plots on a scheme once a week so that each farmer would irrigate his or her crops weekly or fortnightly.

The farmer diverts water from the secondary canal into his supply furrow.

He walks along the ridge beside the water as it flows along the supply furrow and makes sure all cross furrows are closed and that the supply furrow is open, until the water reaches the last cross furrow. Here, he diverts the stream into the furthest set of short furrows and allows each short furrow to be filled in succession.

Figure 7.2: Layout of a short furrow scheme in South Africa



He can choose how much water to allow into a furrow before pushing a hoe-ful of earth into the top end of the furrow to block it, thus very effectively controlling the amount of water applied. Sometimes, particularly when the plants are still young, he blocks the furrow when the water has not quite reached the end of the furrow. At other times, particularly when the plants are bigger or need more water, he lets the water dam up from the ridge at the bottom end of the furrow to fill along its full length before he blocks it. Then he can start weeding the next short furrow while water runs into it.

Immediately after the irrigator has opened the last short furrow of a set, he diverts the water from the supply furrow into the set that is to be irrigated next. The water left over in the cut-off section of supply furrow is enough to fill that last short furrow of the set below. This avoids water wastage.

In this way, the farmer works his way back to the secondary canal, making the most efficient use of water all the way. It generally takes from one to three hours to irrigate one typical plot of 0,1 hectare (1 000 m^2).

7.2.1.1 Advantages

The main advantage of short-furrow irrigation is that there is very **uniform distribution** of water across the whole field, even where the gradient varies or when the flow rate is inconsistent; for example, when another farmer suddenly starts irrigating between the first farmer and the water source. These variations in gradient or flow rate would make other methods of flood irrigation difficult or even impossible. For the soil on which experiments were conducted, at an optimum gradient of 1:300, the uniformity of distribution was calculated to be 85%

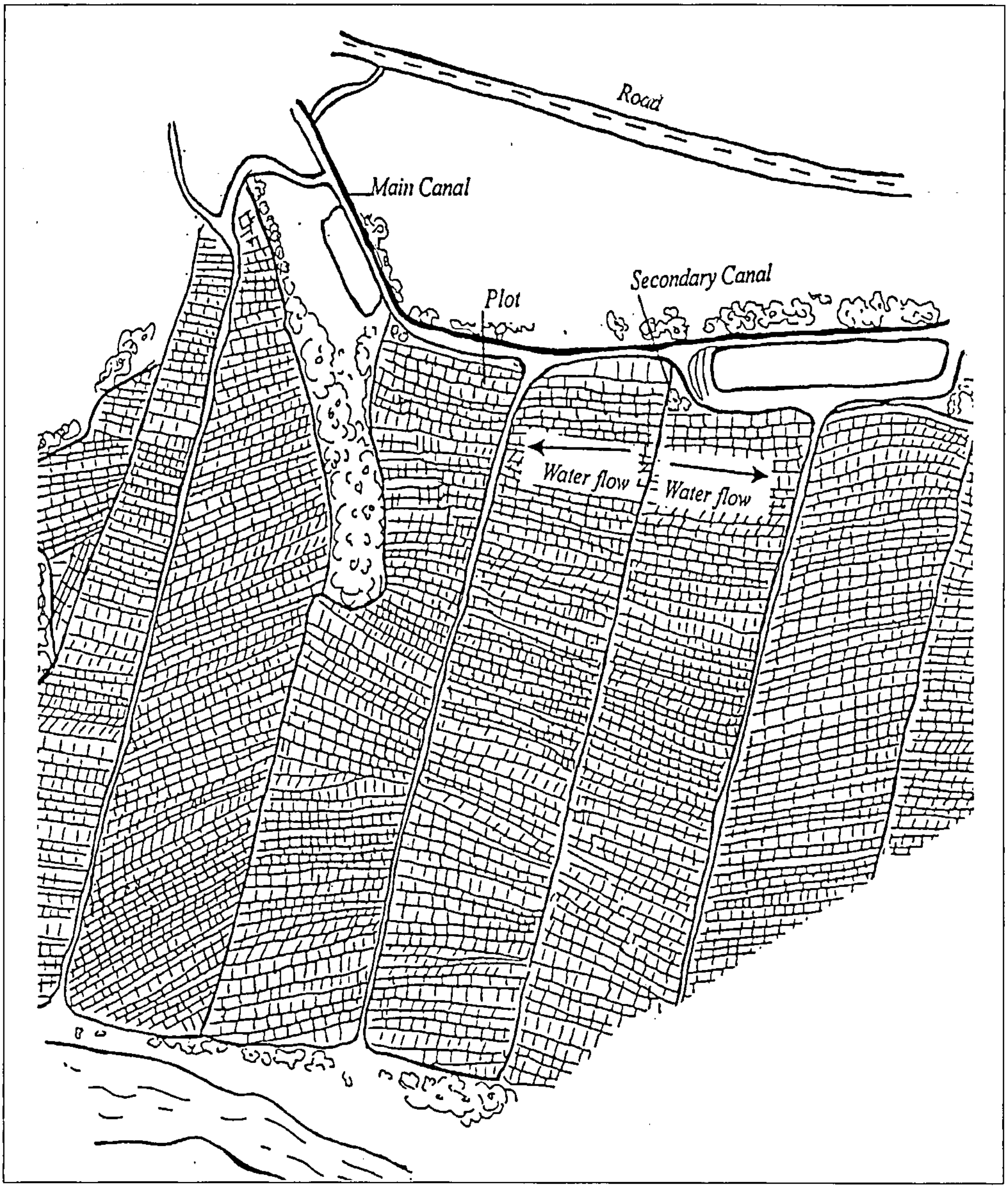
In laying out the plots, the desired **gradient** can be obtained just by changing the direction of the furrows. With other flood irrigation methods, great costs are often incurred in land levelling to obtain suitable and consistent gradients over large areas.

Another advantage is the high level of involvement of the irrigator because this method requires constant opening and closing of short furrows. How long it takes to irrigate one plot depends on how fast the water runs, that is, on the flow rate and on the amount of water the farmer chooses to apply. Each furrow fills quite quickly but the farmer has just enough time to weed and even control insects while each furrow fills. This **regular, close contact with his whole field** means that he can keep a good check on the condition of his crops.

7.3 LAYING OUT SHORT-FURROW SCHEMES

The layout of small-scale farmer flood irrigation schemes in South Africa tends to be stereotyped. Figure 7.3 illustrates a very common arrangement. However, the subject has received considerable attention in Kenya, and the publication *Manual for senior staff on gravity schemes with basin irrigation operated by farmers* (Republic of Kenya, 1990) is a valuable contribution. It stresses again that designing for small-scale farmers is professionally taxing. Several figures in this section are reproduced from this publication.

Figure 7.3: Typical layout of a short-furrow scheme in South Africa

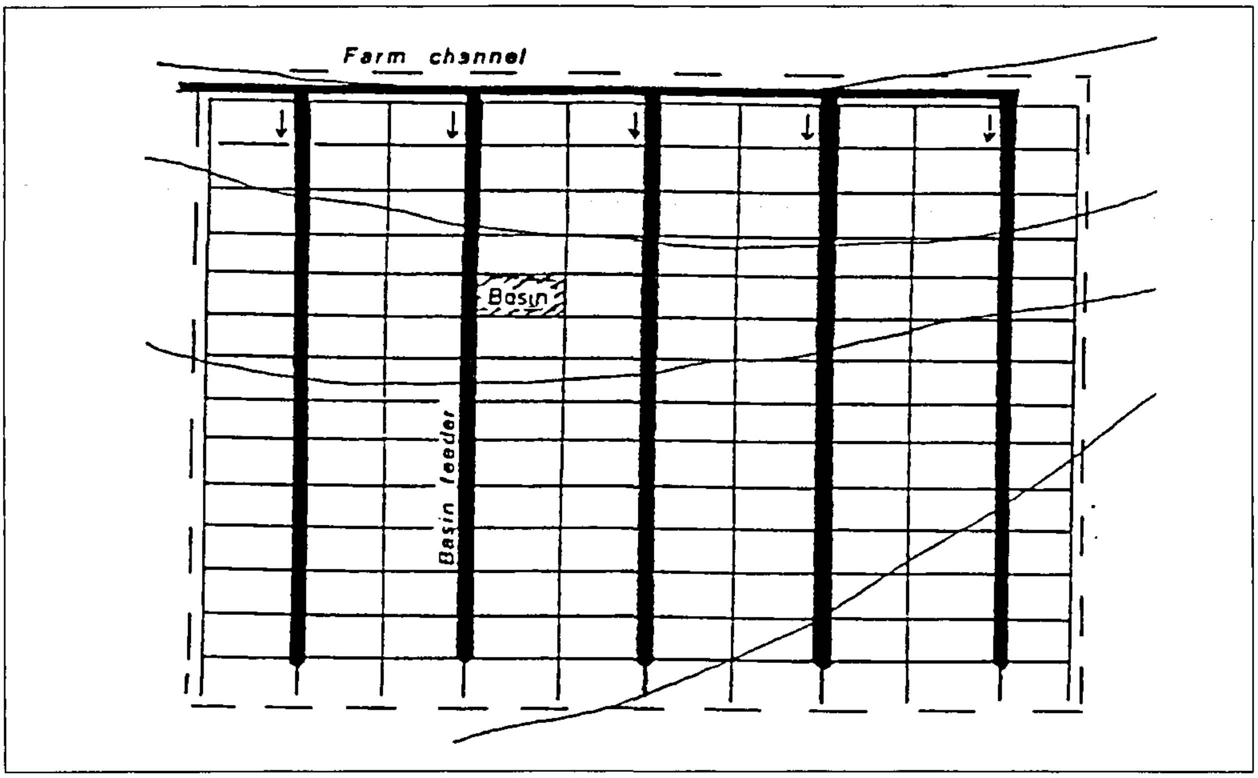


There is a great similarity between the South African short-furrow and basin systems commonly used in Kenya because the group of small furrows fed by a cross furrow forms a basin. In this section, the Kenyan system of naming canals and furrows is used, as it is more descriptive and flexible than the one currently applied to short-furrow systems.

7.3.1 ON-FARM LAYOUT

Figure 7.3.1 gives the best layout of an irrigation farm (or part of a farm).

Figure 7.3.1: Layout of a farm with basin irrigation

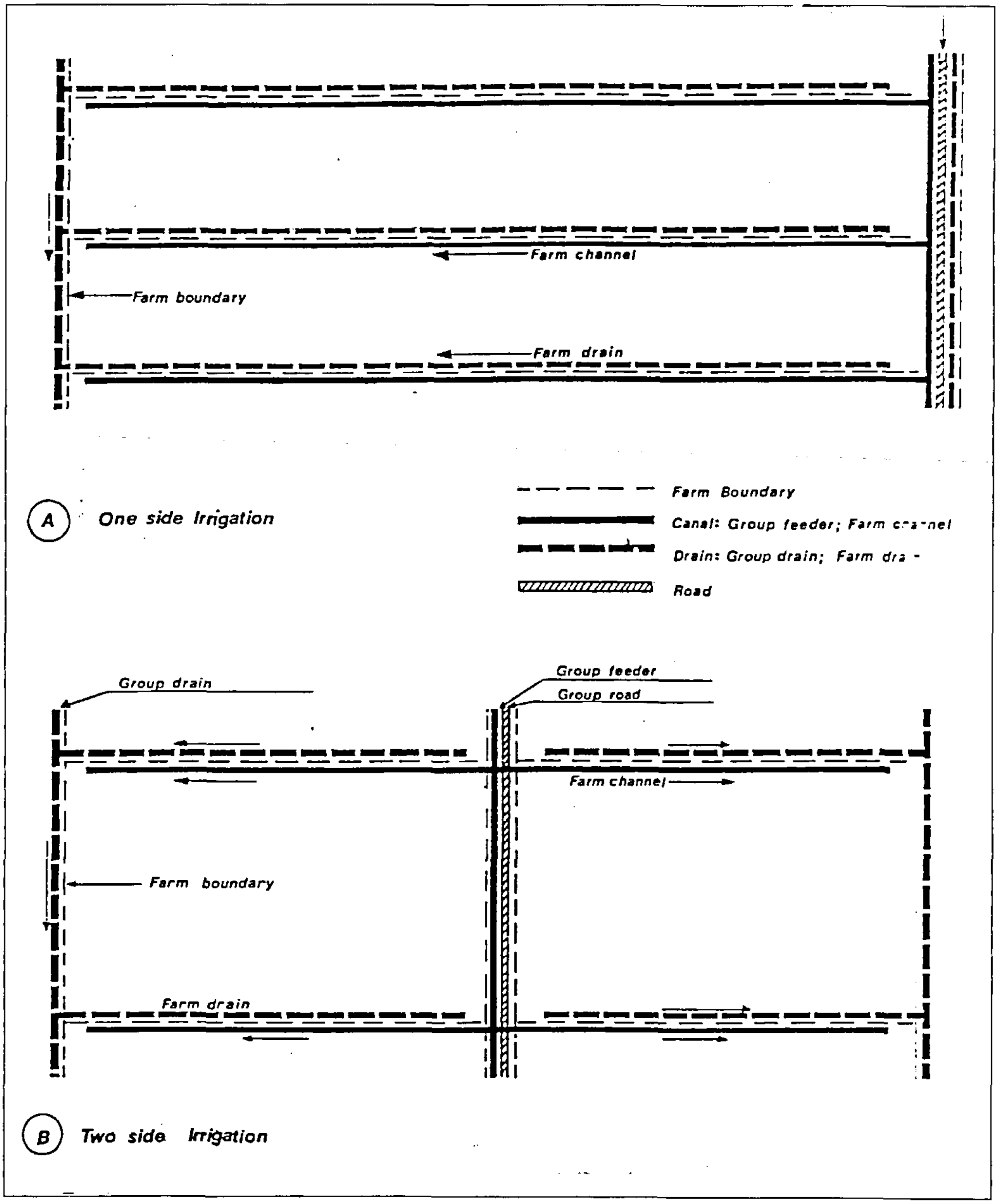


A farm channel runs along the contour lines at the head of the farm and the earth-lined basin feeders (supply furrows) run down the slope. They supply water to the short-furrow basins to both sides (two-sided supply), which means that the total length of the in-field channels is minimised (as is the land loss). However, it might be necessary to shift the general direction of the basin feeder in relation to the longitudinal slope required for flow in the main in-field channels and the maximum allowable longitudinal slope in the in-field channels, as determined by unit flow and erosive velocity.

7.3.2 FARM SHAPE AND ORIENTATION

Figure 7.3.2a shows two typical layouts of farms. In A, one-sided supply of irrigation water to farms is shown, while, in B, irrigation is two-sided. Notice that group feeders supply farms within a group with water, while the main feeder supplies different groups with water.

Figure 7.3.2: Layout of plots in a scheme area



Next, we consider the orientation of the farm. As a model, we assume a farm rectangular in shape, with two equal long sides and two equal short sides:

- One long side along the main feeder and one short side along the group feeder, as shown in Figure 7.3.2 (A and B).
- One short side along the main feeder and one long side along the group feeder.

In Case B, the length of main feeder is reduced, while the length of the group feeders is increased.

The total length of feeders and on-farm canals does not differ much, as long as the short side is not less than 0,4 to 0,5 times the long side. This means that the best farm shapes for the scheme range from 40 x 100 m (or 50 x 80 m) to square. It is generally better to have the short side of the farms along group feeders to reduce their length and, with this, the irrigation water losses. The length of each group feeder should not be longer than 1 000 metres.

In reality however, one is not always free to select the best shape, as the shape of the farm is determined by the following factors:

- shape and topography of the irrigation scheme; and
- the number of groups within the irrigation area and the number of farmers per group.

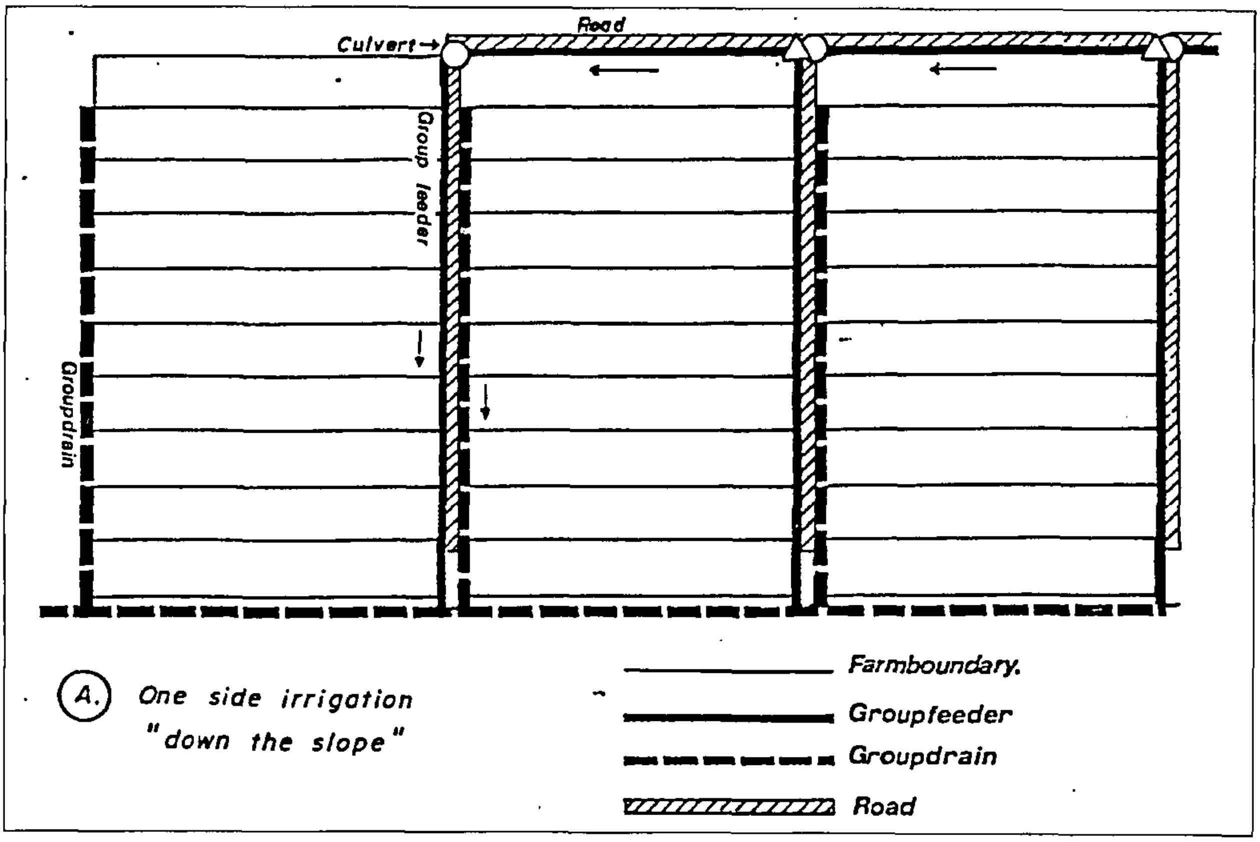
This may result in deviations from the rule, based on the length of on-farm canals, that the short side should not be less than 0,4 times the long sides. Most farmers use supply furrows only on one side, so that the length of supply furrows is twice that of a two-sided supply. A slight increase of supply furrows due to a less than optimum farm size is then negligible. Assume that L equals the length of the group feeder, that M is the number of farmers per group, and that A is equal to the individual holding size. The length of the side of the farm along the group feeder equals L/M metres and the other side is equal to A/(M/L) = (M/L)*A metres.

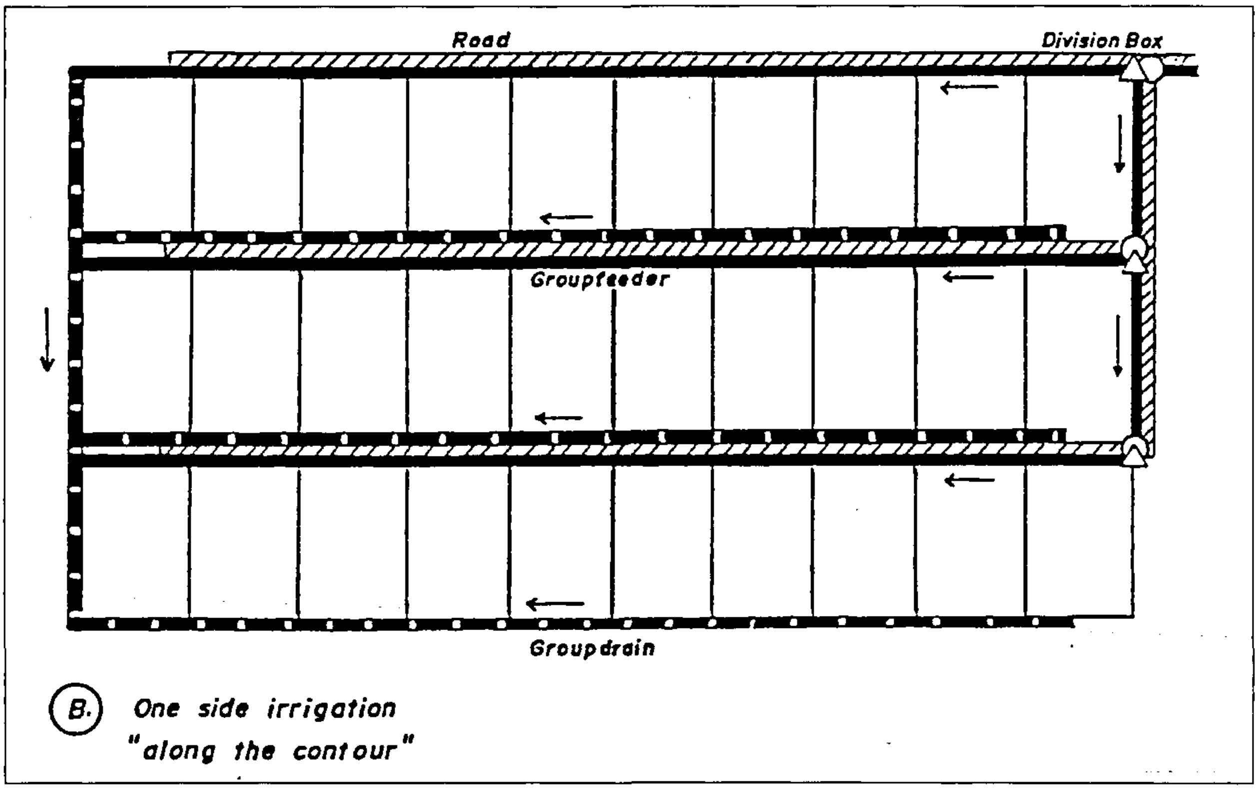
The farm sizes often become ungainly, for instance 20 m x 200 m. In this case, farm shapes must be improved by changing or adapting the design. For example, with some scheme area shapes (eg, elongated, irregular topography, existing roads), one-sided irrigation is sometimes unavoidable. To avoid farm shapes that are too elongated, it is then possible to split the group feeder into two or more branches, and then to use each feeder during part the irrigation interval only.

7.3.2.1 One-sided irrigation

There are two possibilities for one-sided irrigation shown in Figure 7.3.2.1a. The group feeders may run down the slope (A) or along the contours (B).

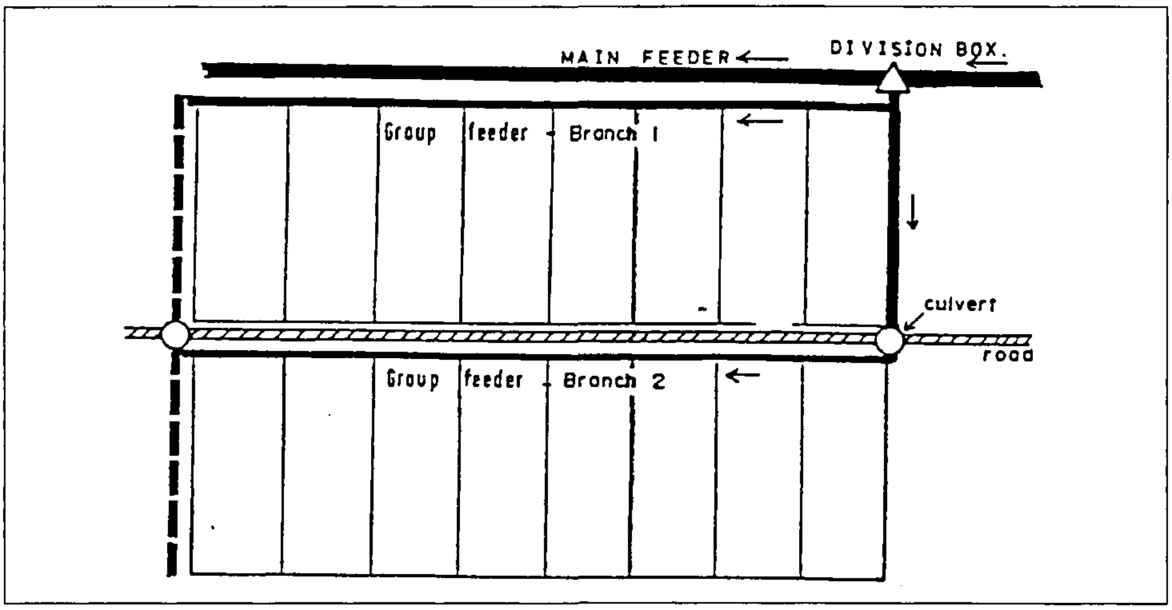
Figure 7.3.2.1a: Plot layout with one-sided irrigation





Whichever way the group feeder runs, the number of group drain(s), group feeder and road equals three. The total reservation width thus equals 3 x (2+6+2) = 30 m.

Figure 7.3.2.1b: A group feeder split into two branches



The nett group width for running the group feeder down the slope is (510 – 30)/3 = 480/3 = 160 m. For a holding 4 000 m^2 in size, the length of the short sides of the farm would be 4 000/160 = 25 m, being 25/160 = 0,16 times the long side. Although the short side correctly runs along the group feeder, the short side is much shorter than the advised minimum of 0,4 times the long side. This layout A is therefore rejected.

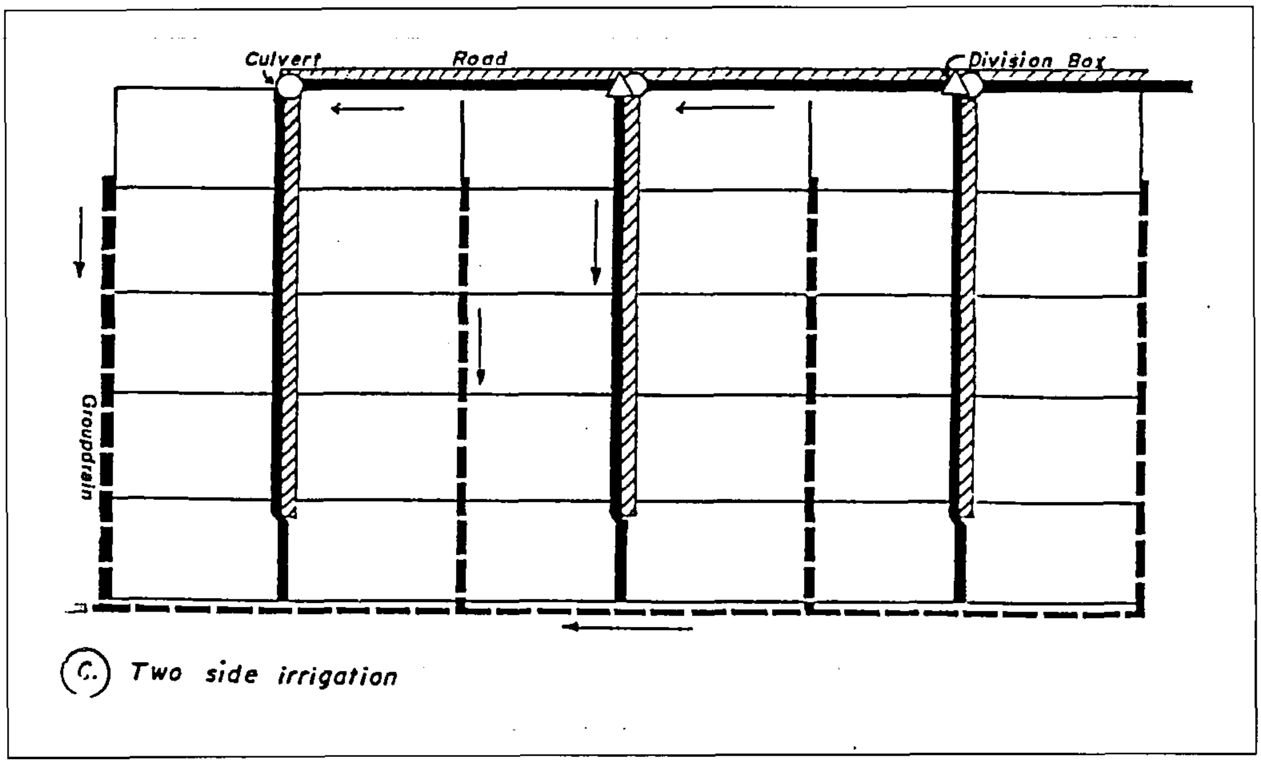
The nett group width for running the group feeder along the contour is (270-30)/3 = 80 m. The short side of the farm is 4 000/80 = 50 m, being 50/80 = 0,62 times the long side. The short side runs along the group feeder and is not less than the advised 0,4 – 0,5 times the long side. This layout B is therefore acceptable.

7.3.2.2 Two-sided irrigation

With irrigation on two sides of the group feeders, the group feeders have to run down the slope (C) (see Figure 7.3.2.2). There are three group feeders and roads and there are four group drains. The total reservation width thus equals 3 x (6 + 2) + (4 x 2) = 32 m. The nett group width covers two farm lengths. The farm length is therefore (510 - 32)/6 = 478/6 = 80 m. The short side of the farm along the group feeder is 4 000/80 = 50 m, being 50/80 = 0,62 times the long side. This layout C is therefore more than acceptable.

The one-sided irrigation layout A down the slope in Table 7.3.3.1 was rejected because the relation between short side and long side is very unfavourable. If the layouts on two sides down the slope and on one side along the contour are compared for lengths of feeders, drains and roads, the two-sided irrigation is much better in feeder and road length and somewhat better in drain length.

Figure 7.3.2.2: Plot layout with two-sided irrigation



7.3.2.3 Comparison of one and two-sided irrigation (organisational)

As Table 7.3.3.1 shows, one-sided irrigation along the contour has a group feeder length of 500 m. The distance a group leader or irrigating farmer has to walk to check all intakes for stealing or leakage is 450 m. With two-sided irrigation this distance is less than half, only 200 m. In this example, the group size is minimum (10) but, with larger groups, the difference between these walking distances increases. However, the shorter this distance, the easier communication will be among farmers of one group, facilitating its organisation. Hence, two-sided irrigation is also preferable in this example in organisational aspects.

Table 7.3.3.1: Comparison of one- and two-sided irrigation (technical points)

	ONE-SIDE IRRIGATION		TWO-SIDE IRRIGATION
	Down the Slope	Along the Contour	Down the Slope
Length group feeder	250 x 3 = 750	500 x 3 = 1 500	250 x 3 = 750
Length main feeder	320	160	400
Total Length	1070	1 660	1 150
Length farm along contour	25	50	80
Length down the slope	160	80	50
Short side: Long side	0,16	0,62	0,62
Reservation width main feeder, main drain road connection	20	10	20
Length group drain	225 x 3 = 675	450 x 3 = 1 350	200 x 4 = 800
Length main drain	500	160	500
Total length	1 175	1 510	1 300
Length of roads	225 x 3 = 675	450 x 3 = 1 350	200 x 3 = 600
Connecting roads	320	160	240
Total length	995	1 510	840

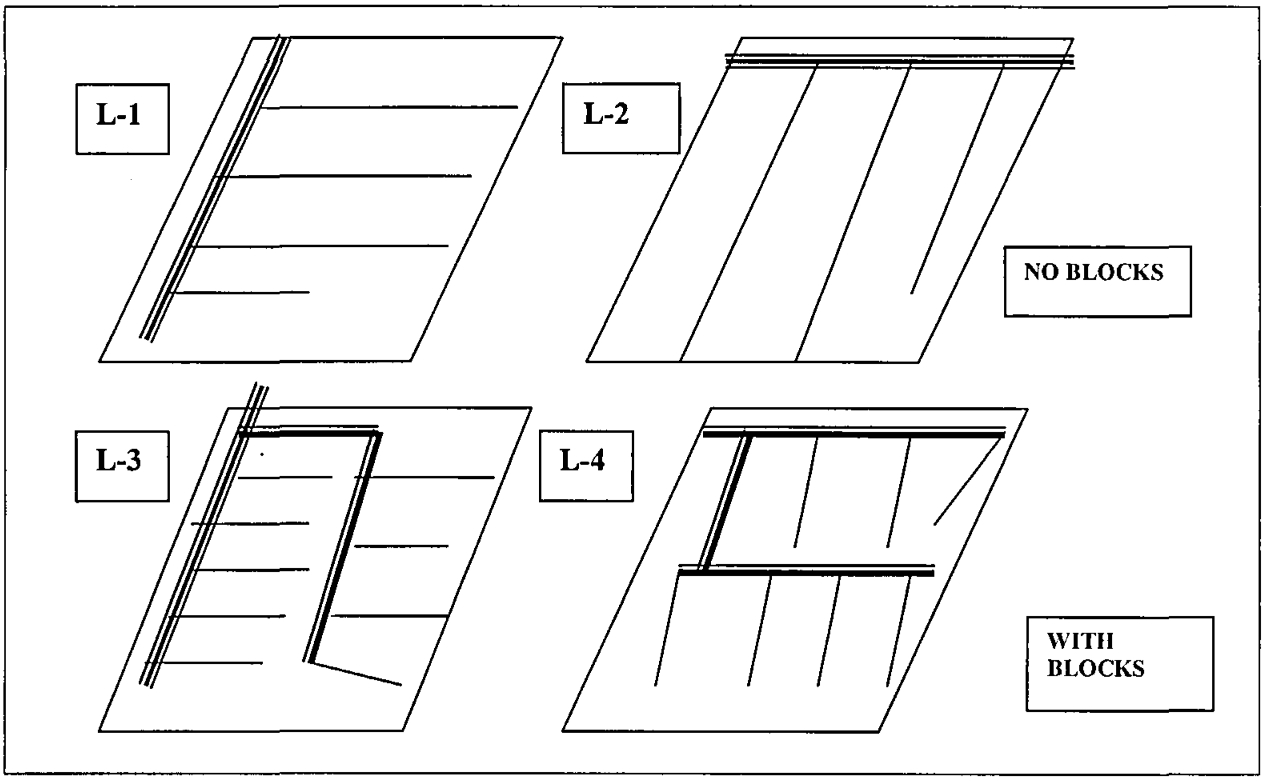
7.3.3 LAYOUT OF SCHEMES

7.3.3.1 Dividing schemes into blocks

Designing larger schemes consisting of six or more groups is comparable to designing smaller schemes, except that the element of scale is introduced, whereby the scheme is divided into blocks. These blocks are independent units of the larger scheme and can consist of several groups.

Dividing the scheme into blocks simplifies the organisation and management of the scheme and creates some flexibility in water distribution between the groups when there is a water shortage.

Figure 7.3.3.1a: Layout in blocks

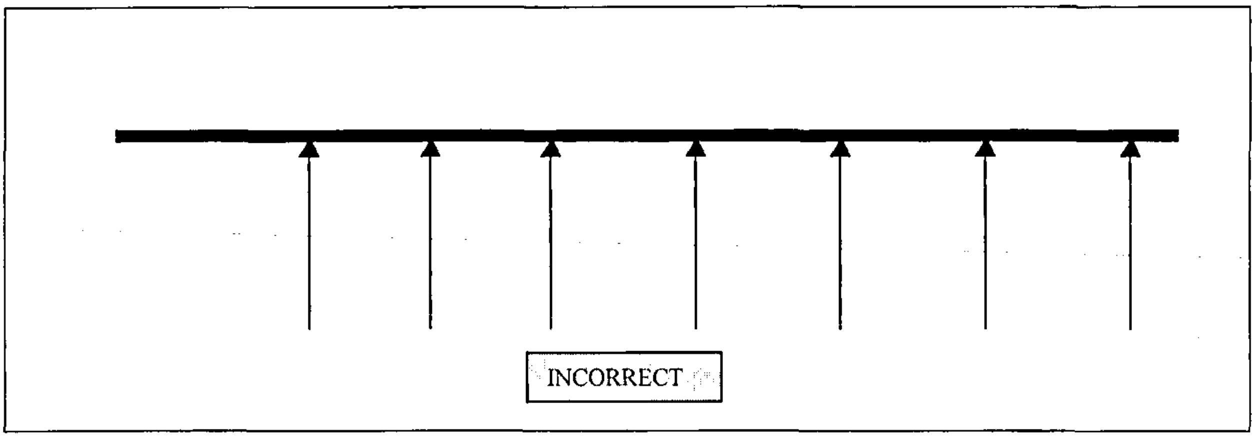


There are no blocks in layouts L1 and L2 in Figure 7.3.3.1a. Each group receives water from the same main feeder, and the water for the last group has to pass all the division boxes before reaching their group feeder.

In Layouts L3 and L4, there are two blocks and the water in the main canal is divided between two main feeders, each main feeder serving a block consisting of two groups.

In larger schemes, a layout like L1 or L2 results in a situation where the last group receives water after it has passed many division boxes. In Figure 7.3.3.1b, an example is given with twelve groups.

Figure 7.3.3.1b: Incorrect layout of a larger scheme – no blocks

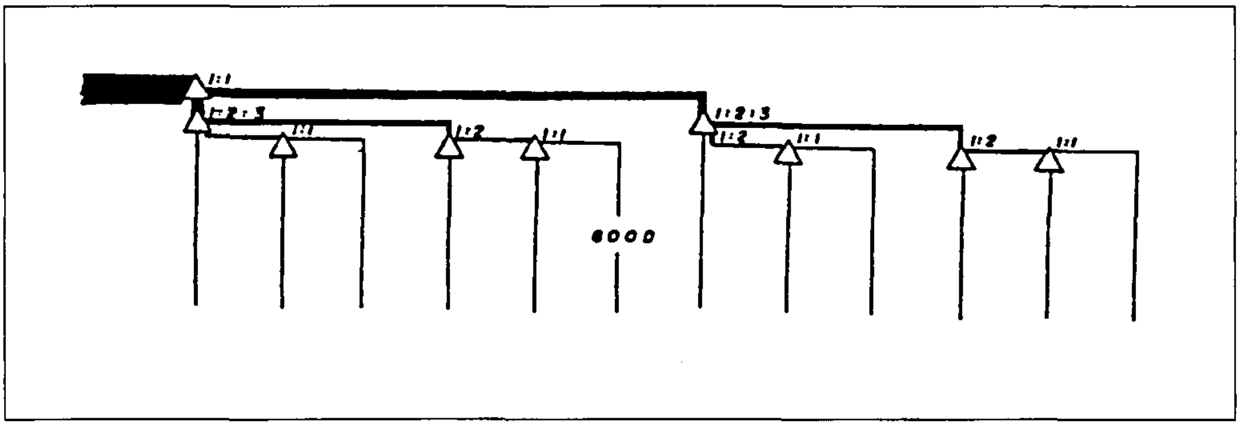


The design of division boxes for proportional flow foresees a distribution according to certain ratios. However, openings will slightly differ from design in dimensions, and other conditions of the canal (weed growth, number of farmers taking water at a time) can influence the distribution. When the downstream water level at the division boxes does not influence the upstream water level (sufficient drop), proportional division becomes more accurate. The required head loss is often a constraint, however. It can only be included in sloping areas where sufficient head is available (in excess of head needed for water conveyance).

As a rule of thumb:

- Water should pass as few division boxes as possible from the head of the scheme to the irrigation group; and
- Ratios of water division close to 1:1 and 1:2 are recommended, while ratios exceeding 1:5 are best avoided.

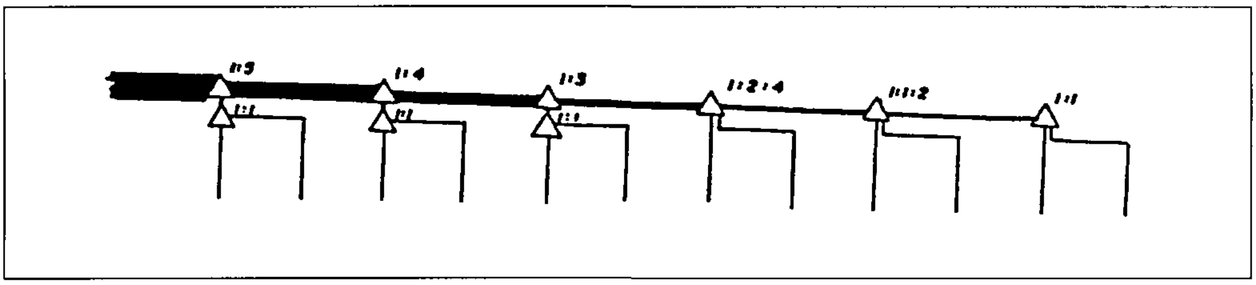
Figure 7.3.3.1c: Correct layout of a larger scheme – blocks



Larger schemes are best divided into blocks and blocks may be sub-divided into sub-blocks. It is important that areas of about the same size get their water from a division box, as is shown in Figure 7.3.3.1c above. If distribution is spread over more boxes, distortion might easily occur.

- Use one structure to divide water over blocks.

Figure 7.3.3.1d: Less suitable layout of larger schemes – No real blocks



In contrast with the layout shown in Figure 7.3.3.1c, a less suitable layout has been shown in Figure 7.3.3.1d. Although the same total number of division boxes is used as in the layout of Figure 7.3.3.1c and ratios over 1:5 are avoided, blocks consisting of two groups do not receive water from the same division box.

7.3.3.2 The importance of a proportional water distribution

The importance of a proportional distribution system is in its delegation of daily operation management from the scheme committee to the individual groups. At times of ample availability of water, this may be only convenient. However, when there are low water flows in the river, distribution becomes a major issue in the scheme. Its management should be, as far as possible, delegated to blocks. The only way to do this is to distribute the water in proportional parts.

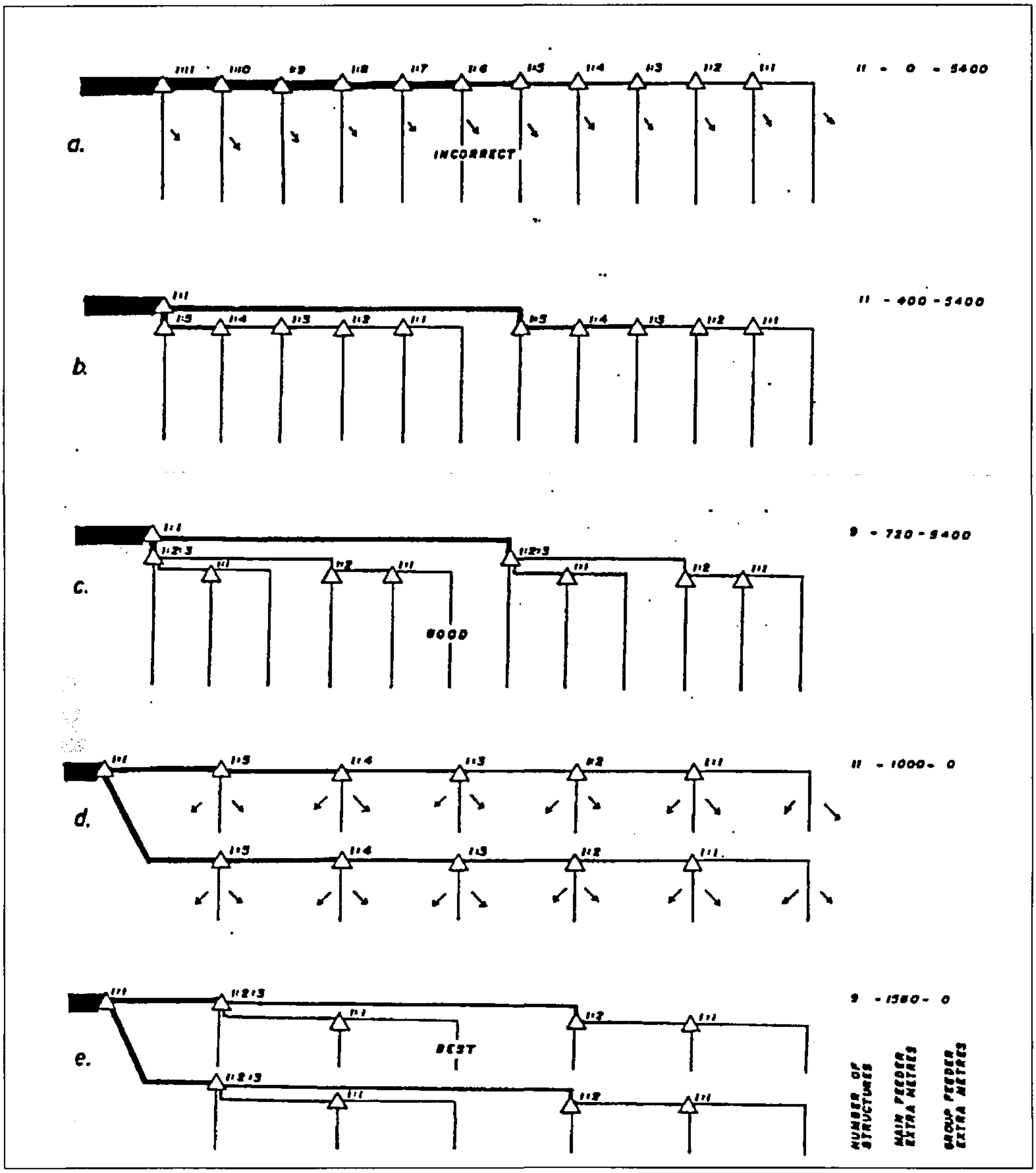
In the first stage, the water availability in the main channel drops below design level and the unit flow to groups is reduced. It is up to the individual members of the group to act upon the reduced water discharge to their farm during their allocated application period in the schedule.

The farmer can either decide to lead less water to all his short-furrow basins (relying partly on water still stored in the root zone after depletion of accessible moisture) or he can continue to give the same amount of water (water depth) to fewer basins.

In the second stage, unit flow may drop to a level where seepage losses become extreme and handling of the small flows on the farm starts taking too long. At flows of 5 to 7 ℓ/sec and below, it may become worthwhile for two or three groups within a block to co-operate by directing the whole flow to one group only. This involves a (temporary) change from proportional to rotational group flow. The allocated time (application duration) could be halved (two groups) or reduced to one-third (three groups). As the larger flow would reduce water losses, it would allow the farmers to irrigate in a shorter time.

Provided the advantages are clear to the farmers, they will agree to this change for as long as the water shortage lasts. It involves co-operation of two or three groups only, and they can act upon the changed situation, without interfering with the rest of the scheme. Some groups may opt for co-operation, others not, and no central enforcement would be required.

Figure 7.3.3.2: Comparison of different layouts



For one scheme with twelve groups, different distribution systems can be compared and ranked from incorrect via good to best. In Figure 7.3.3.2 above, each group consists of thirteen farmers, with plots of 80 m x 50 m. The following items are compared:

- **Occurrence of blocks and structures.** In Layout (a), there are no blocks and the layout is rejected as incorrect. In Layouts (b) and (d), there are two blocks. Their layouts are suitable as no ratios are over 1:5, although water has to pass six structures to reach the last group. In Layouts (c) and (e), there are two blocks and each block has two sub-blocks. Ratios are only up to 1:3 and the last group receives water through four structures only. These layouts also require two division boxes less.
- **One-sided or two-sided irrigation.** Two-sided irrigation occurs in Layouts (d) and (e). The main advantage is compactness of the irrigation group. The length of the group feeder over which water is taken is 9 x 50 m = 450 m. Farm intakes are spaced relatively close together and it is

easier to check on leakage, and other water losses (stealing, over-topping) and obstructions are quickly observed.

Communication among farmers about the preparation of a timetable and changes in allotted time periods between members is facilitated. Commitments for maintenance works are easier to obtain, as is supervision by the group leader.

With one-sided irrigation, the group feeder is twice as long (900 m) and less advantageous.

- **Canal length.** When comparing canal lengths, two factors are involved.

  The total length of group feeders. With group feeders serving farmers on both sides, the total length required is much less. Extra length for group feeders serving one side only amounts to 5 400 m.

  Extra length for the parallel running main feeders or group feeders. Compared to the incorrect layout of (a), for Layouts (b) and (c), an extra 400 to 720 m is required and, for Layouts (d) and (e), an extra 1 000 to 1 560 m is required.

Combining the two aspects, two-sided irrigation requires less total canal length than one-sided irrigation.

For sub-division of blocks into sub-blocks, a little extra canal length is required. This is easily justifiable by a better-managed scheme. For one-sided irrigation, it amounts to 320 m and, for two-sided irrigation, 560 m.

Final preference is for Layout (c), if one-sided irrigation fits better according to topography, and for Layout (e), where two-sided irrigation is possible.

7.3.4 GUIDELINES FOR THE DESIGN OF INFRASTRUCTURE

The *Irrigation Design Handbook* contains comprehensive information on all aspects of irrigation infrastructure design and this available information will not be duplicated here. This section therefore concentrates on the particular aspects that concern small-scale flood irrigation developments, including the rehabilitation of schemes, which is taken from *Smallholder irrigation: Ways forward – Volume 1: Guidelines for achieving appropriate scheme design* (Chancellor et al, 1997).

The design must be functionally correct whatever the size of the scheme. However, the scope of small-scale irrigation developments may rule out solutions that could be considered for large schemes because they are either not practical or not economically viable.

There are many aspects of design to be considered. They include:

- location,
- foundations,
- flood flows,
- backwater effects,
- changes to river bed levels,
- sediment exclusion/extraction,
- water control,
- construction quality,
- reservoir storage,
- field layout/application method,
- field water management,
- delivery systems, and
- operation.

These design factors are discussed below.

7.3.4.1 Location

The approximate location of the intake is usually determined by the water levels required within the scheme. By selecting a suitable canal bed slope, a longer canal will correspond with a lower weir height. The relative costs must be set against the commanded area, which might be greater with a longer canal. The intake should be located, wherever possible, on the outside of a river bend so as to reduce the volume of sediment drawn in. It should never be located on the inside of a bend. The channel reach should be stable and well-incised, otherwise extensive training work will be required.

7.3.4.2 Foundations

The foundation material strongly affects the detailed design of the intake. Firm materials, ideally rock, greatly simplify the design. More usually, gravel, sand or silty clay material will be encountered.

The small scale of the work means that the designer cannot afford to include more than a small number of exploratory holes and a few soil classifications in the site investigation. Nevertheless, trial pits and hand-operated augers can provide information on conditions *in situ* and samples for further testing. Soil classification and grain size distribution will allow the designer to estimate the engineering properties of the soil, such as its permeability, and so to select a safe hydraulic gradient.

Small hydraulic structures usually fail, not because the foundation pressure exceeds the bearing capacity of the soil, but because of scour of the foundation, differential settlement, seepage or outflanking. Small weirs built on rigid foundations impose a very small pressure compared with the soil bearing capacity. However, the contact pressure must be low enough to avoid large settlements of the structure. In the case of flexible gabion weirs, settlement of the foundation is unlikely to create a problem. In the case of small weirs on a rigid raft foundation, a 50 mm settlement should not significantly affect the water level that must be maintained upstream of the weir.

7.3.4.3 Flood flows

Diversion weirs for small schemes should be designed to pass flood flows for a minimum return period of twenty-five years, and for fifty years or more where hazard to life would result from failure. Small weirs on smallholder developments normally have little impact downstream in the event of failure. However, the effect on the scheme itself might be catastrophic. Short-term problems may include total loss of crops for that season. The acquisition of additional funds for repair or reconstruction of the weir might take considerable time and seriously affect the ability of farmers to continue repayments on loans.

7.3.4.4 Backwater effects

The weir should be designed to raise water levels during medium-to-low flows and to minimise the backwater (afflux) under flood conditions. First, the required command level must be established, and the crest level must be set accordingly, then the principal variable is the width of the weir.

In some circumstances, it may be unacceptable to allow any significant afflux. If the water level under design conditions were to be raised by a metre on a river falling at 1 in 2000, the effect would be felt well over two kilometres upstream. Protection must therefore be provided for existing upstream infrastructure, such as bridges, roads and buildings, if the bank heights there are not sufficient.

It is common to make the weir width similar to the existing channel width. However, if an ungated structure is adopted and very little afflux is acceptable, a wide and costly structure may be needed to pass the design flood.

Control structures allow flood flows to be passed without afflux, and can reduce problems of sediment accumulation, but the gates may become worn, rusty or generally inoperable for lack of regular maintenance. Control structures also need an operator and farmers are generally unwilling to post an operator full-time to the site, which is often remote from the scheme. Stop-logs are a relatively low-cost alternative method of controlling water level, but it may be hard to anticipate flooding. During floods, it can also be difficult and sometimes dangerous to remove logs that have been sealed against leakage during the dry period.

7.3.4.5 Changes to river bed levels

The construction of large weirs can lead to erosion of the riverbed for considerable distances downstream and to accumulation of sediment upstream. The problem is less severe with small structures but excess energy of flow must nonetheless be dissipated in a stilling basin or pool immediately downstream. Additional local bank protection in the form of dp-rap or gabions is normally provided but rigid forms of protective pitching should not be used. A cut-off wall can help to resist seepage and also to protect against back-erosion.

7.3.4.6 Sediment exclusion/extraction

On rivers carrying high sediment loads, the river upstream can sometimes silt up to the level of the weir crest, causing major problems in the off-taking canal system. However, where schemes derive their supply from springs, sediment is unlikely to be a problem. More generally, schemes sited downstream of eroding catchments suffer to a greater or lesser degree from water-borne sediment.

Few of the intake structures on the schemes investigated were provided with means to exclude or extract sediment from the system. Sluiceways or flushing gates were generally not constructed so removal of sediment deposited upstream of the weir became a difficult and time-consuming task which was rarely, if ever, undertaken.

Generally, there are a number of possible solutions to the problems of water-borne sediment, but they are not all equally effective nor are they all suited to small schemes, particularly the technical options:

- constructing sediment excluders and extractors, such as settling basins, vortex tubes and vanes;
- closing the intake gates when the river carries high sediment loads, particularly on flood recession; and
- clearing sediment from the system either manually or, where possible and suitable, by machine. Farmers need to organise effectively and set aside funds for the purpose.

The first option requires specialist investigations, design, supervision and training in operation and maintenance. It is expensive and will only be suitable where a large command area can provide returns to justify the initial expense, and there are significant savings in the expenditures on channel clearance.

The second option requires farmers to change their operating practices and possibly to employ a gatekeeper, at least during part of the year. The impact of the change would depend on the site. A good part of the annual sediment load might be excluded in some situations. In other circumstances, the load drawn in during normal flows might still create a substantial maintenance problem. Local investigations would be needed to guide an engineer.

The third option may be the only practical solution for small schemes, but it requires co-operative working to be successful.

7.3.4.7 Water control

The intake should be provided with means for on-off control as a minimum requirement. Regulation could also be achieved with a standard lift gate. Field investigations showed that head gates were rarely, if ever, operated. Nonetheless, the system may need to be shut down in an emergency, so a control must be provided.

Farmers need to be made aware of the consequences for downstream users, and also possibly for the local water table, of taking too much water from the river. It may be necessary to initiate a joint meeting of water users.

7.3.4.8 Construction quality

Most intakes in Kenya were constructed of blockwork with a cement screed. Some cracking had occurred in the weirs and wing walls, but the stability and operation of the structure were not affected. Where failures had occurred, the cause was usually settlement owing to inadequate foundations.

Overall, the quality of construction was found to be satisfactory, with a few poor exceptions. This type of construction appears generally suited to the conditions, skills, and materials available on small schemes in rural areas.

7.3.4.9 Reservoir storage

The inclusion of a reservoir at the intake adds flexibility to operations but is usually only practical on larger schemes where the cost can be offset against greater returns.

Canals typical of small schemes provide negligible storage. Separate storage structures within, or adjacent to, the irrigated area have the following advantages:

- irrigation can usually be carried out during daylight hours;
- the capacity of the main canal or pumps can be reduced if irrigation is done during only part of the 24-hour period;
- pump operating costs can be reduced if pumps are operated at night when electricity tariffs are usually lower;
- variations in demand, particularly following rainfall, can be evened out; and
- unplanned disruption to the main supply can be tolerated for a limited period.

Disadvantages of storage structures are:

- cost. The initial investment needs to be offset against the reduced costs of supply canals;
- loss of potentially productive land;
- progressive siltation and weed growth within the structure. Clearance is a heavy, time-consuming and therefore expensive task, most effectively carried out using machinery; and
- water-borne diseases, such as schistosomiasis, may be encouraged.

The decision as to whether or not to provide storage depends on the relative availability of water, farmers' irrigation practices, the availability and cost of land, and the potential for re-using runoff from the scheme at sites elsewhere.

For schemes with an assured and adequate gravity supply where runoff can be re-used downstream, it is unlikely that storage will be justified.

However, where water is scarce, storage can help reduce waste and simplify management. Storage also balances out mismatches between supply and demand on pumped schemes where changes to the delivery can only be achieved by switching in or out modular pump units.

In most small schemes in Africa, farmers cultivating upland crops irrigate principally during daylight hours, occasionally extending operations at peak times or when the supply is scarce. In Zimbabwe, night storage reservoirs are almost invariably provided within gravity irrigation schemes.

7.3.4.10 Field water management

Rotations at field level should be as simple as possible because complications are introduced if it is necessary to divide the flow between farmers. A one-by-one rotation, under which each farmer receives the water in turn, is therefore best.

It is easiest to arrange an equitable supply to compact blocks of land. Long, extended blocks involve long channels and correspondingly larger losses for farmers situated at the tail end of the block. If the tertiary canal is limited to a length of some 800 m, a rectilinear, 8-hectare nett block (perhaps 9 hectares gross) would be some 100 m wide. It would be better, if the topography allows, to design shorter blocks some 500 m long, with the canal irrigating to both sides.

Communal schemes require co-operation between members. As the number of farmers required to work directly together increases, co-operation tends to break down so the groups of co-operating farmers need to be small. A group is considered to be a number of farmers served by a common water supply, such as an off-take from a secondary canal. The main tasks of the group are to organise water management amongst members, drawing up rotation schedules and maintaining local parts of the system.

The size of the group should be limited by the needs of good water management, considering:

- the area which can be effectively irrigated by a manageable stream size and canal discharge within the critical rotation period; and
- the number of farmers who will have to co-operate.

7.3.4.11 Delivery systems

The functioning of the distribution system affects the overall performance of a scheme. Should a canal system or pipe network be used? Should canals be lined? What are the relative efficiencies of different designs? What are the implications for operation and maintenance?

7.3.4.12 Design for operations

The intended operational pattern of the system also strongly affects the design capacities of individual components. Soil, crop, climate and farming practice influence the operating hours in any given period. Water at any level of the system might be supplied continuously, or according to many possible patterns of rotation.

At the lowest level of distribution, water is continuously provided to all groups simultaneously. Within the group, supply may be continuous, passed from field to field, or rotated between group members for a period related to their holding. Each group becomes effectively self-managing, so less formal organisation is needed at scheme level. Farmers easily understand the procedure. An assured supply is required so those canals can operate at their designed discharges and levels.

Designers must be realistic about the number of hours for which farmers will normally irrigate. In many parts of the world, farmers are unwilling to irrigate at night. If the system is based on 24-hour irrigation, the canals will be undersized. Yields and planted area will be lower than expected. Farmers are unlikely to shut off supply at the head of the system at the end of the working day, so provision should be made for storing excess water or for passing it back to the river.

7.3.4.13 Canal design

Earth canals can be relatively cheap to construct, using farmers' labour under overall technical control to ensure quality of workmanship. They do not require specialist operation and maintenance but poor design, construction or maintenance can seriously affect the proper functioning of the scheme.

Poor scheme performance can be attributed particularly to inadequate de-silting of canals because division structures easily become drowned and ineffective if the downstream water levels are raised by siltation. Farmers are also likely to respond by tampering with the structures, to the disadvantage of the scheme as a whole.

Small canals usually have steeper bed slopes than larger ones. The bed slope of tertiaries should normally be approximately the same as the land slope, if the network has been orientated correctly. The alignment must take account of existing field layouts, if any. The average velocity of flow at design discharge should be within an upper limit, to avoid erosion, and a lower limit, to avoid having sediment settle out. To maintain the transporting power of the flow, the bed slope should not decrease down the network.

Realistic assumptions must be made about the effective roughness of the channel after time has elapsed because poor maintenance commonly makes channels rougher than assumed at the design stage. Conservative assumptions could lead to a channel somewhat over-designed. However, small channels are commonly designed to minimum dimensions imposed by prevailing methods of construction, so the implications for cost are unlikely to be significant.

Tertiary channels tend to lose proportionately more water than larger channels because of their large surface area relative to small rates of flow and the fact that they receive heavy usage at the hands of farmers. As a result, farmers at the tail end of tertiaries often receive little or no water. The channel length should be strictly limited to reduce losses and minimise the block size, and to keep the number

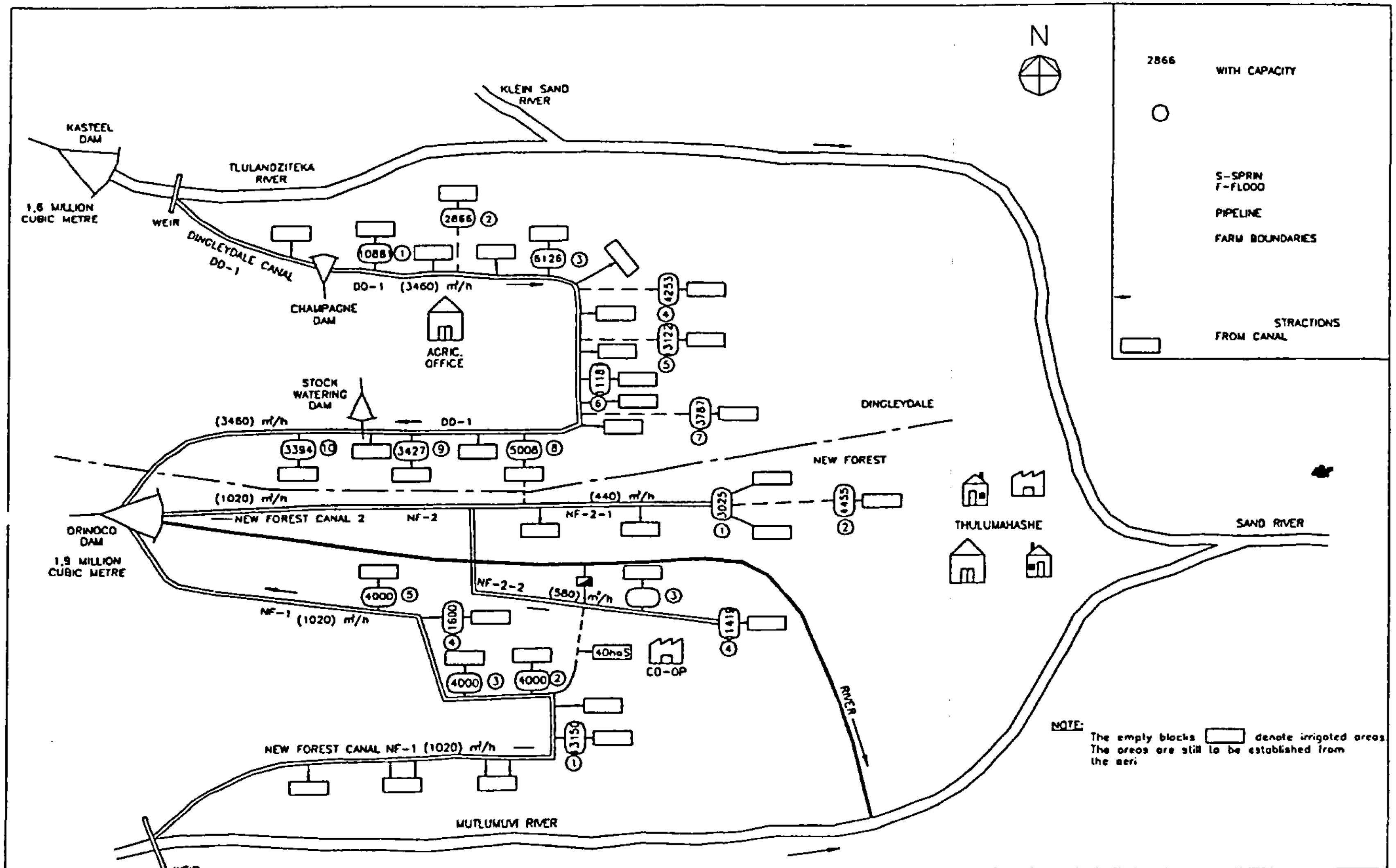


DIAGRAM 1
NOT TO SCALE

DIAGRAMATIC LAY-OUT OF THE WATER SUPPLY TO DINGLEYDALE AND NEW FOREST IRRIGATION SCHEMES of farmers who must co-operate in water use to a workable number. In more permeable soils, a maximum channel length of one kilometre may be too great but farm channel lengths should not be extended to compensate for short tertiary canals, otherwise overall losses will be greater still. The canal layout needs to be designed with sufficient density of canals to serve the blocks adequately.

7.4 LOSSES IN SUPPLY FURROWS

7.4.1 INTRODUCTION

Experimental work was undertaken on the terrain of the Institute for Agricultural Engineering of the Agricultural Research Council to determine the design parameters for short-furrow irrigation. Particular attention was paid to the efficiencies that could be achieved.

The research was carried out on a deep soil of medium texture. It would be desirable to undertake similar work on other soil types but, now that the principles have been established, it is possible to project the results to other conditions with a reasonable degree of confidence.

The **application efficiency in short furrows is relatively high.** This means that most of the water in the short furrows actually reaches the roots of the plants being irrigated. Distribution uniformity in the short furrows can achieve 80–90%. This is a property of small-basin and short-furrow irrigation, provided the basins/furrows have a fall of less than 1:300. On a steep gradient of 1:100, the uniformity of distribution was below 40%, largely due to damming at the lower end of the short furrow. **Self-scheduling** (controlled depth of application) occurs in flood irrigation to some extent because dry soil absorbs more water than wet soil, so the same plot will take longer to irrigate after a dry, hot week than after a cool week and this results in a heavier irrigation application.

The efficiency of water use in the system as a whole, that is, **irrigation efficiency may not be as high, if significant losses occur in the supply furrow.** Consequently, the first phase of the research was to determine the characteristics of earth supply furrows.

7.4.2 DETERMINING INFILTRATION LOSSES IN SUPPLY FURROWS

7.4.2.1 Objective

The objective was to determine the infiltration losses in the supply furrow of a short-furrow system as practised in South Africa, and to validate these with computer simulations developed to facilitate design.

7.4.2.2 Experimental layout

The experiment was done at Silverton, Pretoria. Infiltration was measured in conditions as close as possible to those used in farming. The infiltration rate was determined dynamically by subtracting the outflow rate (Qout) of the water flowing in experimental furrows from the inflow rate (Qin).

7.4.2.3 Furrow length

The length of the experimental furrows was 30 m, the greatest possible length on the land available. However, the furrows should have been longer in order to make the difference between (Qin) and (Qout) significant enough to ensure accurate measurements of infiltration. It would be ideal if the whole furrow could have been wetted simultaneously. In other words, infiltration should start at the same time for the whole furrow to be able to measure the true infiltration curve over time. Nevertheless, measurements were taken for the furrows 30 m long. It took the water only about three minutes to reach the end of the furrow and the difference between (Qin) and (Qout) was up to 30% for a stabilised infiltration rate.

7.4.2.4 Flow rates

Flow rates on irrigation schemes visited varied from 3 to 15 m^3/h. A flow rate around 5 m^3/h was seen to be impracticably low because of long waiting times, whereas 15 m^3/h became difficult for one man to handle. Flow rates of 5, 10, 15 and 20 m^3/h were assessed on the experimental short-furrows by constructing four furrows one metre apart, one for each flow rate, to form a set.

7.4.2.5 *Gradient*

Three sets of furrows were constructed at gradients of 1:75, 1:150 and 1:300 respectively so that the flow rates and gradients represented the typical range found in the field.

7.4.2.6 *Soils*

Three furrow sets described above were constructed and tested at two different locations, to determine the influence of a difference in soil clay content. At the first location, the soil was a red brown Hutton with 20% clay content. The second location was on a soil with a light brown colour and 10% clay content.

7.4.2.7 *Construction*

The dry soil was ripped and disked to prepare a proper surface. The furrows were then made with a ridger and had an average width of 500 mm and a depth of 200 mm.

7.4.2.8 *Flow rates*

The incoming flow rate was controlled at 5, 10, 15 or 20 m^3/h by using a 100 mm propeller flow meter, two gate valves and a bypass. A centrifugal pump, pumping from a reservoir, provided water pressure. The flow from the pump was choked to at least 30% of its maximum flow, resulting in a very stable discharge. The flow rate was sporadically checked after the initial setting, but no differences could be detected. The water was conveyed from the flow meter in a thin-walled plastic pipe (150 mm diameter) to the top of the furrow, where it flowed over a steel plate into the furrow. Slight erosion did occur in the first metre of the furrow while the flow and velocity adjusted to the furrow dimensions. However, only on one occasion was it found that this 'hole' influenced the infiltration measurement.

At the ends of the furrows, sumps were dug for each furrow in the 20% clay soil (Location 1) and trenches were dug across the ends of each set of furrows in the 10% clay soil (ie, Location 2).

The flow rate (Qout) was measured with two calibrated buckets of 26 ℓ and 53 ℓ, and a stopwatch. The 26 ℓ bucket was used for the 5 m^3/h furrows and the 53 ℓ bucket for the 10, 15 and 20 m^3/h furrows. The error in the measurement of the flow rate was determined in our laboratory as 1% of the average of at least three measurements. The error of the flow meter for determining Qin is also, at most, 1% in this flow rate range, which means our infiltration determination may have a 2% error. Although this is a fairly high accuracy, the results should be carefully interpreted at flow rate differences (Qin – Qout) below 10%.

For practical reasons, the measurements (Qout) were done as soon as the water started to flow into the sump through short sections of PVC pipe 150 mm in diameter, which were installed at the end of the furrows.

The measurements were taken continuously for at least the first twenty minutes and then at longer time intervals up to ninety minutes.

7.4.2.9 *Measurements*

The main measurement was the flow rates but other measurements were also taken, in order to gain as much information as possible to assist in predicting the behaviour of the furrows.

7.4.2.10 *Advance time*

The advance front was measured at 5-m intervals and later at 2,5-m intervals on the 10% clay soil.

7.4.2.11 *Gradients*

The gradient of each furrow was measured after each run. Spot readings were taken at intervals of 5 m.

7.4.2.12 Flow velocity

Water velocity was measured with a float. At least three measurements were taken and the average velocity could be estimated by: Vaverage = Cf Vfloat

7.4.2.13 Furrow dimensions

The cross-section of each furrow was measured at intervals of 5 m before each run so that changes in the shape of the cross-section could be detected.

After about one hour of flow in a furrow, the shape of the wetted cross-section was also measured while the water was flowing. Because the shape of the furrow was more or less rectangular, only the top width and average depth of flow was measured. A thin steel ruler was used for these measurements, which were also taken at maximum intervals of 5 m along the furrow.

7.4.3 RESULTS OF THE EXPERIMENTS

7.4.3.1 Furrow gradient

The gradient of the supply furrow does not influence seepage significantly. This holds true only for furrows used for conveyance, ie, where the contact time is three or more times longer than it would take the advance front to reach the end of the furrow. When inflow is cut off as the water reaches the end of the furrow, gradient has a major influence.

7.4.3.2 Furrow width

Furrow width correlates with flow rate. The sides of the furrows erode away and then stabilise. When sedimentation occurs, the width increases as the sand builds up in the furrow, because of the V-shape of the furrow.

7.4.3.3 Depth of flow

Flow depth is a characteristic of the inflow rate. It should be noted that this depth is the average depth of the furrow. Hollows in the furrow and sections with very steep gradients were not taken into account, as they were unrepresentative.

7.4.3.4 Gradient

Flowing water tends to reduce the gradient until scouring stops. In the furrows tested, this happened to the lower sections of the furrows.

7.4.3.5 Infiltration losses

The volume of water infiltrated over a specific time in the supply furrows increases very little as the flow rate increases. This means that almost the same amount of water would be lost in, say, an hour, for different flow rates. However, the percentage of water lost varies significantly. For example, if 1,5 m^3 water is lost in an hour at a flow rate of 5 m^3/h, almost the same amount would be lost at a flow rate of 10 m^3 or 20 m^3. Thus, at a flow rate of 5 m^3/h, 30% of the water percolates but, at a flow rate of 10 m^3/h, 15% is lost and, at a flow rate of 20 m^3/h, only 7% is lost.

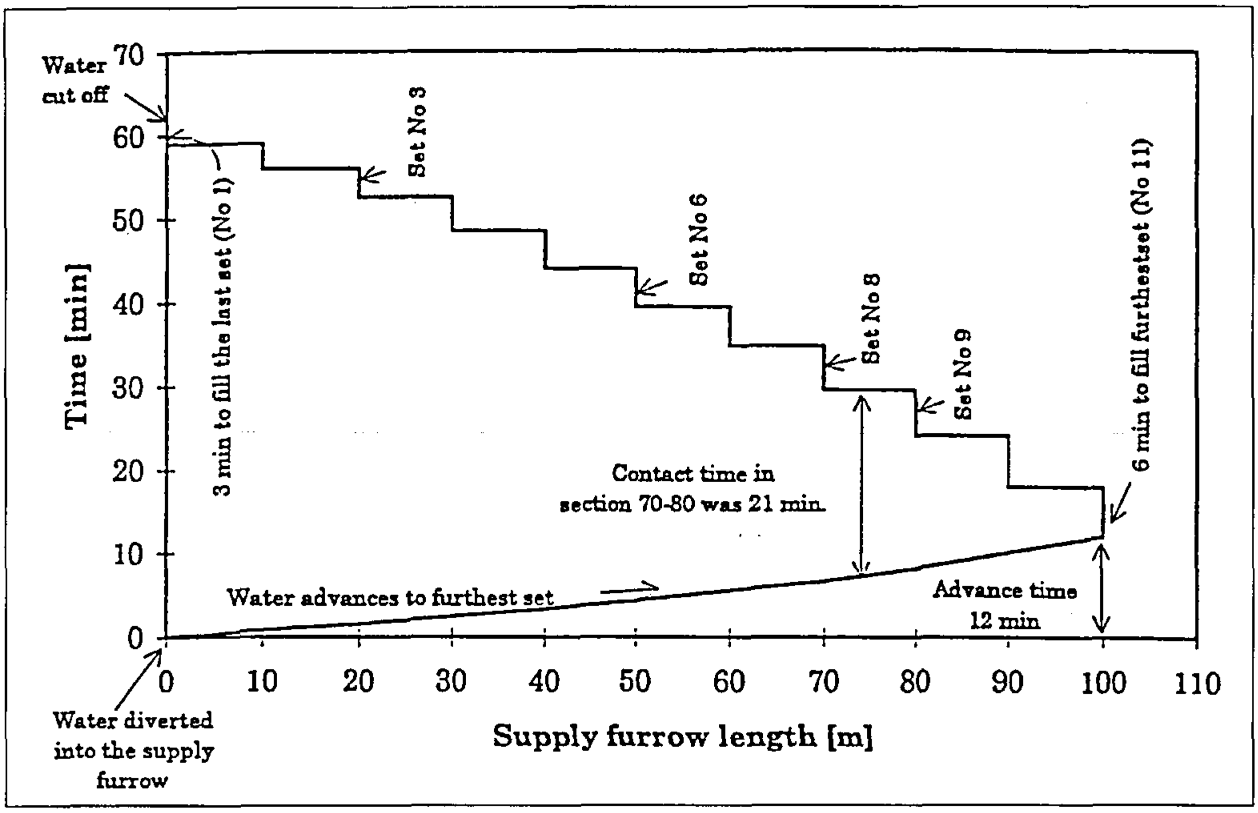
Therefore, because **infiltration per metre of supply furrow is virtually independent of flow rate,** the percentage loss at low flow rates is high and it is desirable to have a higher flow rate to lessen overall losses. Limiting factors are the practical dimensions of the supply furrow and the maximum flow rate a person can handle comfortably. A farmer can only control flow rates of 10-15 m^3/h when short furrows are filled individually.

7.4.4 SIMULATIONS OF SUPPLY FURROW LOSSES

The objective of the experiment was to establish the infiltration characteristics of the soil so that supply furrow infiltration losses could be estimated. If these losses were found to be excessive, then short-furrow irrigation would only be feasible if measures were taken to eliminate or greatly reduce infiltration.

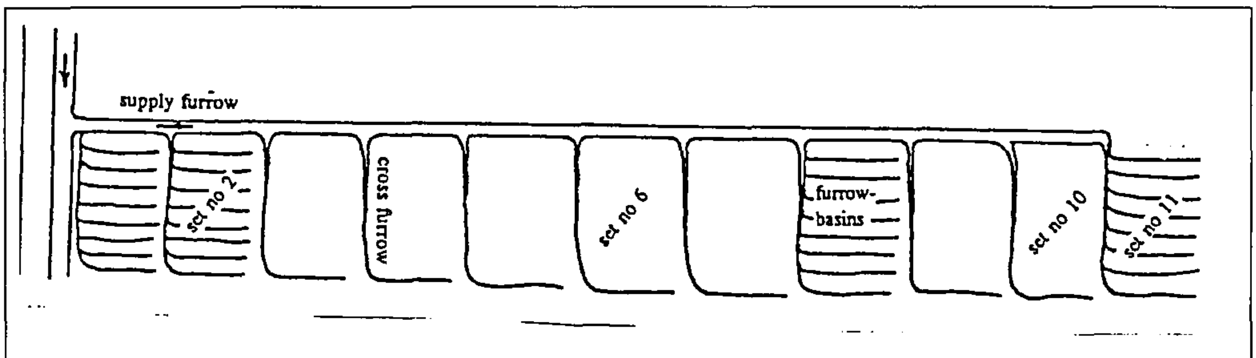
The approach to simulation can best be understood by reference to Figure 7.4.4a, which is derived from the full-scale experimental plot constructed at Silverton and used to gain experience in short-furrow irrigation practice.

Figure 7.4.4a: Time taken to irrigate an experimental plot with eleven sets of short furrows



The irrigation area is 110 m x 4 m. Thus, the supply furrow has a length of 100 m, with a total of eleven outlets into cross furrows at 10 m intervals. Each cross furrow feeds a set of short furrows. The eleven sets are irrigated in succession, starting at the furthest set (at the bottom end of the supply furrow) and working back towards the top end of the supply furrow.

Figure 7.4.4b: Layout of experimental plot



The graph indicates that the advance front to the furthest cross furrow was twelve minutes (ie, the water took twelve minutes to reach the bottom of the supply furrow at the outlet to the eleventh set of short furrows), and then it took six minutes to fill Set 11. The time taken to fill each successive set decreased until the final one, Set 1 at the top end of the supply furrow, took only three minutes to fill.

The difference in time taken to fill each set can be ascribed to the difference in total length of the supply furrow serving each set. The longer the section of supply furrow in which water is conveyed to reach a set, the greater the contact area between the water and the soil, and the greater the total infiltration losses before the water reaches the set of irrigation furrows. Put differently, the flow rate in the supply furrow decreases along the length of the supply furrow, so that the time taken to irrigate sets further along the supply furrow increases.

The graph also indicates the total time each 10 m section of the supply furrow was in contact with the water: for example, for the section between 70 and 80 m from the top end of the supply furrow, the contact time was twenty-one minutes.

7.4.4.1 Applying the experimental infiltration values – SIRMOD simulation

Infiltration rates in flood irrigation are given by the following equation:

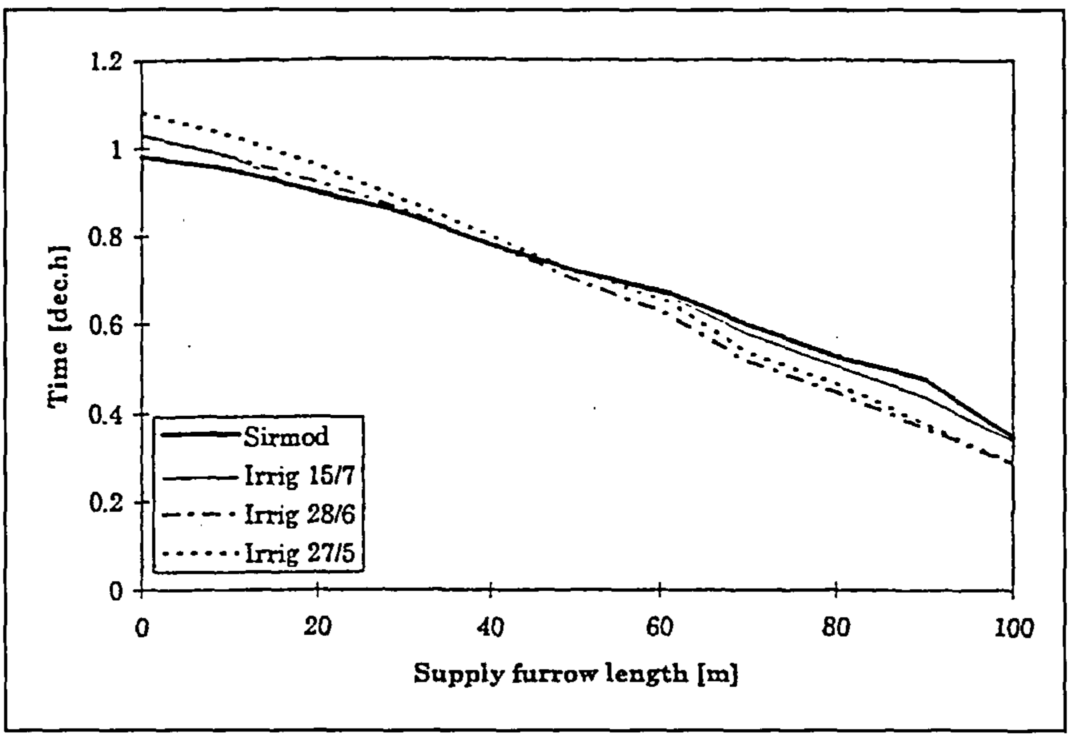
$$Z = K * T^a + f_0 * T$$

where
- Z = depth of application (m^3/m)
- K,a = infiltration parameters determined by the soil
- fo = parameter for constant rate of infiltration (m/min)
- T = contact time between the water and the soil (min)

The measured front advance times, cross-sectional dimensions and flow depths of the twelve short experimental furrows were used to establish values for K and a in the equation for the site soil. The calculated infiltration rate for each furrow corresponded closely with the dynamic infiltration rates measured during the experiments. Values of K and of a, which were considered to be representative of the soil, were then used to run a SIRMOD simulation of water flow and infiltration losses in the supply furrow. (SIRMOD is a surface irrigation simulation program developed by the Utah State University.) The standard SIRMOD simulation normally used for flood irrigation design was modified and used in an iterative mode for this purpose. The simulation results were then compared with three runs made previously on the 100-m long, full-scale experimental plot during actual irrigation runs. The simulation accurately predicted irrigation times and infiltration losses.

See Appendix 7.A entitled Determination Of The Infiltration Characteristics Of The Soil, which explains how to determine the values of the factors K and a.

Figure 7.4.4.1: Irrigation time – Comparison of experimental data with SIRMOD computer simulation



7.4.5 ESTIMATING THE EXPERIMENTAL INFILTRATION VALUES

As an alternative to the SIRMOD simulation and to confirm its general applicability, a computer program, FURROW, was developed, which enables supply furrow performance to be predicted directly from the infiltration experiments. This program uses as inputs the data obtained for the experimental runs done at the various flow rates that represent the position at the top end of the furrow (high flow rate) through to the bottom end of the furrow (low flow rate). A curve is fitted to percentage infiltration loss values and advance times, which enables the 30-m long furrow results to be extrapolated to any selected furrow length.

This method gave very similar results to the SIRMOD simulation and accurately predicted irrigation times and infiltration losses.

7.4.5.1 Supply furrow characteristics as simulated by FURROW.

For the purposes of illustrating the application of FURROW, consider a supply furrow serving a plot 100 m long and 10 m wide. The plot is divided into ten basins, each 10 m x 10 m, with the normal internal short furrows. The area of each basin is 100 m2 and, if the required application is 50 mm per application, the volume required per basin will be 5 m^3. The total net application for the whole plot would be 10 x 5,0 = 50 m^3

Referring to Table 7.4.5.1a, it takes 0,097 h to wet the full length of the furrow, and 1,330 h to fill the bottom basin because the effective flow rate after losses in the long 'dry' supply furrow is only 3,76 m^3/h. It only takes 0,543 h to fill the top basin because infiltration losses have now stabilised and the supply furrow is now very 'short', so that the flow rate into the basin is 9,2 m^3/h. The total elapsed time is 8,792 h and the total water used 87,919 m^3. The total net application is 50 m^3, so that the efficiency is 50 / 87,919 = 57%. This is obviously too low to be tolerated.

Table 7.4.5.1a: Example of FURROW printout for 10 m^3/h stream flow.

Furrow Length	:	100,000 m
Inlet Flow Rate	:	10,000 m^3/h
Number of Outlets	:	10

Summary of infiltration input data used :

Volume Flow (m^3/h)	% Infiltration over 30 m after 1 hour
5,000	31,400
10,000	24,500
15,000	15,800
20,000	8,100

Volume Flow (m^3/h)	Time (min) for water to progress 30 m
5,000	2,500
10,000	1,750
15,000	1,500
20,000	1,500

Time = 0,000 h, startup
Time = 0,097 h, furrow fully wet

Time = 1,427 h,	Plot 10 at	100 m,	took 5,0 m^3	in 1,330 h	at 3,76 m^3/h
Time = 2,617 h,	Plot 9 at	90 m,	took 5,0 m^3	in 1,191 h	at 4,20 m^3/h
Time = 3,686 h,	Plot 8 at	80 m,	took 5,0 m^3	in 1,068 h	at 4,68 m^3/h
Time = 4,647 h,	Plot 7 at	70 m,	took 5,0 m^3	in 0,961 h	at 5,20 m^3/h
Time = 5,513 h,	Plot 6 at	60 m,	took 5,0 m^3	in 0,867 h	at 5,77 m^3/h
Time = 6,298 h,	Plot 5 at	50 m,	took 5,0 m^3	in 0,784 h	at 6,38 m^3/h
Time = 7,009 h,	Plot 4 at	40 m,	took 5,0 m^3	in 0,712 h	at 7,03 m^3/h
Time = 7,657 h,	Plot 3 at	30 m,	took 5,0 m^3	in 0,648 h	at 7,72 m^3/h
Time = 8,249 h,	Plot 2 at	20 m,	took 5,0 m^3	in 0,592 h	at 8,45 m^3/h
Time = 8,792 h,	Plot 1 at	10 m,	took 5,0 m^3	in 0,543 h	at 9,21 m^3/h

Total water used was 87,919 m^3

Table 7.4.5.1b: Example of FURROW prints out with 20 m^3/h stream flow

Furrow Length	:	100,000 m
Inlet Flow Rate	:	20,000 m^3/h
Number of Outlets	:	10

Time = 0,000 h, startup
Time = 0,083 h, furrow fully wet
Time = 0,475 h, Plot 10 at 100 m, took 5,0 m^3 in 0,392 h at 12,77 m^3/h
Time = 0,842 h, Plot 9 at 90 m, took 5,0 m^3 in 0,367 h at 13,61 m^3/h
Time = 1,188 h, Plot 8 at 80 m, took 5,0 m^3 in 0,346 h at 14,44 m^3/h
Time = 1,516 h, Plot 7 at 70 m, took 5,0 m^3 in 0,328 h at 15,25 m^3/h
Time = 1,828 h, Plot 6 at 60 m, took 5,0 m^3 in 0,312 h at 16,04 m^3/h
Time = 2,125 h, Plot 5 at 50 m, took 5,0 m^3 in 0,298 h at 16,80 m^3/h
Time = 2,411 h, Plot 4 at 40 m, took 5,0 m^3 in 0,285 h at 17,53 m^3/h
Time = 2,685 h, Plot 3 at 30 m, took 5,0 m^3 in 0,275 h at 18,21 m^3/h
Time = 2,951 h, Plot 2 at 20 m, took 5,0 m^3 in 0,265 h at 18,85 m^3/h
Time = 3,208 h, Plot 1 at 10 m, took 5,0 m^3 in 0,257 h at 19,45 m^3/h
Total water used was 64,153 m^3

Table 7.4.5.1b reflects the position when the stream flow is increased to 20 m^3/h (a realistic upper limit). The time taken to wet the furrow is much the same, but it now only takes 0,392 h to fill the bottom basin and the total elapsed time is now 3,208 h. The stream flow has doubled, but the time taken to do the job is not half but nearer one-third.

Efficiency is now 50 / 64,153 = 78%.

Thus, it is possible to evaluate various combinations and permutations during design, provided the basic infiltration data has been established.

7.4.6 DEALING WITH SUPPLY FURROW LOSSES IN PRACTICE

Water losses from unlined channels (and therefore from supply furrows) in sandy soils pose a serious problem. Most water will be lost before it reaches the irrigated fields. The consequences of unlined in-field supply furrows in such sandy areas are even more severe, since the inevitable result is waterlogging of the entire irrigated area. Sealing the main and secondary canals with concrete or bituminous products can prevent such conveyance losses. Otherwise, pipes can be used.

A thin-walled plastic lay-flat pipe of 150 mm diameter could be substituted for the supply furrow. These pipes are cheap and efficient but are vulnerable to mechanical damage and must be handled carefully. They can be cut and overlapped by about a metre wherever water needs to be diverted into cross furrows. The pipes can be slid out of one another to let the water out, and folded over to stop the outflow.

Infiltration tests for short-furrow irrigation planning must be done according to a dynamic, simulated furrow system, as described in the appendix. A static determination, eg, with a double ring infiltrometer, is not acceptable, especially for crusting soils. However, it is impossible and unnecessary to do furrow infiltration tests for all the soils in an area. A small number of **representative dominant irrigable soils** in a specific area must be carefully selected for these determinations. The results of these could, at first approximately, also be used for similar sub-dominant or rare soils in the area.

It should therefore be possible to take infiltration losses in supply furrows into account for all short-furrow designs. In the case of identified high-infiltration soils, it can be assumed that the supply furrow would be sealed or lined, and there is little point in doing tests.

Flow control is mainly intuitive - each farmer diverts water from the secondary canal at a flow rate he prefers. This does not present a problem, as there is a natural limit to the flow rate that a farmer can handle comfortably.

7.4.7 TSHIOMBO: A CASE STUDY

7.4.7.1 Introduction

The irrigation scheme at Tshiombo is about 1 000 ha in size, divided into plots of 1,28 ha. Water is supplied by means of a canal from a weir in the Mutale River and distributed to the plots by secondary canals. The scheme is divided into four blocks and the water supply is rotated so that each block receives water once a week, according to a timetable that is effective during the dry season. The farmers use flood irrigation to water their crops, which include maize, sweet potatoes, groundnuts, tomatoes and other vegetables.

7.4.7.2 Measuring method

Infiltration measurements were performed at five different sites on the Tshiombo irrigation scheme. These sites were chosen to be representative of the different soil types found on the scheme, and included one clay, one sandy soil, two sandy loams, and one loamy sand site.

During the tests, water was turned into the distribution furrow and allowed to run for 50 m before cutting off the supply. The inflow rate at the top of the furrow was measured, using a V-notch, and the advance time of the water was taken every two metres. The profile of the furrow was measured at intervals, and the slope determined by survey instrument.

Soil samples were taken at each site; the type and texture of the soils were inspected using a simple soil test, and the infiltration rates were measured with a ring infiltrometer.

The test results are summarised in Table 7.4.7.3.

7.4.7.3 Interpretation of test results

The data acquired through the tests were used to estimate the Kostiakov-Lewis infiltration parameters for each case. These parameters were then entered into SIRMOD, and a number of runs were simulated to establish better values of the parameters by means of an iteration process. The data obtained from four of the five tests could be fitted successfully and, after the final values had been determined, runs were simulated for other circumstances than the original ones in order to create an infiltration model for each case. These models were then used to simulate the irrigation of a complete plot served by a supply furrow,

Table 7.4.7.3: Summary of simulated results

Site number	Time (hours)	Vol. Water (m^3)	Efficiency (%)
1	1,896	11,375	68
2	1,781	12,469	62
3	3,494		
4	4,635	14,833	52
Average	2,952	12,892	60

The highest efficiency obtained was 67,69% at Site 1. It would appear that water is being wasted in the field – on a scheme where the water supply is already inadequate. According to the simulation on Site 3, which was on very sandy soil, the stream in the supply furrow did not even reach the ninth take-off at 80 m from the top.

From discussions with the farmers, the average time to irrigate one plot was found to be three hours, which coincides well with the simulated average of 2,95 hours. It was said that three farmers could irrigate from one secondary canal at the same time, but up to twenty farmers had to share one such canal and water was let into it only once a week. This means that it would be impossible for each farmer on this secondary canal to irrigate his whole plot every week. On the assumption that the area of the plot was 0,1 hectare, the gross application would be 13 mm, or less than 2 mm/day.

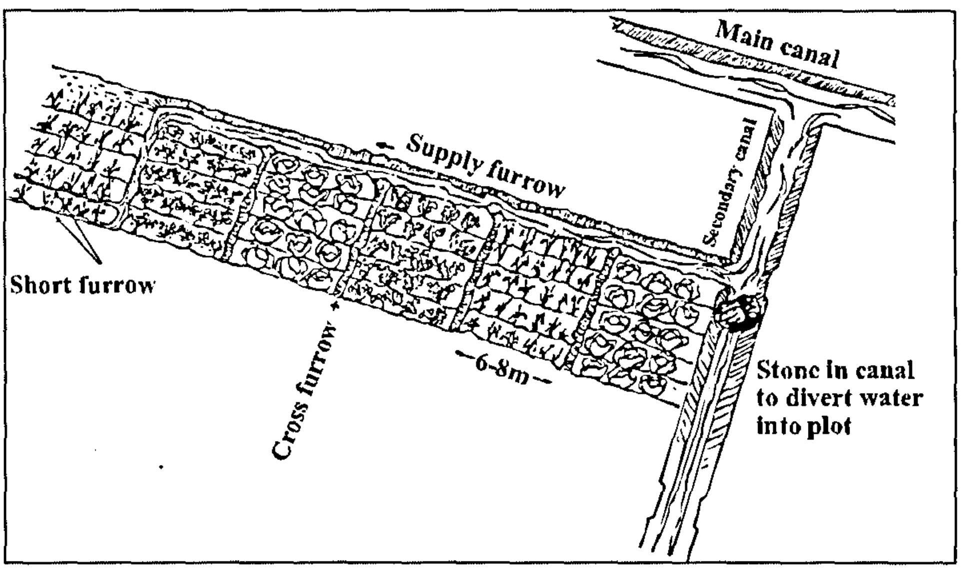
7.4.8 DINGLEYDALE AND NEW FOREST: A CASE STUDY

Farmers at the Dingleydale and New Forest schemes use the short-furrow irrigation method, which is an indigenous modification to long furrow irrigation. It is highly manageable and requires comparatively little in terms of permanent infrastructure and maintenance. However, this simplicity of operation is only possible through correct system design, which requires a balance between water flow rates, furrow slope and length for the specific soil. In this method, the farmer prepares his plot by first ploughing followed by disking the soil on the contour. Ridges are then made to form a strip of three to six furrows, about 1 m wide and 200 mm deep. These long strips, between 50 and 120 m long, are subdivided into sets of furrow basins approximately 8 to 10 m long, by constructing **cross furrows** with a hoe at right angles across the strip. Each set of basins should be as level as possible so that the water infiltrates evenly into the soil, ensuring uniformity of irrigation application.

The top furrow is used as a supply furrow to convey water to each of the cross furrows. Water is diverted into the supply furrow from a **secondary canal** (concrete) by placing an obstacle in this canal just downstream of the supply furrow inlet. The flow rate into the supply furrow is regulated by the size of the obstacle, which can be a large stone, a sandbag or a metal plate. It should not completely stop the flow of water otherwise farmers further along the secondary canal cannot irrigate at the same time. If several farmers irrigate at the same time, it is unlikely to achieve equitable distribution

The secondary canal gets its water from the main concrete canal, which brings water to the top of the lands from a dam or river, often over several kilometres. Thus, water is carried from the river to each short furrow via a main canal, a secondary canal, a supply furrow and a 6m cross furrow as shown in Figure 1. The farmer diverts water from the secondary canal into the supply furrow, walks along the ridge beside the water as it flows along the supply furrow and makes sure all cross furrows are closed and that the supply furrow is open, until the water reaches the last cross furrow into which the water is then diverted. The stream is diverted into the furthest short furrow and thereafter each subsequent short furrow is filled in succession from the cross furrow, working back to the supply furrow. The farmer can choose how much water to allow into a furrow before pushing a hoe-full of earth into the top end of the furrow to block it, thus very effectively controlling the amount of water applied. Sometimes, particularly when the plants are still young, the furrow may be blocked before the water reaches the end of the furrow. When the plants are bigger and need more water, water may be allowed to dam up from the ridge at the bottom end of the furrow to fill the full length before the furrow is blocked. When the last short furrow is opened, water is diverted from the supply furrow into the set that is to be irrigated next. The water left over in the cut-off section of supply furrow is enough to fill that last short furrow of the set below. This avoids water wastage. In this way, the farmer works back to the secondary canal, making the most efficient use of water all the way. From field tests done at Dingleydale, it was found that it takes between 20 and 40 minutes to irrigate one typical plot of 0,055 hectare. (110 m x 5 m).

Figure 7.4.8: Typical layout of short furrow system in South Africa



7.4.8.1 Measuring infiltration characteristics

During research conducted by the ARC-ILI in 1997, it was found that the **application efficiency in short furrows is generally high.** This means that most of the water in the short furrows actually reaches the roots of the plants being irrigated. Distribution uniformity in the short furrows can achieve 80–90%. This is a feature of small-basin and short-furrow irrigation, provided the basins/furrows have a slope of less than 1:300. On a steep gradient of 1:100, the uniformity of distribution was below 40%, largely due to unequal damming in the short furrow. **Self-scheduling** (controlled depth of application) occurs in flood irrigation to some extent because dry soil absorbs more water than wet soil, so the same plot will take longer to irrigate after a dry, hot week than after a cool week and this results in a larger irrigation application. The overall irrigation efficiency in the **system may not be so high if significant losses occur in the supply furrow.** Consequently, three tests to determine the characteristics of earth supply furrows on the schemes were conducted on two different soils in the scheme. Water was let into the supply furrow as would be done during a normal irrigation. The advance time of the water down the furrow at 2 m intervals and the flow rate into the top end of the furrow were recorded for the duration of the tests. After the water had passed through the furrow, the furrow dimensions (top, middle and bottom width, and depth) were measured at 10 m intervals. One of the tests was discarded due to the large variation of the flow rate into the supply furrow during the test. The other two were representative of two different soil types and furrow lengths, referred to here as Test 1 and Test 2. A summary of the data that is shown in Table 5.

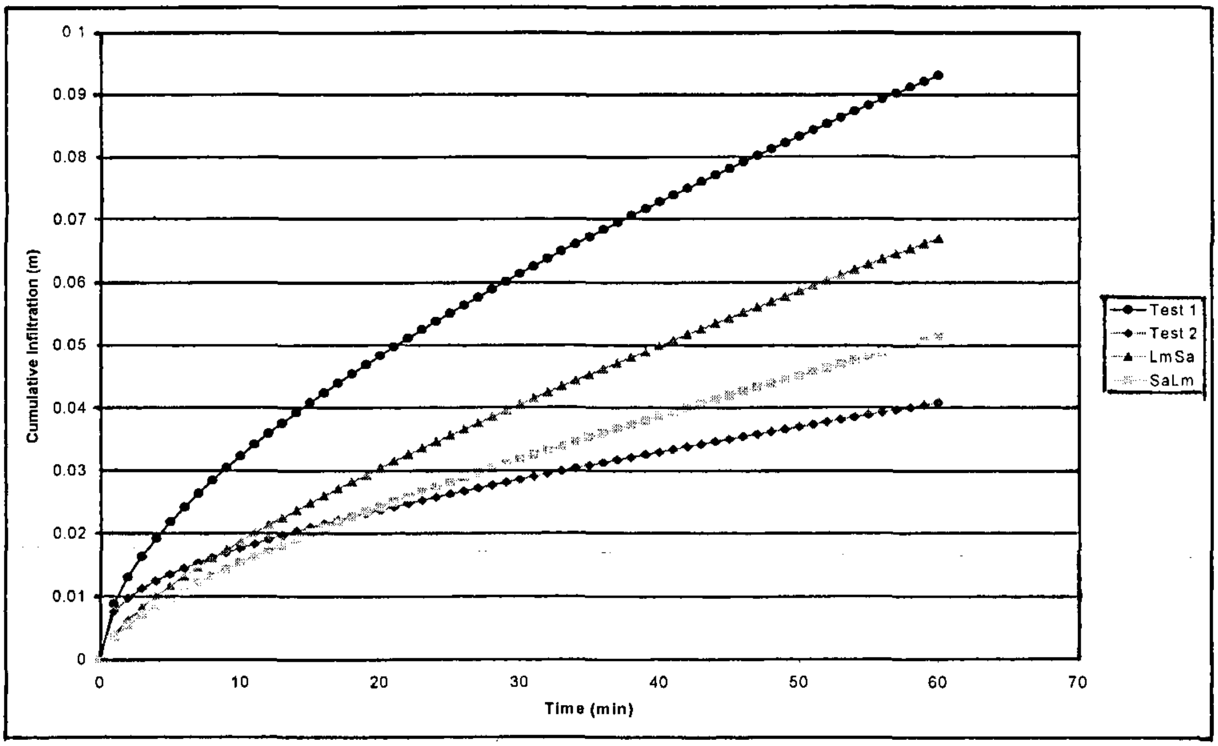
Table 7.4.8.1: Summary of test data

	Soil type	Length	Average slope	Average flow rate	Advance time to end of furrow
Test 1	Sandy	60 m	0,29%	16 m^3/h	6,65 minutes
Test 2	Loamy sand	105 m	0,55%	16 m^3/h	8,27 minutes

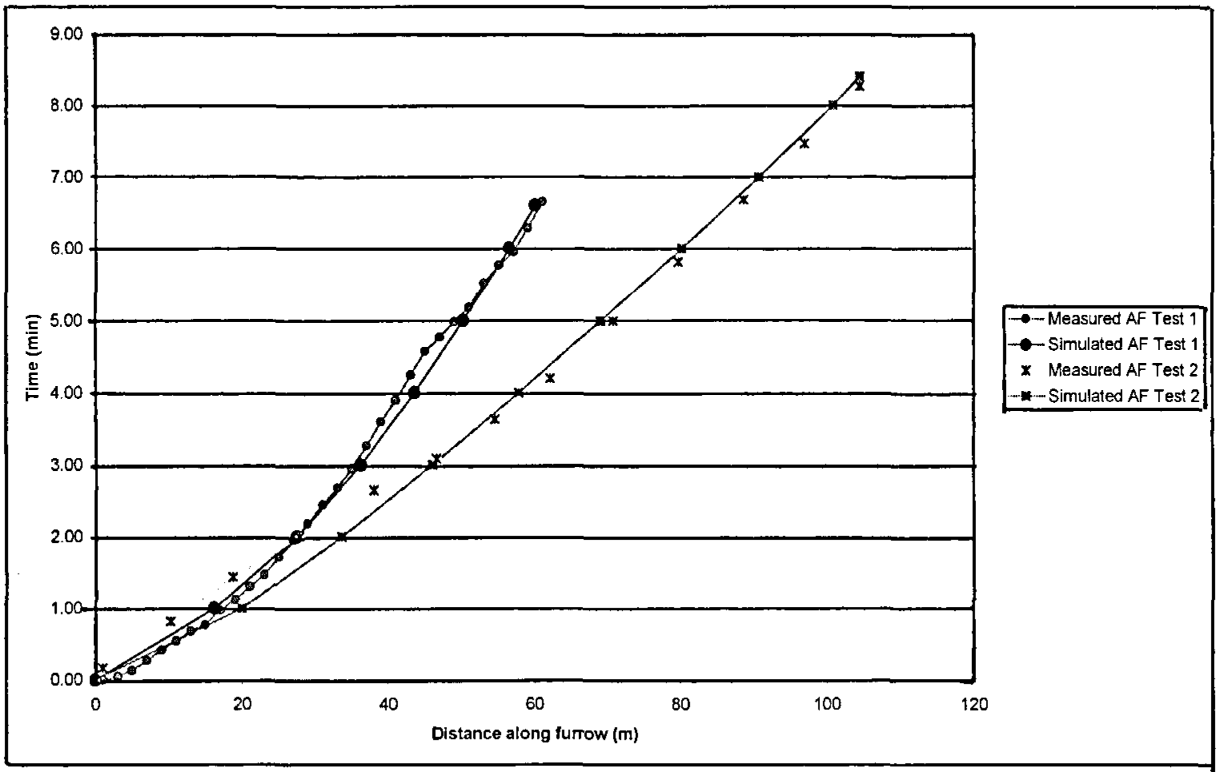
This information was then used to determine the Kostiakov-Lewis infiltration parameters (k, a and fo) for the two soils, and their infiltration curves plotted. The curves are shown in Figure 7.4.8.1, together with those of a known loamy sand and sandy loam soil. From the graph, one can see that the soil from Test 1 has a high infiltration rate, as can be expected due to its low clay content. Graph 7.4.8.1a shows the results of the advance front measured graphically for Test 1 and Test 2. The longer advance time of Test 1 compared to that of Test 2 at the same distance along the furrow is significant, once again due to the higher infiltration rate of the soil. In order to determine losses in the supply furrow during irrigation, the decrease in flow rate along the furrow (due to infiltration) must be known. This is very difficult to measure in practice but can be calculated fairly accurately using the information that was gathered during the tests. A computer program called SIRMOD was used to simulate the two tests and the results are shown in Graph 7.4.8.1b, together with the measured values. The simulated values compare well with the measured values with no divergence of the curves, therefore the calculated values for the flow rate at various points along the supply furrow can be accepted as a good estimation.

Test 2 included the observation and data recording of a complete irrigation by a farmer. The plot consisted of 13 blocks, each between 7,6 and 10,2 m long and containing three or four short furrows. The data recorded included the advance time of the water to outlet to the last block and the subsequent times to irrigate each of the blocks. Using this information, the complete irrigation was simulated in SIRMOD and the volume of water actually applied in each of the blocks were calculated by multiplying the estimated flow rate to the specific block by the measured time it took to be irrigated. Then, since the total amount of water used for the complete irrigation was known, the efficiency could be calculated.

Graph 7.4.8.1a: Infiltration Curves



Graph 7.4.8.1b: Measured and Simulated Advance front



7.5 DISTRIBUTION UNIFORMITY IN SHORT FURROWS

The efficiency of a short-furrow flood irrigation system is not only dependent on the infiltration losses in the supply furrow, but also on the distribution uniformity of the application in the short furrows. Since the results from the SIRMOD simulations of the supply furrow losses compared well with the field data from the experiments, it was decided that the programme could be used to produce a set of design guidelines for the application of water using the short furrows.

The shape of the furrow used for the simulations was taken as parabolic, with a maximum flow depth of 0,18 m and considered blocked at the bottom end. The simulations were performed for two lengths of furrows (10 m and 20 m), for two flow rates (5 and 10 m^3/h), at two gradients (1:300 and zero), for three different soils (sand, loam and clay).

The aim of the simulations was to determine the approximate time of application required under the various circumstances while aiming for distribution uniformity higher than 90%. As can be observed from the tabled results, this could not always be achieved, due to certain combination of the influencing factors.

7.5.1 FACTORS THAT INFLUENCE EFFICIENCY

7.5.1.1 The gradient of the furrows

It was found that the distribution was most uniform at a flat gradient, regardless of the flow rate or soil type. Since the furrows are blocked at the bottom end, a steep gradient caused damming at the bottom end and thus uneven distribution.

7.5.1.2 The flow rate of the water

The effect of the flow rate is dependent on the gradient. At a flat gradient, a higher flow rate is more desirable. The reason is that, in the case of a low flow rate, a high percentage of water infiltrates at the top end of the furrow, because the contact time is longer than for the same volume of water applied at a high flow rate. At a steeper gradient, a low flow rate will induce a more uniform distribution. A high flow rate together with a steep gradient will cause all the water to run to the bottom end of the furrow and result in uneven distribution.

7.5.1.3 The soil type

The effect of the soil type is also dependent on the gradient. At a flat gradient, soil with a high clay content makes for better distribution uniformity than sandy soil. This is due to the low infiltration rate of clay combined with the long contact time resulting from the flat gradient. In the case of a steep gradient, however, sandy soil is more desirable. The shorter contact time as well as the high infiltration rate of the soil causes the water to start infiltrating immediately and minimise damming at the bottom end of the furrow.

Table 7.5.1.3: Possible Gross Applications (GA) mm at high Distribution Uniformity (DU)

Soil: Loam			**Gradient**			
			1:300		**Zero**	
			L = 10 m	**L = 20 m**	**L = 10 m**	**L = 20 m**
Flow rate (m^3/h)	5 m^3/h	Ta(min)	1,0	2,8	2,0	4,9
		Tc(min)	0,55	1,2	0,8	3,3
		GA(mm)	6,25	6,25	8,33	17,1
		DU(%)	72	89	86	87
	10 m^3/h	Ta(min)	0,9	1,8	1,0	2,2
		Tc(min)	0,2	0,6	0,35	1,2
		GA(mm)	4,375	6,67	7,3	12,5
		DU(%)	90	80	91	91

Soil: Sand			**Gradient**			
			1:300		**Zero**	
			L = 10 m	**L = 20 m**	**L = 10 m**	**L = 20 m**
Flow rate (m^3/h)	5 m^3/h	Ta(min)	0,9	2,5	1,0	3,2
		Tc(min)	0,6	1,3	1,2	3,0
		GA(mm)	6,25	6,78	12,5	15,63
		DU(%)	80	82	95	85
	10 m^3/h	Ta(min)	0,6	1,6	0,75	1,8
		Tc(min)	0,23	0,55	0,6	2,0
		GA(mm)	4,79	5,73	12,5	20,83
		DU(%)	75	90	98	95

7.6 RECOMMENDATIONS FOR DESIGN

7.6.1 FLOW RATE IN SUPPLY FURROWS

Flow rates in earth furrows should be as high as possible. Limiting factors are:

- scouring or erosion
- manageability of the stream

7.6.2 SUPPLY FURROW LENGTH AND LAYOUT

Percentage irrigation efficiency is a product of the percentage application efficiency in the short furrows and the percentage losses in the supply furrows.

The percentage application efficiency in the short furrows can easily be determined and is a function only of the short-furrow gradient, provided the flow rate is high enough and the furrow is short enough to be filled rapidly.

By deciding the acceptable level of overall irrigation efficiency, the acceptable percentage losses (ie, infiltration) in the supply furrow can be determined. This then determines the maximum acceptable length of unlined supply furrow in a specific soil.

Each supply furrow should be used to irrigate as much land as possible. Overall losses can be limited by using the same supply furrow uninterrupted, rather than using a number of supply furrows consecutively, because infiltration is very high during the initial wetting of a supply furrow, and decreases rapidly until the infiltration rate stabilises.

7.6.3 SUPPLY FURROW GRADIENT

Gradients should be in the region of 1:300. Flatter gradients could be used if the construction is very precise, or in other words, if a very uniform gradient can be obtained over the length of the furrow.

7.6.4 RECOMMENDED FURROW WIDTH

Within the flow rate ranges measured, furrows may easily stabilise at 400 mm wide, and even wider if the furrows slope is uneven. Furrows should not be spaced less than 700 mm apart, otherwise they may collapse their ridges.

7.6.5 EROSION PREVENTION

The top section of the furrow should be sealed to prevent erosion at the top of the furrow because continued scouring increases seepage losses.

7.6.6 RECOMMENDED DESIGN NORMS

Table 7.6.6: Short-furrow lengths and maximum advance times

FURROW GRADIENT LEVEL			
Soil	**Furrow length m**	**Flow rate m^3 / h**	**Max time min**
Clay	30	5 – 15	5
Loam	20	7 – 15	4
Sand	10	10 –15	3
FURROW GRADIENT 1 : 300			
Soil	**Furrow length m**	**Flow rate m^3 / h**	**Max time ins**
Clay	15	5 – 15	4
Loam	12	7 – 15	3
Sand	10	10 – 15	3
FURROW GRADIENT 1 : 100			
Soil	**Furrow length m**	**Flow rate m^3 / h**	**Max time min**
Clay	4	5 – 10	2
Loam	6	7 – 12	2
Sand	8	8 - 15	2

7.7 CONCLUSIONS AND RECOMMENDATIONS

The essential elements of designing and laying out short furrow flood irrigation systems have been established. It will, however, be necessary to ensure that all concerned with irrigation development in the deep rural areas be made aware of these procedures. A special publication supported by training courses may be desirable. It will be necessary to follow up developments in the field in order to establish area specific norms and guidelines.

Well managed the more conventional irrigation methods have a place in small-scale farmer irrigation projects but there are inherent dangers that should be brought to the attention of planners.

APPENDIX 7.A. DETERMINATION OF THE INFILTRATION CHARACTERISTICS OF THE SOIL

The infiltration characteristics of the soil are of paramount importance in the proper design of furrow-basin systems. These characteristics of the soil ultimately determine the percentage of water lost in the supply furrows, and they must be taken into account when making decisions regarding furrow length and gradient.

7.A.1. *Infiltration characteristics of soils as determined by the Walker two point method*

The key element in describing the infiltration characteristics of a soil is in determining the rate at which water will infiltrate at various points along the length of the furrow after a certain period of time has elapsed.

The two-point method of Walker is recommended, as this method closely approximates the practical use of an irrigation furrow. It is also very well suited to determining the relationship between the infiltrating water, the soil and contact time.

In this section, the empirical relationships between the various parameters are introduced. Methods for practical determination of data to be used in these relationships are discussed later.

The procedure followed here for estimating parameters is based on the method described in detail by Walker. The relationship between the position of the advance front of the water in the furrow, and the time elapsed since water entered the furrow can be described by the simple power function:

x = p(tr) (1)

where:	x	the distance the front has advanced	[m]
		(inlet x = 0; outlet x = L = the furrow length)	
	t	time elapsed since entering the furrow	[min]
	pr	empirical constants determined experimentally	

By substituting measured values for x and t, any appropriate curve fitting routine, such as the least squares method, can be used to determine the coefficients p and r, in order to solve equation 1 for the two points (t0,5L, x = 0,5L) and (tL, x = L).

The relationship between the volume of water infiltrated and the time elapsed since entering the furrow can be described by the Kostiakov-Lewis equation:

Z = k ta + fo t (2)

where	Z	average infiltrated volume per unit length	[m^3/m]
	t	infiltration time	[min]
	fo	basic, or equilibrium intake rate	[m^3/(m/min)]
	k[?],a	experimentally	

Using essentially the above equations, and providing for complications introduced by the varying cross-sectional flow area of water along the furrow length, Walker derives an equation describing a volume balance for any time during the wetting event.

$$Q0 = Qy\ A0\ x + Qz\ k\ ta\ x + fo\ t\ x /(l + r) \qquad (3)$$

where:

Q0	Inlet discharge	[m^3/min]
A0	cross-sectional area of flow at the inlet	[m^2]
t	elapsed time since irrigation started	[min]
Qy	surface storage shape factor, a constant Normally 0,7 to 0,8	
Qz	subsurface shape factor	

The unknowns *k* and *a* in Walker's third equation can be determined by solving it for the points (0,5L, t0,5L) and (L,tL), using the experimentally determined values. The substitution of the experimental values yields two equations that can be solved simultaneously.

Rearranging terms and using a logarithmic transformation to linearise the two equations, yield:

$$a = \ln (VL/V0{,}5L) / [\ln(tL/t0{,}5L)] \qquad (4)$$

where: $$VL = (Q0tL/L) - (Qy\ A0) - [fotL/(1+r)] \qquad (5)$$

and $$V_{0,5L} = (2Qo\ t0{,}5L / L) - (Qy\ A0) - [fotL/(1+r)] \qquad (6)$$

Once the coefficient *a* is known, the value of Qz can be found from the relationship:

$$Qz = [a+r(1-a)+1] / [(1+a)(l+r)] \qquad (7)$$

With both *a* and Qz known, the value of *k* is obtained by solving:

$$k = VL/QztLa) \qquad (8)$$

7.A.2. *Practical determination of the infiltration parameters p,r,k,a,fo and A0 with a dynamic infiltration test*

At present, there are no quick methods for obtaining values for the parameters describing the infiltration behaviour of a specific soil. There are no tabulated values, nor are there any empirical relationships which can be used to estimate k, a or fo without measured field data. In order to determine reliable values of the parameters, a number of practical experiments with test furrows are therefore required.

The following is a step-by-step description of a method that can be followed to obtain the necessary data to evaluate the above equations.

1. On the field to be developed, construct one test furrow (but preferably at least three), with an even slope of 1:300, and a length of at least 50 m. The furrows must have a uniform shape and slope so that ponding is prevented. If different soil types are encountered on the field to be irrigated, construct a set of furrows on each soil type because the results obtained from one soil type cannot be used for making predictions for another soil type.

   It is important to construct furrows on ploughed land because the presence of a large percentage of organic matter such as grass, roots, etc, changes the infiltration characteristics significantly. If the field is covered with vegetation, the field, or a section thereof, must be ploughed and left for at least a month before the experiments are conducted.

2. Place markers at 2-m intervals along the length of each furrow.
3. Determine the actual gradient of each furrow at each of the 2-m markers before each irrigation event. This repeated determination of the gradient is necessary because water flowing in a furrow alters the shape of the furrow.

4. Determine the shape of each furrow at every 2-m marker. The following measurements must be noted:
   - the width of the furrow at the top,
   - the width of the furrow halfway between the top and the bottom,
   - the width of the furrow at the bottom, and
   - the depth of the furrow.

   In practice, the shape of a furrow can differ substantially over a very short distance. If significant variations in furrow dimensions are observed at the marker where measurements are to be taken, obtain a representative value for the dimensions listed above by taking the average of at least three measurements.
5. Divert water into the test furrow. The flow rate of the water must be kept as constant as possible and a flow rate of approximately 10 m^3/h is recommended at the inlet to a furrow. An accurate flow meter or calibrated V-notch weir must be used to determine the flow rate at the inlet.
6. Record the exact time at which the advance front of the stream reaches each of the 2-m markers. Repeat this process for each test furrow.
7. Measure the depth of the water and the width of the furrow at the water surface level, at a point approximately 0,5 m beyond the inlet, after the water has advanced to end of the furrow, ie, when the flow at the inlet region is well established. Directly after the wetting event, determine the shape of the inlet region (at the same point where the water depth has been determined) by taking the following measurements:
   - the width of the furrow halfway between the previously recorded water depth and the bottom of the furrow; and
   - the width of the furrow at the bottom.

These measurements are used to determine the cross-sectional area of the water stream at the inlet. If significant variations in furrow dimensions are observed at the point where measurements are to be made, obtain a representative value for the dimensions listed above by taking the average of more than one measurement.

It is important to note that infiltration characteristics of a soil change during the first few wetting events. Parameters obtained for a freshly tilled furrow can only be used for predictions regarding freshly tilled furrows. The experiments described above must be repeated at least three times, allowing the soil to dry for a least one week between experiments. The drying period between experiments must be similar or equal to the anticipated interval between future irrigation events.

The following is an example of a typical data sheet that can be used for tabulating results for approximate furrow irrigation:

Figure 7.A.2: A typical data sheet

Experiment No:				**Date**	
Description:				**Time**	
Location:					
Flow Rate:					
Wetting Event No:					
Furrow No:					
	Advance time	**Width (top)**	**Width (mid)**	**Width (bottom)**	**Depth**
Marker 1	2 m				
Marker 2	4 m				

7.A.3. *Determination of fo*

In order to solve the equations for determining the infiltration characteristics of a soil type, it is important to obtain an accurate estimate of *fo*, the basic or equilibrium intake rate of the soil.

At the third test, a V-notch can be installed at the ends of each furrow. The V-notch weir at the downstream end of the furrow must be installed so that the least amount of water is dammed up due to the presence of the V-notch weir. A fairly steep section ~1:150 ~5 m at the downstream end of the furrow will be ideal to install the V-notch weir at the end of that section.

After the manual measurements have been taken, keep the flow rate constant and measure the weirs at regular intervals (15 minutes at the most).

Record the flow rate of the water in and out of the furrow for approximately three hours, or until the flow rate out of the furrow has reached and maintained a constant value for thirty minutes. For the majority of South African soils, a three-hour duration would be enough for the infiltration rate to stabilise.

Although the procedure explained above is recommended, a ring infiltrometer may also be used to obtain an indication of fo, provided it is driven at least 150 mm into the soil layer, the infiltration rate is measured over a three-hour period, and the soil surface is not disturbed by the test.

Chapter 8

COMMUNITY GARDENS

See also ***Irrigation Design Manual*** (Institute for Agricultural Engineering, 1997) for definitions and further information about irrigation design in South Africa.

TABLE OF CONTENTS

8.1 INTRODUCTION 8-1
8.1.1 Food plots 8-1
8.2 REVIEW OF FIELD INVESTIGATIONS 8-2
8.2.1 The role of community gardens 8-3
8.2.2 How community gardens are organised 8-3
8.2.3 Irrigation methods and management 8-4
8.2.4 Water supply 8-5
8.2.5 Water storage 8-6
8.2.6 Fencing 8-6
8.2.7 Approach to infrastructure 8-7
8.2.8 Case studies of gardens 8-7
8.2.9 Planning Community Gardens 8-9
8.2.10 Water delivery and application design criteria 8-11
8.2.11 Irrigation requirements and costs 8-13
8.2.12 Water and soil quality 8-14
8.3 CONCLUSIONS AND RECOMMENDATIONS 8-15

APPENDIX 8.A. LAYOUTS OF SOME OF THE COMMUNITY GARDENS VISITED 8-16
APPENDIX 8.B. MILESTONES AND RESPONSIBILITIES IN THE DEVELOPMENT OF COMMUNITY GARDENS 8-21

TABLES

Table 8.2.10.1: Furrow lengths and maximum advance times 8-12
Table 8.2.10.2: Discharge from garden hoses 8-12
Table 8.2.11: Irrigation and cost data for five community gardens in the Northern Province 8-13

8.1 INTRODUCTION

Community gardens are located in any area where a community has settled. These areas may be small villages in the rural areas, or fairly large rural towns, or even urban settlements. The size of the gardens can vary too, anything from a hectare to ten hectares. They are communal in the sense that a number of people share the infrastructure, and there is generally an overall management committee responsible for the maintenance of infrastructure and the orderly management of the garden.

The production from community gardens is making a major contribution to food security. The total number of community gardens in the country at the moment can be reckoned in thousands. When it is appreciated that there may be anything from twenty-five to a hundred participants in each community garden, it is evident that a large number of people are concerned. They are producing food at relatively low cost but, more importantly, they are producing it where the people actually live.

Normally, only a minority of the residents in a community is interested in gardening on any scale. However, there are residents who are enthusiasts. Some of what they grow is for their own use and for friends, but the bulk of the production is for sale, so that each participant in a community garden is essentially a commercially-orientated small farmer, and should be regarded as such.

Some community gardens are successful; many are not. The successful gardens were usually developed on the initiative of the community. It is where the infrastructure was provided by an external agency and the community was presented with a fenced area, irrigation system, water supply, etc, on a plate, that the results are often unsatisfactory.

However, where a group of farmers, very often women, club together of their own accord, the chances are that the enterprise will flourish. They contribute finance, help with the clearing of an area and the fencing, elect a managing committee and then as a body go to the authorities for assistance with the development of a water source. However, sustained success often depends on an individual, who may be the chairman of the managing committee, or a dedicated extension officer.

For all practical purposes, the participants are market gardeners. They each work their own allocated area for their own profit. There are sometimes a number of communal plots on which the participants take turns to provide labour and inputs, and the proceeds are used to provide for fuel, repairs and similar common expenses. The all-important management committee keeps full records.

The availability of water is a major problem. Sinking and equipping a borehole is expensive, and mechanical maintenance of engines and pump can be a difficulty so some community gardens carry water by hand over considerable distances to water the crops.

In gardens that are developed with outside funding, there is a tendency to over-elaborate the irrigation equipment. Often, what is required is just a source of water. The actual application can be done by hose, or by bucket, provided that there is sufficient water and it is in the right place.

8.1.1 FOOD PLOTS

One of the strategies adopted on the original Bantu Affairs irrigation schemes was that of the food plot, which had much in common with present-day community gardens. The food plot size was normally about one-tenth of a hectare. In the Eastern Cape, for example, and in some schemes in the Northern Province, the basic schemes were laid out to cater for plots of 1,28 ha for each farmer but, in order to accommodate the large number of people who wanted land, the 0,1-ha plots were allocated separately. They were irrigated out of the same system and the larger plots were really a multiple of the smaller food plots.

Much the same practice has been followed with the new developments at Komati in Mpumalanga, in that, on the same schemes that are laid out for ±10-ha sugarcane plots, there is provision for food plots to produce vegetables and associated crops. The food plots are attached to irrigation schemes and obtain their water supply by courtesy of the larger scheme. It can be assumed that the bulk of the production from these food plots is for the family but they can also sell or barter their products to other members of the community. There are examples where the land allocation has been such that some of the better or more influential farmers who started with 0,1-ha plots have been able to acquire additional plots and to extend their holdings. Such food plots could feature in the reconstruction and rehabilitation of existing irrigation schemes.

A recent study of the current position in the Eastern Cape is a valuable contribution to policy formulation in respect to food plots. The comments that follow are abstracted from the executive summary of the report (Van Averbeek *et al*, 1998)

> Conceived as the social component of irrigation scheme development, food plot sections were introduced into irrigation scheme design to compensate land right holders for making available their land for the development the scheme. Yet, food plots have been one of the relatively successful aspects of irrigation scheme development in central Eastern Cape. Food plot developments offer a high degree of equity. This makes them attractive under conditions where land earmarked for irrigation is pre-owned and held under communal tenure.
>
> In schemes developed on land held in common property there is a need to strengthen the security by which food plots are held. This can be achieved by addressing limitations in the breadth, duration and assurance of the rights plot holders have over their plots. Enhancing security of tenure may lead to the development of a market for land rentals. Land transaction through rentals preserve equity and are expected to increase allocation efficiency.
>
> The results of the study suggested that an increase in the size of land holdings would be accompanied by a shift in the production objectives of farmers from subsistence to market
>
> oriented production and a concomitant increase in the proportional contribution of agriculture to household income. This shift was found to expose farmers to a number of new challenges, of which production practices, marketing and financial management were the most important.
>
> The shift was also found to create new demands in terms of scheme organisation and supply of support services. Factors such as ready access to inputs, good quality land preparation, a reliable water supply and expert extension co-determine successful small scale irrigated cropping. Well-organised farmers organisations were found to be able to handle many of these new challenges, and their development needs to be encouraged and supported.
>
> Designed to be a trap, by failing to incorporate the progression of farmers from subsistence oriented to market oriented producers into their design, food plot schemes do offer the possibility for progression. For progression to occur at these schemes suitable institutional reforms with respect to land tenure will need to be developed and adopted by land right holders.
>
> Whereas food plot schemes appear to be a suitable model of introducing irrigation on land held under communal tenure, it is not recommended for settlement schemes. The size of standard food plots (0,25 ha or less) is just too small to make irrigated agriculture a viable livelihood option. From the study it appeared that a minimum plot size of 2 ha is required in order for agriculture to become the main source of income for farming households.
>
> On settlement schemes farmer selection is of major concern. The experience at Horseshoe Irrigation Scheme showed that a system of voluntary entry and exit, whereby participation in the scheme demands farmers to make regular financial contributions towards the cost of water supply and its maintenance, had the desired results without causing undue social conflict. The success of this self-regulating system of farmer selection appeared to be heavily reliant on the presence of experienced farmer trainers and a good overall support system at the scheme.
>
> Generally, timely access to good quality land preparation services and 'to a ready supply of irrigation water were the two most important factors determining success in food plot production.

8.2 REVIEW OF FIELD INVESTIGATIONS

Community gardens tend to be located adjacent to peri-urban settlements or villages, where they are not on an irrigation scheme. They are intended to enhance food security and provide some semi-economic activities for the residents. In recent times in some provinces, the establishment of community gardens has been semi-formalised, particularly in areas that can be regarded more as urban areas than as rural areas. Usually, the plots are anything from one-tenth of a hectare down and they are operated by individuals.

8.2.1 THE ROLE OF COMMUNITY GARDENS

Community gardens provide rural and urban communities with an opportunity to improve their standard of living. Almost all gardeners consulted, who had been producing continuously for a number of seasons, produce considerably more than their family's consumptive needs. They then aim to sell vegetables to augment the family income. The vegetables provide a cheap food source and can reduce malnutrition, especially of children less than five years old. However, although vegetables are important for their vitamins, additional energy and protein sources are required: The money that is saved by being independent in vegetables is often used to buy cooking oil and other foods high in energy and protein.

Some women growers pointed out that their gardening enterprise makes them less dependent on the salaries earned by their menfolk in the cities.

Small-scale growers have full control over their project so they develop a broad spectrum of skills, while taking full responsibility for all production decisions, marketing, etc.

The total number of community gardens in South Africa is not known but there are a great many of them. On the assumption that there are at least five thousand gardens, averaging one hectare per garden (although many are considerably larger), there are more than five thousand hectares currently being gardened. If it is accepted that there will be at least thirty participants (although there are gardens with as many as ninety), it means that at least 150 000 people are taking part in vegetable gardening. Furthermore, if the average family size is taken as five, it means that at least 750 000 people in South Africa are benefiting directly from community gardens.

Community gardens benefit all the people in their community.

8.2.2 HOW COMMUNITY GARDENS ARE ORGANISED

It must be emphasised that gardens are not worked communally. The participants manage their own plots independently. However, they share common expenses and all matters are handled by the management committee. Normally, a management committee is elected and has seven members. The main duties of this committee are as follows:

- *arrange water supply and irrigation schedules;*
- arrange bulk buying of inputs – seed, fertiliser, etc.;
- buy diesel;
- receive contributions;
- keep records;
- arrange work schedule for fund-raising plot; and
- handle general garden matters.

The garden is managed according to a constitution, which is usually drawn up by the group with the help of an extension official. This constitution specifies action if a member defaults or abandons his/her plot, and the constitution is submitted to the tribal village authority for approval.

The extension officer (EO) plays an important role. Successful gardens very often have a committed EO who is easily available, trustworthy and knowledgeable. EOs not only teach people to grow vegetables, they help to plan and constitute gardens. Lady EOs also advise on other matters, for example, the cooking of vegetables, home economy, etc. EOs sometimes provide transport to buy inputs and can be important in developing local markets for the produce. They act as the link between the garden and the Department of Agriculture, and they arrange Women's Days, Farmers Days, agricultural shows, training, etc.

The role of the Departments of Agriculture varies in different provinces. There are several approaches to the services provided. Many departments provide maintenance of pumps and equipment. Some departments do the complete planning and design of gardens. Sometimes this is by request of the participants, where the officials or consultants consult them. But sometimes the gardens are officially organised and designed and handed to the community on a plate. Some departments in the old days provided subsidies in one form or another: free seed, diesel engines, fencing material, as well as an actual monetary subsidy. Some provided literally everything, including diesel. This pattern has changed in recent times, and many of the gardens are funded out of RDP funds after the submission of a business plan. It was noticeable that more technical advice is needed, and the greatest possible participation of the private sector, particularly the companies supplying equipment.

8.2.3 IRRIGATION METHODS AND MANAGEMENT

Considerable ingenuity and understanding is evident amongst gardeners. The irrigation methods used are:

- bucket:
  - from river,
  - from canal or furrow,
  - from collecting well,
  - from a tap stand,
  - from pipe outlet, and
  - from hosepipes.
- hosepipe:
  - from a tap stand.
- irrigation furrows:
  - fed by supply furrow,
  - fed by pipe, or
  - fed by hose.
- sprinkle irrigation:

  This is very seldom used for gardening, except when located near one of the larger schemes. Many gardeners are not very anxious to use sprinklers for vegetables.
- micro irrigation:

  Some homemade types – almost piped furrow irrigation schemes – are becoming used to a limited degree in specialist circumstances.

Unfortunately, as practised on many of the gardens, flood irrigation proved to have a poor distribution uniformity. However, there can be no doubt that, through re-design and better practices, very much improved efficiencies can be achieved. This is, to a large extent, a matter of training.

It is general practice to plant in wide rows, possibly to facilitate access to the plants for cultivation and insect control, but probably more to provide a moisture buffer in the soil profile. This is a defence against the inevitable interruptions in water supply, especially during dry periods and is undoubtedly a very sound approach. However, because fencing is so expensive, the additional land being used implies longer fencing, and this should perhaps be re-assessed.

Otherwise, the furrows so often used for irrigation vary widely, depending on the soil, the circumstances, and the personal preferences of the gardeners. Usually they are relatively short so that water can dam up and be specifically applied to the plants concerned.

An irrigation probe or spike can be used as one method of checking the amount of irrigation. One does this by seeing how far a sharpened reinforcing rod can be forced down into the soil. It is normally possible to judge how far the water has penetrated and how much water has been stored in the profile.

The estimation of crop water requirements developed by means of the program SAPWAT is specifically suited to catering for the type of planting pattern used on these community gardens, where the rows are wide and by no means all the surface is wetted.

8.2.4 WATER SUPPLY

Water supply is a major problem in community gardens. It is not only the availability; it is also the cost. In the more arid areas, the supply is usually dependent on boreholes, which are normally barely adequate to provide for human consumption and animal watering. There is seldom a surplus available for gardening purposes but sinking boreholes specifically for community gardens is an extremely expensive and often very chancy operation. After the expenses of drilling, there are the expenses of providing with pumping equipment and the necessary piping. Furthermore, quite apart from the amount of water that is available, and the limited pumping periods that are permissible if the borehole is to be sustainable, is the question of water quality. In many areas of the country, the water from boreholes is marginal for irrigation purposes. If this is coupled to unsuitable soils, the chances of being able to create a successful garden are greatly reduced.

The recent releases by the Department of Water Affairs and Forestry of national guidelines on underground water and its suitability for exploitation are a major advance and, in any preliminary investigation, these guidelines should be followed before money is expended on more detailed investigations.

There is a particular demand, obviously, for community gardens in arid or semi-arid areas where vegetables are extremely difficult to obtain and to produce. Unfortunately, in the deep rural areas in the arid parts of the country where community gardens can make a tremendous contribution to the well being of the communities, water is virtually unobtainable except at a great price. In many areas, particularly in KwaZulu/Natal, there are a large number of community gardens with very inadequate water supply. In many cases, community gardens are irrigated by water that has to be transported in wheelbarrows or by physically being carried by hand in containers. The water is then rationed out in small portions to each plant.

However, on some of the smaller plots, it can be advantageous to stay with bucket watering. Elaborate irrigation systems are out of place on community gardens and, very often, short-furrow irrigation or variations on this, supplied by a tap and hose, is more than adequate. The main issue here is that the water should be available on site and should not have to be carried from any distance at all. Additionally, it should be available at all times, so that the farmers can go and water as and when they can find the time to do so.

There is no simple solution to this water supply problem, although the actual irrigation technology once water has been made reliably available presents very few problems. If the garden is located near to a perennial river, most of the problems are solved, although equipment can still be lost or damaged in floods.

8.2.4.1 Pumps

Electricity is seldom available for pumping purposes in the rural areas. Diesel engines are most commonly used but lack of maintenance and delayed repairs are a serious and disheartening problem. Gardens are often without their pumping facilities during critical stages of irrigation. One very interesting photograph taken during the survey was that of a lady EO repairing a diesel engine. Possibly, this is the answer to the common frustration of delayed repairs.

Technical support in the correct sizing of engines and pumps is often lacking, resulting in inefficient pumping and high pumping costs.

The cheaper, smaller pumps available on the market are generally inefficient for irrigation work. Firefighting pumps are sometimes used but are not designed to work long hours, day after day. They have their points, however, because, although they are not very robust, they are easy to prime and, with a bit of help, they can be carried home at night and stored safely.

The irrigators are well aware of the question of fuel costs and one remarked that pumping for flooding was cheaper than for sprinkling: It only took fifteen litres petrol versus twenty-five litres diesel to complete a cycle.

There is frequently a debate on the question of using diesel versus petrol for pumping purposes. The diesel engines are more robust than the available petrol engines and some of the old, slow diesel engines are still operating satisfactorily thirty or forty years on. Petrol engines are much cheaper than diesel engines, however, and petrol is more available in the rural areas.

There is a new generation of Chinese-built diesel pump systems on the market, which is still being evaluated, and mixed reports have been received from the field. They are generally much lower in cost than the traditional diesel engines that have been used in the past.

Borehole pumps require attention and servicing and this remains a major expense and a vulnerability throughout the community garden set-up. It is obviously a big advantage if the community gardens are located near to a scheme where water supply is available under pressure and the additional cost of the pumping is minimal.

8.2.4.2 Conveyance systems

The pipeline from the pump can be galvanised steel, PVC or polyethylene. One of the biggest problems encountered was the incorrect sizing of the piping because nobody was available to make the necessary calculations. Another problem was leakage due to physical damage, because of the pipes' not having been installed or buried to the correct depth.

Earth distribution furrows are very commonly used, and the water is supplied under gravity from a reservoir into the supply furrow or, alternatively, the water is pumped directly from source into the furrow system. Insufficient stream size due to low pressure from the reservoir can result in very inefficient flood irrigation. Then, too, depending on the type of soil, there is very often deep leakage due to infiltration in the supply furrow. Long supply furrows aggravate this problem. This can very often be overcome by re-arranging the layout of the garden. Much can be done to prevent seepage losses if knowledge is available beforehand and if the water is conveyed in pipes for part of the distance. It is also possible to use bentonite to help stabilise the earth or, alternatively, to use lay-flat piping. The principles of designing the short furrow systems and supply furrows have been discussed in the chapter on flood irrigation.

Pipe networks to tap stands are normally gravity-fed from a reservoir, where insufficient pressure can again be a problem, not providing sufficient water. Blockages can also occur. In some cases, with suitable safeguards, pumping takes place directly into the piping system.

Concrete canal distribution systems are expensive in terms of capital cost and the amount of work that is necessary to build them, but they do have many advantages.

8.2.5 WATER STORAGE

Not all gardens have reservoirs. Those that do have reservoirs often have them right next to or inside a garden, 'because it belongs to the garden'. As a result, insufficient pressure is available to supply a stream size large enough for furrow irrigation. Out of desperation, the furrow system is replaced with a pipe network supplying tap stands so that everybody has water at the same time. However, this system actually requires even more pressure so, very soon, the expensive tap stand system is deserted and furrow irrigation is reverted to. Or the expensive reservoir is bypassed by pumping directly into the irrigation system. Garden groups therefore need technical advice so that they do not spend their hard-earned money on faulty technology.

Small storage systems, sometimes only drums but otherwise troughs or some other similar measure, are frequently used when the rates of flow are very low. This enables water to be held very close to where it is required and it can then be distributed by buckets.

8.2.6 FENCING

Fencing is of vital importance and, unfortunately, is expensive. It can account for 25% of the capital required for establishing the community garden. The primary purpose of the fence is, of course, to keep animals, both domestic and wild, out of the garden. Interestingly enough, it was sometimes necessary to 'improve' fences with paper bags, plastic bags, etc, in order to make it more chicken-proof. Where communities have developed their own community gardens with very little aid, they sometimes came up with ingenious approaches to this problem. They use thorn bushes and various hedge-type plants, etc, but none were very happy with this approach.

Community garden fencing also often has a secondary purpose, which is to keep people out. Particularly in the case of the urban and peri-urban community gardens, theft is a major factor. In the Northwest Province, for example, a very large proportion of the cost of the community gardens was in security, not only through fencing, which had to be man-proof, but also the provision of guards. This has now been discontinued, which has apparently had an adverse effect on the viability of these community gardens.

8.2.7 APPROACH TO INFRASTRUCTURE

Naturally, the communities wish to have their gardens in close proximity to their living areas, for both security and convenience, and this means that many community gardens have been developed in areas where the soil or water is intrinsically unsuitable.

Unfortunately, there is frequently administrative and political pressure placed on the authorities to accede to unsuitable requests for community gardens. This is understandable because very often the people need the facility and have really no alternative. At the same time, this can have very serious consequences and far too many community gardens have been abandoned in the past. There is therefore a need to examine the whole policy and philosophy of food plots and community gardens in the light of what is financially and practically possible.

8.2.7.1 Appropriate technology

Agricultural engineers have long faced the dilemma of designing something that is workable and low-cost for farmers and rural settlements. Unfortunately, if the money is being provided from official sources or is part of a scheme, then 'acceptable' engineering standards must be met. This immediately escalates the price. Where funds are in short supply, the possibilities of developing these gardens on the basis of 'appropriate technology' should be seriously considered.

Experience has shown that, where infrastructure is genuinely under the control of the community and has been built by the community, then they will manage to keep it operating. Probably not sufficient attention has been paid to this aspect to date and a more intensive study should be made of the nature of appropriate infrastructure. What is clear however from the do-it-yourself efforts of communities is that, whatever else happens, knowledgeable professionals and technicians should guide the infrastructure development. This is because, although the design should be as simple as possible, it must still obey the rules for pump types, power requirements, pipe sizes, etc. Only too often, the infrastructure has failed because the 'design' broke all these normal rules for selecting pumps and pipe sizes and pressure classes. Tragically, there was all too often no chance that that these do-it-yourself efforts could succeed.

Technical information on irrigation equipment is freely available, but designers of community garden irrigation systems found that they lacked information on the flow that could be expected from conventional garden hoses and sprinklers at various operational pressures. The Institute for Agricultural Engineering (ARC) has now carried out a series of tests on this equipment and selected examples of the reports are reproduced in Appendix 8-C.

8.2.8 CASE STUDIES OF GARDENS

The short case studies and examples of actual garden layouts that follow can advance an understanding of the general principles identified in the course of the fieldwork.

8.2.8.1 Community Garden 1

This community garden was started when a company wanted to do something for their retrenched workers. The project did fairly well while the extension officer was there to handle the management, the ordering of seedlings, fertiliser and all other inputs, and while she was also available on demand to give production advice to the grower. However, this project and four others disintegrated when this particular extension officer accepted a job in another town. This example shows the importance of taking into account:

- the building know-how and independence within a farming group; and
- the lack of experience of people who are forced into a project which is essentially someone else's idea of what they need and should want.

8.2.8.2 Community Garden 2

This garden started off with help from the government in creating the water supply infrastructure but is now fully independent and managed by an elected committee. The constitution drawn up by the gardening group determines that any participant whose land lies fallow will lose the right to work it. Gardeners take turns to travel by bus and taxi to a neighbouring town to buy seeds and other inputs. The farmers are very happy with the extension advice that they are receiving from the Department of Agriculture. One grower has started a small nursery to supply seedlings to the community gardeners, as well as fruit trees to neighbouring farmers. All produce is marketed to the surrounding villages.

8.2.8.3 Community Garden 3

Like most successful community gardens, this garden group manages itself through an elected committee. They have drawn up a proper constitution whereby common concerns are governed, with agreed penalties for transgressions. One of the realities facing a woman in their area is that she may *be summoned at any time by her husband to join him in Johannesburg, which means that she will be* forced to abandon her garden plot for an indefinite period. As agreed and stipulated in the garden constitution, she forfeits her rights to her plot after a month, unless she can make private arrangements with someone to cultivate the plot on her behalf until her return.

At the request of the garden group, the constitution was read and signed by the local chief to make it legally binding.

8.2.8.4 Community Garden 4

This community garden allows only women as members "because men tend to dominate and are generally lazy"! The garden group is largely independent from outside assistance, except that their diesel engine belongs to the government and must be repaired through government, which sometimes causes delays in peak season. Gardeners are full of praise for the good cropping advice they receive from their extension officer, but need technical (engineering) assistance with their irrigation system.

8.2.8.5 Community Garden 5

This garden of 3 ha shares the pump that serves 4 ha of irrigated pastures belonging to the chief. The pump attendant is a relative of the chief and has little regard for the priorities of the women in the garden group, as well as often not being available when they need water. The women are reluctant to approach the chief with their problem, as they fear they may lose access to the pump completely. They are seeking technical advice to obtain a suitable pump to make them fully independent in water supply.

8.2.8.6 Community Garden 6

When this garden had built up sufficient funds from member contributions and selling crops produced on their 'fund-raising plot', they decided to replace their furrow irrigation system with a piped distribution to tap stands "to save water and make life easier." However, they soon discovered that their hard-earned money had been wasted and went back to using the furrow system. They didn't realise that their reservoir couldn't supply enough pressure to overcome the friction in the pipes. They could therefore use only one or two taps at a time and even that lasted for only a short while, as the buried pipes soon started blocking with leaves and dirt from the reservoir.

8.2.8.7 Community Garden 7

The participants in this garden used to have access to domestic water to irrigate their crops. Water was pumped directly into a reservoir. However, when drought struck, they were no longer allowed this privilege and had to make alternative plans. An NGO heard of their plight and donated a pump! The group bought piping and dug a trench from the river to their reservoir, situated on a hill next to the garden. Unfortunately, when they started the pump, no water reached the reservoir... They realised that the pump was incapable of doing the job, so they started digging a new trench, this time directly to the garden, which is situated lower than the reservoir. However, they still could not be certain that, this time, they would be successful. Meanwhile, many farmers were still keeping their crops alive by fetching water by bucket from the river, a kilometre away.

This while a simple calculation could have told them the capacity of their pump and the required pipe diameter!

Five examples of community garden layouts are included in Appendix 8-B for background information and to show the diverse situations encountered during the survey by designers.

8.2.9 PLANNING COMMUNITY GARDENS

8.2.9.1 Administrative processes

The factors that need to be taken into consideration when developing a community garden are set out in the schedules that follow. The milestones and responsibilities in the development of a user-managed community garden are set out in Appendix 8-B. Note the role of the various institutions.

If the project is to be RDP-funded, the normal application form is required and must be supported by a business plan.

8.2.9.2 Principles

- Community gardens should not be given to people who do not want them.
- The gardening group should be established even before any investigations are carried out. If they are going to be successful, they will have to be entrepreneurial in approach – the development of the garden and overcoming technical, institutional and financial problems is a valuable school for entrepreneurs!
- There must be a 'need-to-know" approach – many gardens have failed to materialise because large teams of professionals have spent up to two years investigating them!
- The gardening group should decide whether a formalised, expensive irrigation system (which can and will break down) is really necessary.
- The need for external maintenance support should be avoided.

8.2.9.3 Guidelines for decisions by the Gardening Group

ITEM	CONSIDERATIONS AND TYPICAL VALUES
Number of growers	15-90+; 50 typical (eg, 600 m^2 each on 3 ha total garden size).
Criteria for selection	Varies from group to group. Some typical criteria found were: the poorest of the poor; single-headed households; those who are willing to bush-clear; etc.
Plot sizes	Land available; number of growers; time available for gardening: 100 to 600 m^2; eg, 10 x 10, 20 x 30; 45 x 5, depending on type of irrigation.
Garden size	Land available; potential market: 1-10 ha; 3 ha typical.
Bush-clearing, trench-digging, installation	Labour, responsibility, reward? Preferential access to plots?
Fencing	Type, labour, responsibility for maintenance
Cycles and schedules; 'irrigation turns'; operational agreements	Growing season (some areas winter only – too hot in summer); number of plots served by one outlet/furrow; flow rate; time needed for one irrigation; etc
Type of irrigation; layout	Is a formalised irrigation system needed at all? Cost, especially for running and maintenance, should be kept as low as possible; time needed for one irrigation; ease of operation & maintenance; etc. Typical: bucket systems; furrow systems; taps with or without hoses. Very seldom sprinkler variations, usually associated with larger schemes, often pressure problems. Very little drip, and in a specialised form – warrants investigation. No micro.
Type of source	
Power and pumping	
Type of storage	
Sources and procedures for obtaining inputs	
Sources and procedures for obtaining advice	
Handling of member complaints	
Tradability of plots/ handling of fallow land	
Operators; accountability, payment	
Handling of break-downs	
Constitution & management	
Etc	

8.2.9.4 Guidelines for decisions by Local Authorities

ITEM	CONSIDERATIONS
Land – plot sizes, etc	
Tradability of plots	
Underwrite garden constitution	

8.2.9.5 Guidelines for decisions/contributions by Support Organisations

ITEM	CONSIDERATIONS
Crop options	Especially marketability, varieties.
Engineering options	See below: Section 8.2.9.6: Some technical considerations.
Advice on soils	NB: 'NEED-TO-KNOW' APPROACH Especially for salinisation problems, crusting (sprinkler, micro), infiltrability (furrow), danger of erosion. What irrigation systems cannot be used as a result of soil characteristics?
Advice on water	Quantity; availability, accessibility, reliability and, especially, quality.
Marketing possibilities	Local market? External – formal/informal? Help establish links with external markets, especially for niches.
Etc	

8.2.9.6 Some technical considerations

TYPE	CONSIDERATIONS
BUCKET	Maximum practical plot size (100 m^2?) – time needed to do one irrigation, related to carting distance, source flow rate, practical bucket size, time available for irrigation; cycle and number of growers. Bed size and shape – type of crop, bucket size, irrigation application. Typical layouts.
FURROW	Limit supply furrow length! Infiltrability. Lining needed? Options (eg, inexpensive lay-flat piping – check reordering possibilities and procedures; compaction with tractor wheels). Layout – number of plots sharing supply furrow; irrigation furrows preferably on the contour; length 5-10 m. Flow rate (10 m^3/h is practical, efficient, yet non-erosive). Typical layouts.
TAPS	Number of plots sharing a tap – with bucket system: practical carting distance (? m); – with hoses: maximum length of hose, weight (full) and manoeuvrability, crops damage! (10-20 m max?). Type of hose – robust, weight. Tap stands v hydromatic valves (anti-theft, special hose fitting, use with buckets?). Optimisation of pipe costs. Typical layouts.

Appendix 8-D consists of a typical planning report for a community garden developed by the consultant, Eksteen, van der Walt and Nissen (International) (Pty) Ltd, for the Northern Province Department of Agriculture, Land & Environment, Directorate of Agricultural Engineering.

8.2.10 WATER DELIVERY AND APPLICATION DESIGN CRITERIA

8.2.10.1 Short furrow flood irrigation

The length of furrow depends on the gradient, the stream flow and the soil type. Whether reasonable distribution is being achieved or not can be judged by the time in minutes that it takes the water to reach the far end of the furrow.

Table 8.2.10.1: Furrow lengths and maximum advance times

FURROW GRADIENT: LEVEL			
Soil	**Furrow length (m)**	**Flow rate (m^3/h)**	**Max time (min)**
Clay	30	5 – 15	5
Loam	20	7 – 15	4
Sand	10	10 –15	3
FURROW GRADIENT 1 : 300			
Soil	**Furrow length (m)**	**Flow rate (m^3/h)**	**Max time (min)**
Clay	15	5 – 15	3
Loam	15	6 – 15	3
Sand	15	8 – 15	3
FURROW GRADIENT 1 : 100			
Soil	**Furrow length (m)**	**Flow rate (m^3/h)**	**Max time (min)**
Clay	4	4	2
Loam	6	5	2
Sand	8	6	2

Supply furrows

Outside garden;

Less than 100% of longest supply furrow in garden;

Gradient level to 1:150.

SUPPLY FURROW IN GARDEN			
1:150 to 1:500	**Furrow length (m)**	**Flow rate (m^3/h)**	**Max time (min)**
Clay	150	5 : 15	20
Loam	100	5 : 15	15
Sand	50	6 – 15	10

8.2.10.2 Flood irrigation with water supply by hose

The Institute for Agricultural Engineering of the ARC has published information on the flow rates that can be expected from conventional garden hoses with and without sprinklers.

Table 8.2.10.2: Discharge from garden hoses

15 mm hose (flow in m^3/h)			
Head m	**30 m long**	**20 m long**	**10 m long**
10	0,7	0,8	1,1
20	1,0	1,3	1,6
30	1,2	1,6	2,0
20 mm hose (flow in m^3/h)			
Head m	**30 m long**	**20 m long**	**10 m long**
10	2,1	2,7	3,7
20	3,2	4,0	5,6
30	4,1	5,1	7,0

Note that the discharge from the 20 mm hose is reasonable for furrow irrigation purposes, but that the 15 mm hose is not suitable.

8.2.10.3 Hose and garden sprinkler irrigation

Tests were repeated with 'bee hive' sprinklers fitted to the hosepipes and the discharge was only a fraction of the free discharge value. Typically in the case of 20 m long hoses at 20 m head, the discharge of the 20 mm hose dropped from 4,0 to 1,1 m^3/h, and the discharge of the 15 mm hose dropped from 1,3 to 0,8 m^3/h.

8.2.11 IRRIGATION REQUIREMENTS AND COSTS

There are interesting differences between the community gardens in Table 8.2.11: *Irrigation and cost data for five community gardens, Northern Province.* They range from a 4,2 ha community garden where water is pumped from a river, right through to one where the total area is only 0,1 ha and the water is pumped from a borehole using a hand pump. Both are community gardens but they are totally different propositions.

The second community garden, (B), is also provided with water from a river but, in this case, it is rather smaller.

The largest of the borehole-served community gardens is (C), which has a nett irrigated area of 1,4 ha. In the arid areas where there is no running water or dam, the size and scope of the community gardens are largely determined by the borehole water supply. One of the most important factors to take into consideration is the sustainability of this supply: Pumping is usually not permitted for more than eight to ten hours a day, so that the borehole has time to recover overnight. The reliability of the borehole is obviously of major importance and the greatest care needs to be taken that it is not over-pumped.

The three larger community gardens, (A), (B) and (C), all have the 'standard' 0,1 ha size of plot, but the shape varies quite significantly. Short-furrow irrigation is applied, the water being led to the furrows by means of a dragline hose. This is the case in all the gardens, except (E), where the water is pumped into a small reservoir by hand from the borehole and the water is then taken out in buckets to be carried to the plants.

Table 8.2.11: Irrigation and cost data for five community gardens in the Northern Province

	A	B	C	D	E
Borehole yield (m^3/d)	356	210	94	22	6
Nett irrigation area (ha)	4,2	2,1	1,4	0,33	0,1
Nett plot area (ha)	0,1	0,1	0,1	50 m^2	50 m^2
Max irrigation period (h/d)	10	10	8	6	
Available soil water (mm/m)	130	130	80	100	110
Irrigation method	Flood	Flood	Flood	Flood	Bucket
Peak irrigation (mm/d)	7 S 3 W	7 S 3 W	7 S 3 W	7 S 3,W	7 S 3 W
No of plots irrigated together	14	7	4	2	–
No of participants	42	21	14	66	20
CAPITAL COST	**(R)**	**(R)**	**(R)**	**(R)**	**(R)**
Land preparation	5 000	6 000	1 200	4 000	500
Fencing	10 000	18 000	28 000	10 000	3 000
Pumps	62 000	45 000	62 000	35 000	10 000
Pipes	50 000	50 000	46 000	30 000	9 000
VAT	16 800	15 400	15 240	9 380	2 500
TOTAL	**143 800**	**134 400**	**142 240**	**88 380**	**25 000**
Capital cost/participant	3 423	6 400	10 160	1 340	1 250
Capital cost/hectare	34 200	64 000	101 600	267 800	250 000
ANNUAL COST TOTAL	3 488	6 820	2 733	2 866	375
Annual cost/participant	83	325	195	44	19
Annual cost/hectare	830	3 079	1 952	8 684	3 750

Community gardens (A) and (B), the two gardens next to rivers, can afford the cost of pumping from the river. Water supply is through a trailer-mounted centrifugal pump and diesel engine. Garden (A) has electric power and pumping is by electricity. It is interesting to note that the operating costs for Garden (A) are very much lower than for Garden (B), about half, although the area irrigated and the amount of water pumped is twice as much – because of the availability of electric power. The capital investment in electric pumping is not, however, non-significant. The electrical switchgear at Garden (A) was estimated at R20 000, while the ESKOM connection fees, etc, were R15 000,

Garden (A) can, obviously, be regarded as being a very attractive proposition, of significant size and implication. The cost per hectare is R34 200, and the cost per participant on a 0,1 ha plot is R3 423. The total capital cost of the scheme is R143 800. These are not insignificant sums but, when one thinks that the annual operating cost per participant is only R83, one can see this in perspective.

Garden (B), with the diesel-powered pumping unit, is only marginally lower in cost than (A) but only half the area is irrigated. Consequently, the cost per hectare is R64 000 and the cost per participant is R6 400.

Garden (C), with fourteen participants using a reasonably large borehole, has very reasonable operating costs, largely because electric power is available, but capital cost is now up to over R10 000 per participant for a 0,1 ha plot, and over R100 000 capital investment per hectare.

When discussing community gardens, it must always be appreciated that they are not cheap. Their cost must obviously always be weighed up against the other requirements of the community. An investment of nearly R150 000, with fourteen participants, would need to be considered very carefully.

In the case of Gardens (D) and (E), both served by boreholes with very limited capacity, where gardening takes place on 5 x 10 m (50 m^2) plots, the situation is rather different. Here the cost per participant is relatively low, about R1 250, because each person is only working a very small plot. The cost per hectare exceeds R250 000. Total cost, though, is low, particularly for the small Garden (E), which is only R25 000.

There may be ways of reducing these costs. It must be remembered that, for Gardens (C), (D) and (E), the only provision made was for fitting out three boreholes which had already been drilled, probably for some other purpose (and certainly funded from another budget).

It is interesting to trace the genesis of a project. In one of the cases, the RDP proposal was submitted for the irrigation of a five-hectare block by ten farmers growing maize and wheat only, and it was estimated that the total cost would be R69 000. The business plan was then developed with the help of the Department of Agriculture and the funding request was much the same, namely, R74 000. However, the suggestion now was to divide the project into ten equal portions of about 4 000 m^2 each, creating ten job opportunities for its members and their families. To quote, "It will increase the vegetable crop for Kranskloof and the adjacent communities. It will serve as training for vegetable production, hence boost the health and the education standards of the people." After investigation by consultants and, one can assume, many discussions, the final plan came down to twenty-one equal plots of 1 000 m^2 each. The nett irrigation area is therefore 2,1 ha. The capital cost of the project is R134 000.

This evolutionary development in the project is important. It takes time and experience to develop a programme of this nature. It can be anticipated that, once actual construction starts and designs are finalised, there will be further changes, particularly in respect of the physical layout and the equipment. All five of the projects listed in Table 8.2.11 are community gardens but there is a very considerable difference between them.

It can be anticipated that there will also be a very considerable difference in the ways in which they are managed and the approach that is adopted by each of the relevant committees. This is one of the great attractions of community gardens: They are small enough to allow individuality in management and operation, which becomes lost in the large schemes. Even here, where there are more than twenty members of a community garden, it takes discipline and dedication to ensure effective management.

8.2.12 WATER AND SOIL QUALITY

As can be anticipated, people want a community garden because of the arid climate and the lack of dryland potential for vegetable production. This, almost inevitably in the northern parts of the country, requires borehole water and, only too often, this borehole water is of indifferent quality. Similarly, the soils may or may not be suitable for irrigation. In many cases, they are marginal. That is why, wherever community gardens are proposed, the soils should be sampled and a full analysis should be done on their properties. A profile pit is essential if a detailed soil survey is not available. A combination of poor soils and indifferent water inevitably makes the task of the gardeners much more difficult and this must be taken into consideration. Possibly, even under those circumstances of marginal water and soils, development can be recommended, but it will be necessary to discuss this very, very thoroughly with the community.

In the case of the five community gardens in Table 8.2.11 that we are considering as examples, the situation is reasonable.

Garden (A) has water that, due to faecal contamination upstream, cannot be recommended for potable use without purification but, being a mountain stream, it is assumed that there would be very little difficulty in using it for irrigation. Similarly, the soils are very uniform: Huttons with a good infiltration rate and moisture-holding capacity, and a depth greater than two metres. In other words, the whole situation is extremely favourable to irrigation.

Garden (E), the other river scheme, has much the same rating for water and, once again, the soils are deep so that root penetration should be very satisfactory. There is a warning, in this case, that the soil is moderately saline and a note made that the layout has been planned so as to exclude these soils where possible.

The borehole water on Garden (C) is reasonably good but is classified as a Class 3, due to high *conductivity and it is stressed that irrigation with water from the borehole could induce salinisation,* unless salts are leached regularly and water tables are kept low by adequate drainage. Recommendations are given for handling this.

The soils, too, are reasonable, being shallow Huttons, but with a sandy loam texture which reduces the water-holding capacity. It is recommended that the low nutrient status be counteracted by adequate fertilisation. In other words, a warning is implicit, in connection with both the water quality and the soils themselves. Attention should be paid to an analysis of this sort, otherwise the level of production might prove to be disappointing in the long term.

Garden (D) has very similar water to Garden (C) and much the same precautions would have to be taken. It is suggested that the production of sensitive vegetable crops, such as beans, tomatoes, carrots, onions, parsnips and peas, be avoided, and that attention be given to the more tolerant vegetable crops, such as squashes, beets, cabbage and spinach. The soils, too, appear to be marginal. The notes read, "The measured low nutrient status would necessitate adequate fertilisation. Pre-treatment with gypsum at 2 500 kg/ha is recommended." That would be about 12,5 kg per plot.

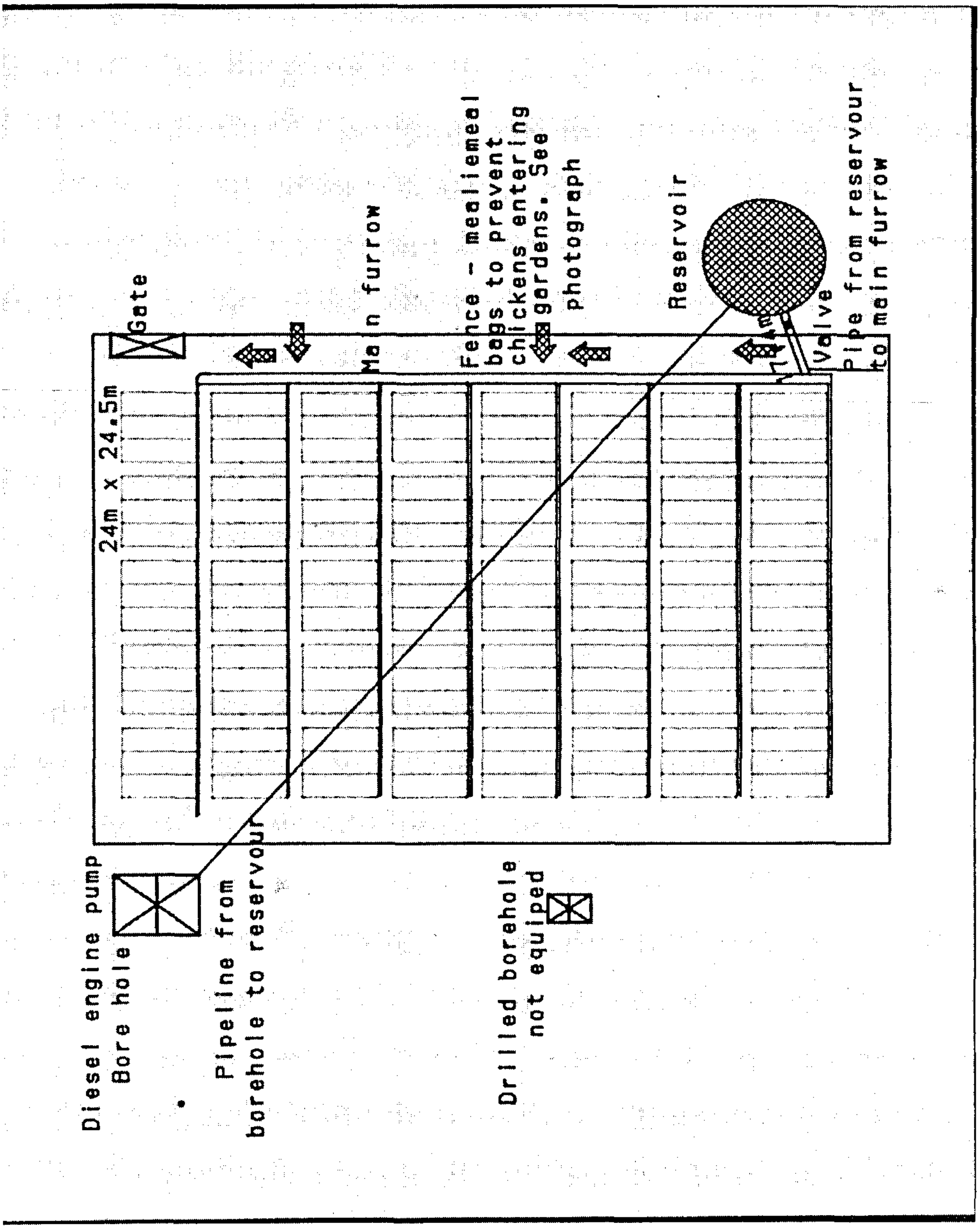
8.3 CONCLUSIONS AND RECOMMENDATIONS

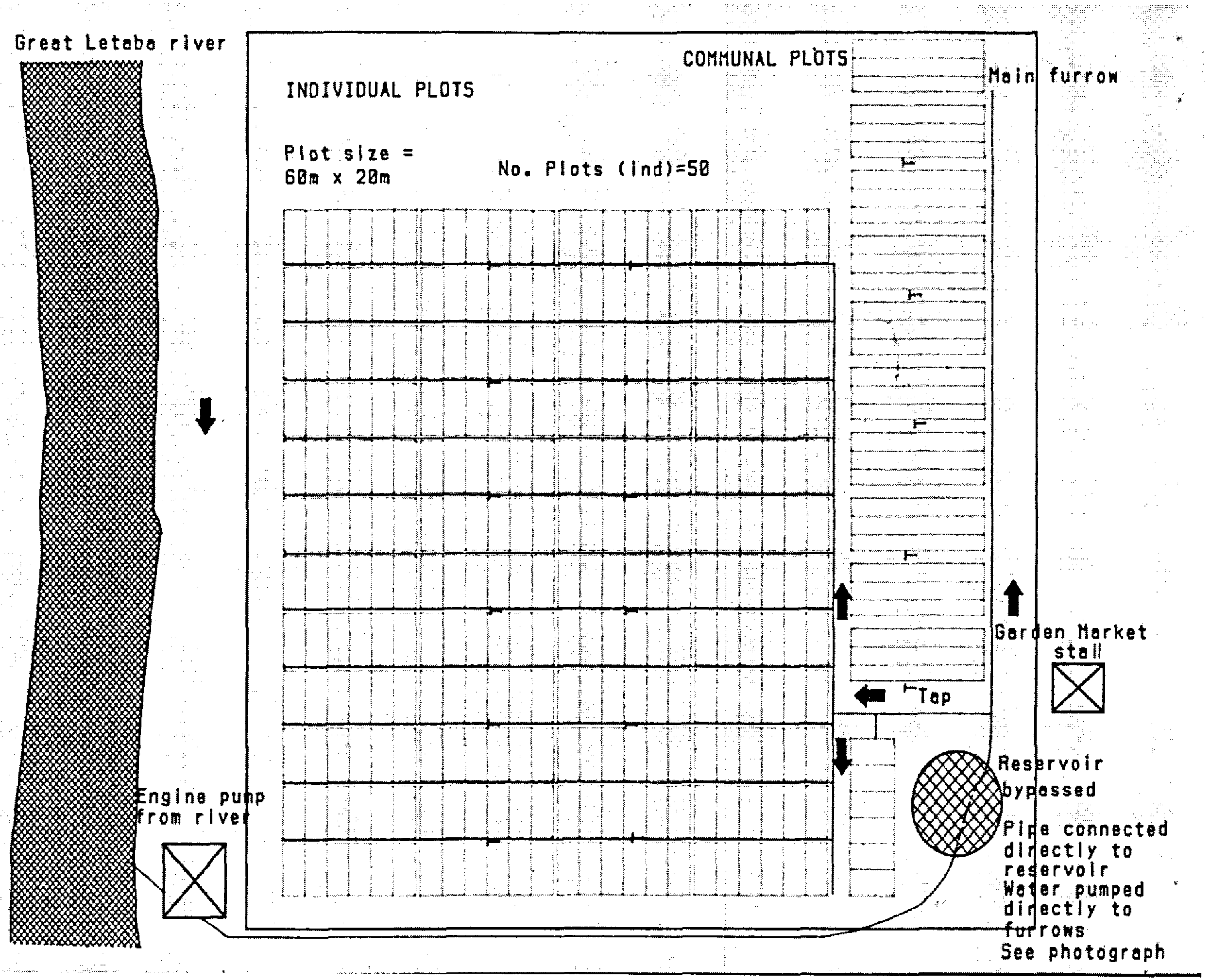
It would be naive to believe that community gardens have all been successful. Many have, however, proved to be a major asset to their communities. A distinction must be drawn between the rural gardens and those located in the urban areas, which are being developed appropriately for the objectives that have been set for this project. Quite apart from the differences in sociological and living circumstances, the availability of water in the urban areas is far more favourable than it is in the arid rural areas.

The percentage of irrigation schemes that will be appropriate for rehabilitation will be limited. The availability of infrastructure should, however, frequently promote community gardens in their stead. These will always be assets to their communities if their development and support is judiciously handled. Experience has shown that the participants can manage community gardens and that there is usually acceptance of responsibility for maintaining the gardens. The exception is the big and over-sophisticated gardens that have been developed by various authorities and imposed on communities. If security is a problem, the wrong route has probably been taken some way down the line.

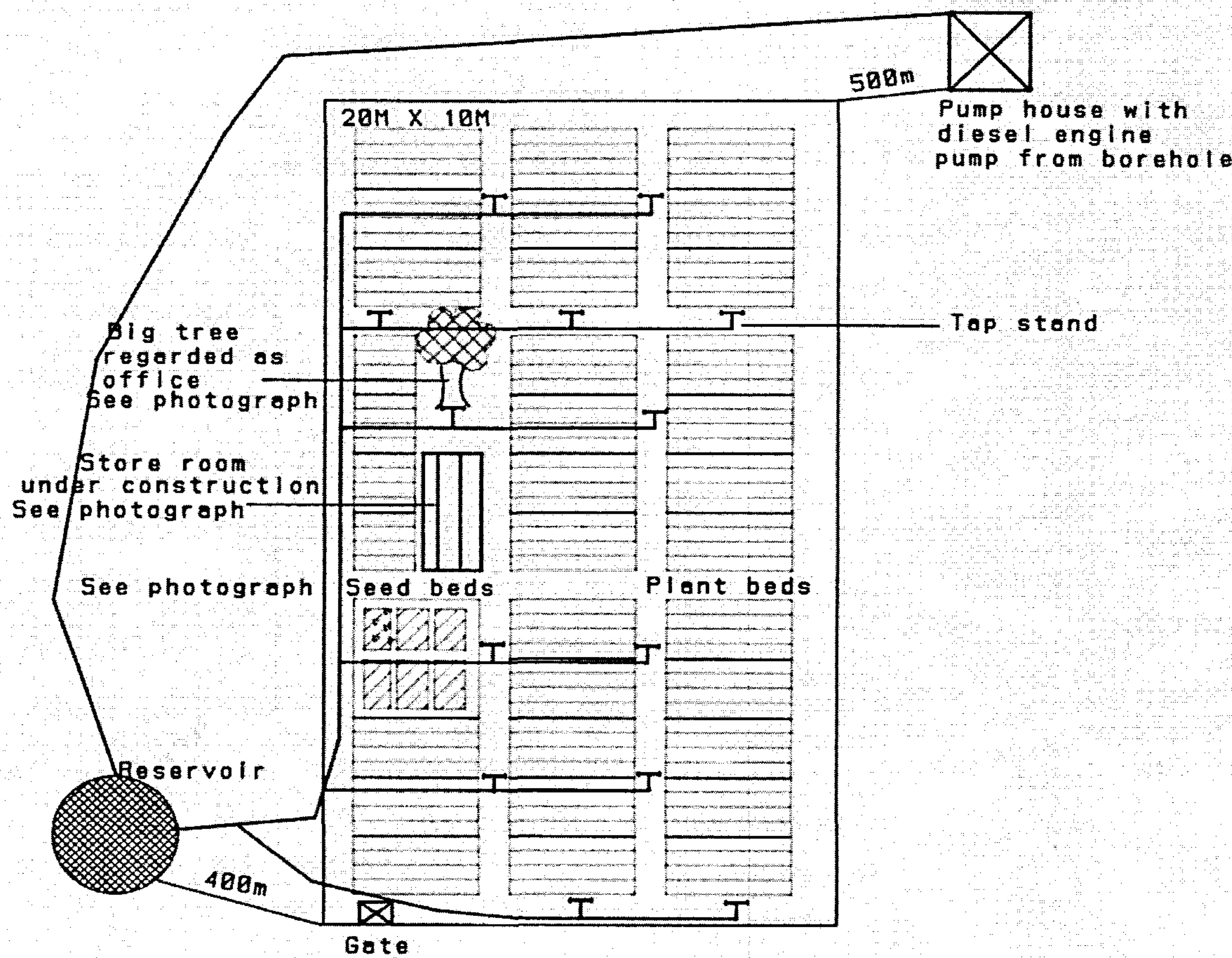
Cost is a major deterrent. Ways and means will have to be sought to enable participants to develop their own irrigation infrastructure and more appropriate specifications seem to be essential.

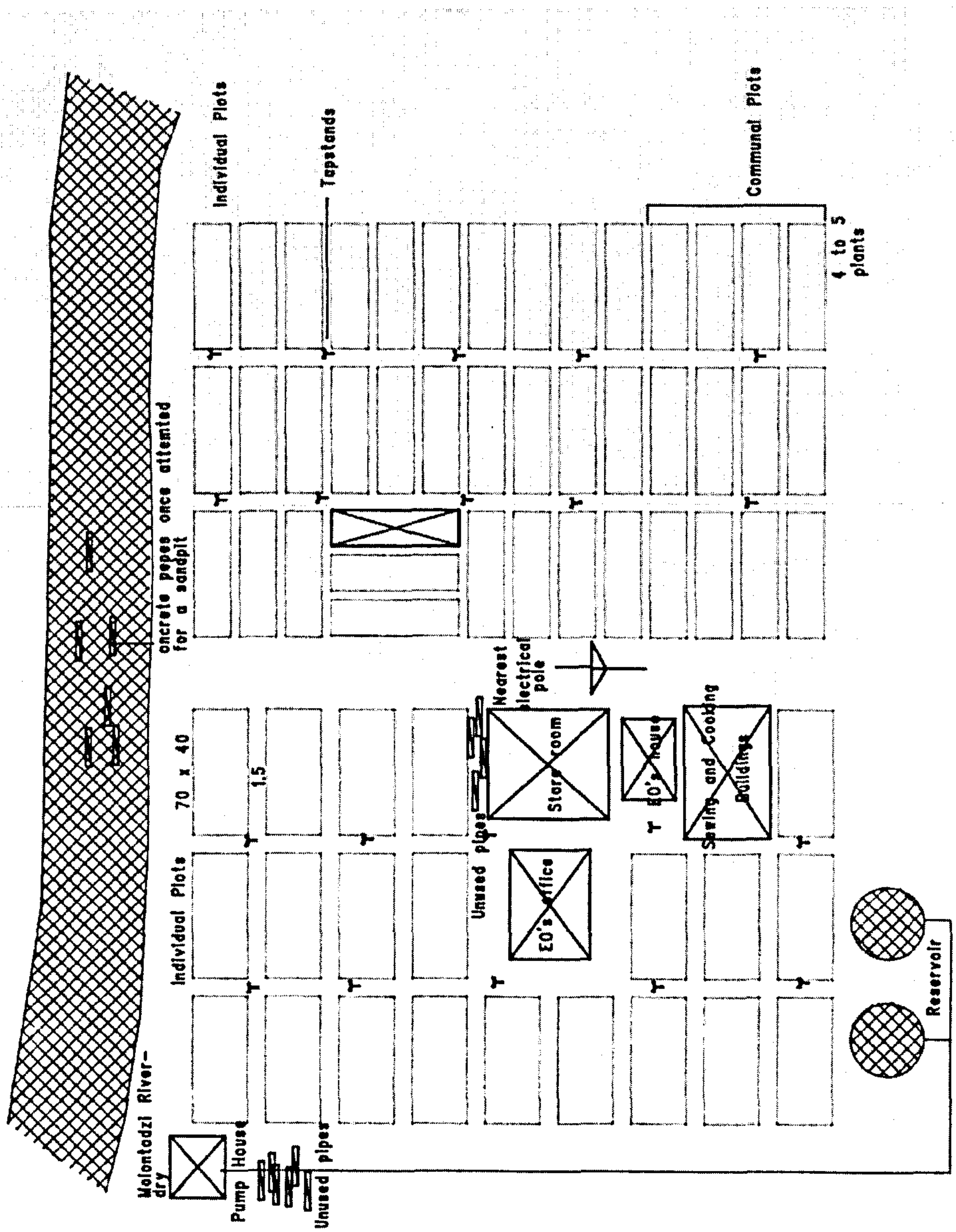
APPENDIX 8.A. LAYOUTS OF SOME OF THE COMMUNITY GARDENS VISITED

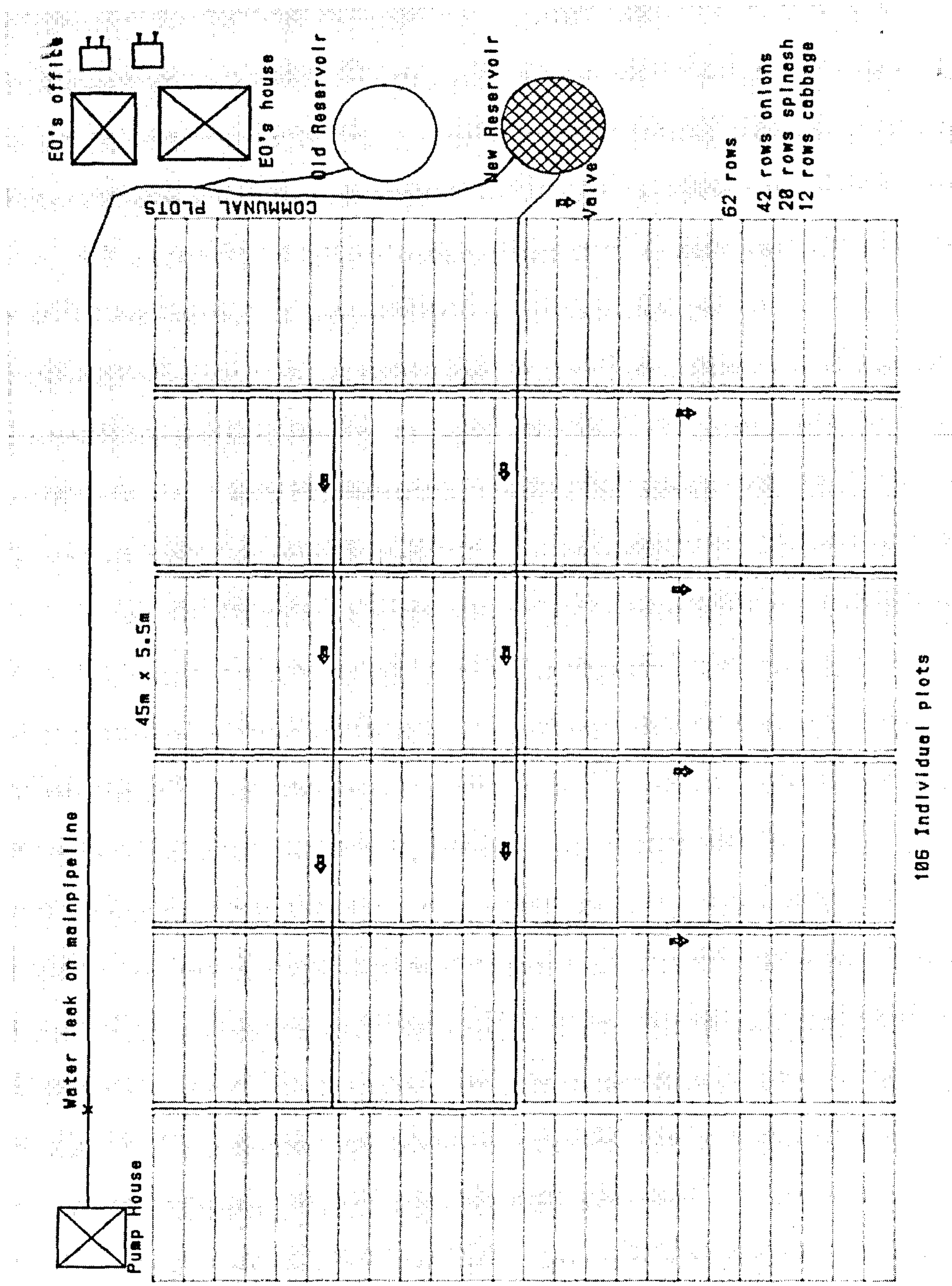




Great Letaba river
INDIVIDUAL PLOTS
COMMUNAL PLOTS
Main furrow
Plot size =
60m x 20m
No. Plots (ind)=50
Garden Market
stall
Tap
Reservoir
bypassed
Pipe connected
directly to
reservoir
Water pumped
directly to
furrows
See photograph
Engine pump
from river


20M X 10M
500m
Pump house with
diesel engine
pump from borehole
Tap stand
Big tree
regarded as
office
See photograph
Store room
under construction
See photograph
See photograph
Seed beds
Plant beds
Reservoir
400m
Gate


Individual Plots
Tapstands
Communal Plots
4 to 5 plants
oncrete pepes once attemted for a sandpit
Nearest electrical pole
70 x 40
1.5
Store room
EO's house
Sewing and Cooking Buildings
Unused pipes
EO's office
Individual Plots
Reservoir
Pump House
Unused pipes


EO's office
EO's house
Old Reservoir
New Reservoir
COMMUNAL PLOTS
Valve
62 rows
42 rows onions
28 rows spinash
12 rows cabbage
45m x 5.5m
106 Individual plots
Water leak on mainpipeline
Pump House

APPENDIX 8.B. MILESTONES AND RESPONSIBILITIES IN THE DEVELOPMENT OF COMMUNITY GARDENS

MILESTONE	RESPONSIBILITY (d-decide f-facilitate i-information a-acknowledge)						
	gg	gg-pc	gg-mc	l/auth	doa+	eng+	fund
INITITIATION							
Garden group formed	d				f		
Land obtained	i			d	f		
Application for assistance submitted	i	i			f	f,i	a,d
PLANNING							
Technical options and implications for operation and maintenance considered	I					d	
Garden layout and infrastructure decided	d					i	
Engineering design completed	i					d	
Responsibilities for installation/construction agreed	d			d	d	d	d
IMPLEMENTATION							
Construction						d	
Membership finalised	d						
Constitution/rules and regulations finalised	d				f	i	
Management committee elected	d				f		
Appoint operator(s)			d	d,i	f?	I	

MILESTONE	RESPONSIBILITY (d-decide f-facilitate i-information a-acknowledge)						
	gg	gg-pc	gg-mc	l/auth	doa+	eng+	fund
COMMISSIONING							
System commissioning	i						
Training in operation and maintenance to all garden members and operators	I					d	
Agreement on roles and reponsibilities of all roleplayers (participants, committee members, operators, support organisations' staff, etc.)						d	
OPERATION							
Irrigation system fully operational							
Operation and maintenance managed by elected garden management committee							
Crops produced successfully by individual participants, each on their own plot							
Successful and sustained marketing of produce, mainly individually, jointly by the group if so agreed							

gg garden group
gg-pc gg elected planning committee
gg-mc gg elected management committee
l/auth local athority
doa+ department of agriculture +other support organisations
eng+ engineers +other professionals
fund funder(s)

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MILESTONE	RESPONSIBILITY (d-decide f-facilitate i-information a-acknowledge)						
	gg	gg-pc	gg-mc	l/auth	doa+	eng+	fund
INITITIATION							
Garden group formed	d				f		
Land obtained	i			d	f		
Application for assistance submitted	i	i			f	f,i	a,d
PLANNING							
Technical options and implications for operation and maintenance considered	I					d	
Garden layout and infrastructure decided	d					i	
Engineering design completed	i					d	
Responsibilities for installation/construction agreed	d			d	d	d	d
IMPLEMENTATION							
Construction						d	
Membership finalised	d						
Constitution/rules and regulations finalised	d				f	i	
Management committee elected	d				f		
Appoint operator(s)			d	d,i	f?	I	