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Irrigation Manual

Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation

Developed by

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Volume I

Modules 1 – 6

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Foreword

The first edition of the Irrigation Manual was published in 1990 in two volumes by the "Smallholder Irrigation" Project (UNDP/FAO/AGRITEX/ZIM/85/004). The authors of this first edition were FAO Staff on the project[1]. This edition of one hundred copies ran out within two years from publishing.

Although the manual was written with Zimbabwe in mind, it soon became popular in several countries of the sub-region. In view of the high demand, it was decided to proceed with a second edition. The experience gained from using the first edition of the manual as the basic reference for the AGRITEX[2] training programme of irrigation practitioners and the University of Zimbabwe, was incorporated in the second edition which was published in 1994, in one volume by the "Technical Assistance to AGRITEX" project (UNDP/FAO/AGRITEX/ZIM/91/005). This second edition was published under the same authors as the first edition, with the assistance of a review committee from AGRITEX[3]. The two hundred copies of this edition also ran out within two years of publishing.

In 1995, the FAO Sub-regional Office for East and Southern Africa (SAFR) was established in Harare, Zimbabwe, in order to provide easy access to technical assistance and know-how for the countries of the sub-region[4]. In view of the high demand for support in the field of smallholder irrigation by the countries of the sub-region, this office was strengthened with four water resources management officers and a number of on-going programmes have been developed to provide this support. One of these programmes is the publishing of a new regional edition of the irrigation manual in support of the on-going national training programmes within several countries in the sub-region and to provide the basic reference for another important programme, which is the sub-regional training on planning and design of smallholder irrigation schemes.

This third edition aspires to further strengthen the engineering, agronomic and economic aspects of the manual and to introduce new modules related to social, health and environmental aspects of irrigation development. The emphasis is directed towards the engineering, agronomic and economic aspects of smallholder irrigation, in view of the limited practical references in this area. This manual, being directed to the irrigation practitioner, does not provide an in-depth analysis of the social, health and environmental aspects in irrigation development. It only attempts to introduce the irrigation practitioner to these areas, providing a bridge between the various disciplines involved in irrigation development.

The initiatives and efforts of the Water Resources Management Team of SAFR in publishing this Manual are considered as a valuable contribution to the dissemination of knowledge and training of irrigation practitioners in the sub-region. The material covered by this manual is expected to support both national and sub-regional training programmes in the planning, design, construction, operation and maintenance and on-farm water management of irrigation schemes. This will support the implementation of FAO's mandate to increase food production through water control, intensification and diversification, which are the basic components of the Special Programme for Food Security (SPFS).

The manual is the result of several years of field work and training irrigation engineers in the sub-region. The approaches have been field tested and withstood the test of time.

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[2] *Agritex: Department of Agricultural Technical and Extension Services, Ministry of Lands and Agriculture, Zimbabwe.*

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[4] *The following 21 countries are part of the FAO-SAFR region: Angola, Botswana, Burundi, Comoros, Eritrea, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Rwanda, Seychelles, South Africa, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe.*

For ease of reference to the various topics covered by this Manual, the material has been divided into 14 modules, covering the following:

Module 1:	Irrigation development: a multifaceted process
Module 2:	Natural resources assessment
Module 3:	Agronomic aspects of irrigated crop production
Module 4:	Crop water requirements and irrigation scheduling
Module 5:	Irrigation pumping plant
Module 6:	Guidelines for the preparation of technical drawings
Module 7:	Surface irrigation systems: planning, design, operation and maintenance
Module 8:	Sprinkler irrigation systems: planning, design, operation and maintenance
Module 9:	Localized irrigation systems: planning, design, operation and maintenance
Module 10:	Irrigation equipment for pressurized systems
Module 11:	Financial and economic appraisal of irrigation projects
Module 12:	Guidelines for the preparation of tender documents
Module 13:	Construction of irrigation schemes
Module 14:	Monitoring the technical and financial performance of an irrigation scheme

To those who have been waiting for so long for a practical irrigation engineering manual: here it is. I am sure that it will have a lot to offer to both new and experienced irrigation engineers.

Victoria Sekitoleko
FAO Sub-Regional Representative
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The whole project was managed and coordinated by Andreas P. Savva and Karen Frenken, Water Resources Development and Management Officers at FAO-SAFR, who are the main authors. Karen Frenken also is the main technical editor.

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Unit conversion table

Length

1 inch (in)	0.0254 m
1 foot (ft)	0.3048 m
1 yard (yd)	0.9144 m
1 mile	1609.344 m
1 metre (m)	39.37 inches (in)
1 metre (m)	3.28 feet (ft)
1 metre (m)	1.094 yards (yd)
1 kilometre (km)	0.62 miles

Area

1 square inch (in^2)	6.4516 x 10^{-2} m^2
1 square foot (ft^2)	0.0929 m^2
1 square yard (yd^2)	0.8361 m^2
1 acre	4046.86 m^2
1 acre	0.4046 ha
1 square centimetre (cm^2)	0.155 square inches (in^2)
1 square metre (m^2)	10.76 square feet (ft^2)
1 square metre (m^2)	1.196 square yard (yd^2)
1 square metre (m^2)	0.00024 acres
1 hectare (ha)	2.47 acres

Volume

1 cubic inch (in^3)	1.6387 x 10^{-5} m^3
1 cubic foot (ft^3)	0.0283 m^3
1 cubic yard (yd^3)	0.7646 m^3
1 cubic centimetre (cm^3)	0.061 cubic inches (in^3)
1 cubic metre (m^3)	35.315 cubic feet (ft^3)
1 cubic metre (m^3)	1.308 cubic yards (yd^3)

Capacity

1. imperial gallon	0.0045 m^3
1. US gallon	0.0037 m^3
1. imperial barrel	0.1639 m^3
1. US. barrel	0.1190 m^3
1 pint	0.5681 l
1 US gallon (dry)	0.0044 m^3
1 litre (l)	0.22 imp. gallon
1 litre (l)	0.264 U.S. gallon
1 litre (l)	0.0061 imperial barrel
1 hectolitre (hl)	100 litres = 0.61 imperial barrel = 0.84 US barrel
1 litre (l)	1.760 pints
1 cubic metre of water (m^3)	1000 l = 227 U.S. gallon (dry)
1 imperial barrel	164 litres

Mass

1 ounce	28.3286 g
1 pound	0.4535 kg
1 long ton	1016.05 kg
1 short ton	907.185 kg
1 gram (g)	0.0353 ounces (oz)
1 kilogram (kg)	1000 g = 2.20462 pounds
1 ton	1000 kg = 0.984 long ton = 1.102 short ton

Pressure

1 pound force/in^2	6894.76 N/m^2
1 pound force/in^2	51.7 mm Hg
1 Pascal (PA)	1 N/m^2 = 0.000145 pound force /in^2
1 atmosphere	760 mm Hg = 14.7 pound force/in^2 (lbf/in^2)
1 atmosphere	1 bar
1 bar	10 metres
1 bar	100 kpa

Energy

1 B.t.u.	1055.966 J
1 foot pound-force	1.3559 J
1 B.t.u.	0.25188 Kcalorie
1 B.t.u.	0.0002930 KWh
1 Joule (J)	0.000947 B.t.u.
1 Joule (J)	0.7375 foot pound-force (ft.lbf)
1 kilocalorie (Kcal)	4185.5 J = 3.97 B.t.u.
1 kilowatte-hour (kWh)	3600000 J = 3412 B.t.u.

Power

1 Joule/sec	0.7376 foot pound/sec
1 foot pound/sec	1.3557 watt
1 cheval-vapor	0.9861 hp
1 Kcal/h	0.001162 kW
1 watt (W)	1 Joule/sec = 0.7376 foot pound/sec (ft lbf/s)
1 horsepower (hp)	745.7 watt 550 ft lbf/s
1 horsepower (hp)	1.014 cheval-vapor (ch)
1 kilowatt (kW)	860 Kcal/h = 1.34 horsepower

Temperature

^{0}C (Celsius or centigrade-degree)	^{0}C = 5/9 x (^{0}F - 32)
^{0}F (Fahrenheit degree)	^{0}F = 1.8 x ^{0}C + ^{0}F
K (Kelvin)	K = ^{0}C + 273.15

Irrigation Development: a Multifaceted Process

Social, Economic, Engineering, Agronomic, Health and Environmental Issues to be Considered in a Feasibility Study

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List of abbreviations

AC	Asbestos Cement
AGRITEX	Department of Agricultural, Technical and Extension Services (Zimbabwe)
EIA	Environmental Impact Assessment
FFS	Farmers Field School
ILO	International Labour Organization
IPM	Integrated Pest Management
ILRI	International Institute for Land Reclamation and Improvement
IMC	Irrigation Management Committee
NGO	Non-Governmental Organization
NPSHA	Net Positive Suction Head Available
O&M	Operation and Maintenance
PRA	Participatory Rural Appraisal
PT&E-FWM	Participatory Training & Extension on Farmers' Water Management
SEAGA	Socio-Economic And Gender Analysis
uPVC	unplasticized Polyvinyl Chloride
WUA	Water Users Association

Chapter 1
Introduction

Drought and floods are recurring events affecting the livelihoods of millions of people around the world. This, the result of climatic variability, contributes to the risks of farming across most of East and Southern Africa. In response, people living in drought or flood prone areas have developed livelihood and production systems to minimize the risks posed by the extreme climatic variations. However, with the population increases of the last century and the growing pressure on land, land use has become more intensive, and land and people have become more vulnerable to the effects of climatic events. Within a more complex environment and through sophisticated production systems, people, livestock, crops and wildlife are competing for increasingly scarce resources. Over time, these pressures will lead to greater susceptibility to future droughts and floods resulting in further degradation of resources and loss of productivity - a downward spiraling effect.

A serious drought or a series of consecutive droughts can be a disaster-triggering agent that exacerbates social and economic problems, and reduces society's overall livelihood security. These problems are most severe where economies are least diversified, where virtually everyone depends either directly or indirectly on agriculture. Despite the low returns to land, labour and capital, farmers have long maintained a suite of indigenous strategies and options to manage risk and to deal with poor overall productivity. However, it is generally acknowledged that low-resource agriculture is no longer capable of meeting the livelihood demands of rising populations in fragile dryland environments. Methods need to be developed to assure that natural resources are managed in a sustainable way given the prevailing circumstances.

1.1. The river basin or catchment approach

A catchment, or drainage basin, forms an excellent framework for the management of natural resources and development of rural land, and to a large extent urban and peri-urban land as well. It is basically defined as a hydrological unit, but it can also be used as a physical-biological unit or a socio-economic-political unit for the planning and management of natural resources.

Catchment or river basin management is the process of formulating and carrying out a course of action involving the manipulation of resources in that area to provide goods and services without adversely affecting the soil and water base (FAO, 1996). Catchment management must consider the social, economic and institutional factors operating within and outside the basin. A basic principle of catchment management is that all planning and implementation takes place through participatory approaches and related tools at regional or national level, at sub-basin level, and at community and farm level.

This approach has a number of recognized advantages, especially where drought and water management are crucial issues. It offers a geographical setting where the dynamic relationships between local drought or flood conditions and underlying causes can be faced in a coordinated and programmed way and it also provides a natural framework for achieving optimal hydrological and environmental conditions as well as for increasing sustainable productivity within the catchment area.

1.2. Soil and water conservation

A range of technologies for integrated natural resources management by improving soil, water and nutrient management in ways that are profitable and easily adopted are available to smallholdersand include the following:

- ❖ Quality on-farm management of farmyard manure, where available, with targeted application of farmyard manure and mineral nitrogen (singly and in combination)
- ❖ Improved on-farm use and management of other organic materials
- ❖ The use of legume rotations, especially with different spatial arrangements for inter-cropping to improve soil fertility, particularly drought tolerant and versatile legumes
- ❖ Adopting zero slope contours, infiltration pits, modified tied ridging and other relevant rainwater harvesting techniques to increase rainfall capture and infiltration
- ❖ Good land preparation and land cover, and timely planting to coincide with good soil moisture

Through improving soil and water conservation, rainfed agriculture has a real potential to produce more food per unit of land and unit of water, a process which would significantly contribute to food security. In fact, the bulk of the world's food, especially in the East and Southern Africa region, originates from rainfed agriculture. However, only some 15-30% of the rainfall is exploited for food production from crops. 70-85% of the rainfall in water-scarce farming systems is 'lost' from the crop field and losses are generally even higher, with less than 10% used in productive food making by the crops, where surface runoff is high and soil nutrient depletion is severe.

Even if low yields are characteristic of rainfed agriculture, these yields could be increased within the available water balance in rainfed farming systems by improving water-soil-crop management through, for example, conservation agriculture[1]. The challenge is to increase the amount of water that can be made available to the crops to satisfy their crop water requirements over time, maximize the infiltration and water-holding capacity of the soils and improve plant water-uptake capacity.

Crop yields and returns per unit of rainfall received could be maximized with, season by season, coupled with responsive management of the cropping system. The implementation of responsive farming programmes[2] would provide localized information about expected rainfall behaviour for the forthcoming season and offer guidelines or detailed recommendations to farmers about how best to proceed according to the rainfall forecast.

In dryland farming and rainfed agriculture in particular, the focus should be on minimizing water loss through runoff and evaporation and maximizing transpiration. This can be done through *in situ* water conservation or through water harvesting. *In situ* water conservation aims at preventing runoff and keeping the rain, as much as possible, where it falls and minimizing evaporation. Water harvesting is the collection and concentration of rainwater and runoff which is then used for irrigation (FAO, 1991). More precisely, it is the process of collecting and concentrating rainfall as runoff from a larger catchment area to be used in a smaller cultivated area. Different water harvesting techniques are available and water harvesting can in fact be considered as a type of irrigation.

For more detailed information on rainfed agriculture, soil and water conservation and water harvesting techniques the reader is referred to literature specialized in the subject. This Irrigation Manual concentrates on the development of surface, sprinkler and localized irrigation systems.

1.3. Surface, sprinkler and localized irrigation development

The social and institutional context of irrigation development has immense bearing on the ultimate performance of irrigation schemes. Over the years, the process of implementation of irrigation projects, especially those spearheaded by governments and some donors, has followed a top-down approach. However, experience has shown that if farmers are not involved in all the development stages of a project, they will lose the sense of ownership and therefore treat that project as alien to them. Consequently, the long-term performance and sustainability of the scheme is negatively affected. According to FAO (1995), projects planned with beneficiaries, rather than for them, have proved more sustainable and no more costly. Chapter 2 provides guidelines for participatory development of smallholder irrigation schemes.

It is important to select the appropriate irrigation system. There are many factors to consider before selecting a particular irrigation system. These include water resources, topography, soils, climate, type of crops to be grown, availability and cost of capital and labour, type and appropriateness of a particular irrigation technology to farmers and its associated energy requirements, water use efficiencies, as well as socio-economic, health and environmental aspects. Chapter 3 explores the different criteria that should be at the disposal of the planners and engineers for the selection of the most appropriate irrigation system for the particular circumstances. The actual planning and design of the different irrigation systems will not be described in this module, but will be dealt with in the modules 7 (surface irrigation), 8 (sprinkler irrigation) and 9 (localized irrigation).

Continuous monitoring and evaluation of the health and environmental impact of irrigation is necessary. Chapter 4 is intended to sensitize irrigation planners and users alike to water-related diseases, which may result from irrigation projects. It also proposes hydraulic engineering safeguards that have to be incorporated in irrigation planning and design, and environmental management techniques geared towards the reduction of diseases related to water and the preservation of the environment.

Checklists for socio-economic, agro-technical, health risk and environmental impact assessments of irrigation development are provided in Chapter 5.

Finally, Chapter 6 explains how the various social, economic, physical, crop production, engineering and environmental aspects are incorporated into a feasibility study.

[1] *Conservation agriculture: a concept aiming at conserving, improving and making more efficient use of natural resources through the integrated management of available water, soil and biological resources in combination with limited external inputs.*

[2] *Responsive farming: flexible a system of farming in which key decisions affecting crop water utilization and crop yield are modified each season in response to pre-season and early season predictions of season rainfall amount, duration, intensity index and other parameters as appropriate.*

Chapter 2
Farmers' participation in irrigation development

According to Chancellor and Hide (1996), there is only very scant information published on the determinants of success and failure of the design and implementation process of smallholder irrigation schemes in developing countries. Most design manuals make very little reference to socio-economic issues related to community scheme development, operation and management. Problems of farmer participation are rarely encountered in privately owned schemes or those initiated by farmers. However, for schemes initiated by donors or governments, there is a need for close consultation between farmers and implementing agencies in all stages of development. This can be achieved through participatory planning, designing, construction and management of irrigation schemes (Table 1).

2.1. Principles of participation

The purpose of stakeholder participation in project development is to give planners and the parties involved an overview of all persons, groups, organizations and institutions involved in or connected with the project. Participation is expected to result in the incorporation of the interests and expectations of all parties significant to the project. It will also provide room for the clearing of potential conflict areas.

The steps to take in encouraging participation of interested groups are to:

- ❖ Identify the persons, groups and organizations connected with or influenced by the project
- ❖ Identify their level of influence on the project, for example key stakeholders such as women, who provide the bulk of the labour, and displaced persons should have a significantly stronger influence than secondary stakeholders such as middlemen
- ❖ Involve them in all decision-making processes and characterize their influence on the project
- ❖ Assure them and make them feel that they have the power to influence the course of development

In order to capture the determinant issues for farmer participation, planners have to understand:

a) The characteristics of the farmer groups they are dealing with:
   - social background, religion and cultural aspects
   - status of groups in society, formal or informal
   - organizational and leadership structures
   - current constraints and farmers' priorities

b) Farmers' interests, motives and attitudes:
   - needs and aspirations
   - openly expressed, hidden and vested interests
   - hopes, expectations and fears related to the project
   - attitudes, friendly or hostile, towards implementing agencies and other groups

c) The farmers' potentials:
   - strengths of groups with regards to skills, resources, knowledge, rights, etc.
   - weaknesses and shortcomings, for example knowledge of benefits of project or otherwise
   - what the group can contribute to or withhold from the project

d) The implications of the above on the planning, design and construction of the project:
   - how the project should be designed and implemented in order to address the concerns and needs of the farmers or farmer groups.

In this respect the use of the PRA tool will facilitate, for the planner, the understanding of existing constraints and the farmers' perceptions of how irrigation can be used to remove some of the constraints in crop production. During the same process, and in order to avoid interference by individuals or groups that may have vested interests, farmers should identify the stakeholders that will be involved with the participatory planning. Also, right from the outset not only the advantages but also the responsibilities that come hand-in-hand with a new scheme should be made clear to all involved.

2.2. Identification of stakeholders

Stakeholders are individuals, groups or organizations who have an interest in a particular project. For irrigation projects these are normally farmers, persons displaced by the project, lending institutions, government, donors, input suppliers, service suppliers and buyers.

Table 1

Project development stages and activities for smallholder irrigation (Adapted from: Chancellor and Hide, 1996)

Project stage	Main activities	Purpose
PROJECT IDENTIFICATION	• Facilitate farmers' awareness • Perceived needs by farmers • Farmers' request for assistance	• Ensure development is demand-driven
PRE-FEASIBILITY	• Initial field visits and PRAs • Collect existing physical and socio-economic data • Stakeholder analysis • First approval or rejection of prefeasibility by stakeholders	• 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 conflict and strengths • Use existing data and findings to indicate preliminary feasibility
FEASIBILITY	• Detailed physical data collection and field investigations • Socio-economic survey/assessment • Financial and institutional review • Preliminary design and costs • Participation of farmers in design choices • Initiate appropriate farmers' organization • Prepare project feasibility report including financial and economic appraisal	• Ensure adequate resources to meet farmers' objectives • Ensure resources available for proposed development • Determine farm budgets and organization needs for assistance • Provide basis for discussions with farmers • Provide opportunities to modify design or withdraw request • Provide basis for loans, management, O&M • Enable comparison of projects or project designs competing for funding
CONDITIONAL APPROVAL	• Approval by irrigation professionals and farmers	• Ensure quality of design
DETAILED DESIGNS	• Review O&M capabilities and needs • Final data assessed and final farmers choices • Detailed designs, quantities and contract documents prepared • Funding arrangements organized • Farmers' contributions clearly determined and agreed by contract	• Match design with farmers' capabilities • Allow informed commitment of farmers • Finalize details and costs • Assure farmers of credit availability and cost • Enable farmers to take responsibility for financial and practical commitment
FINAL APPROVAL	• Approval by all major stakeholders	• Multi-directional responsibility implemented
IMPLEMENTATION (OVERSEEN BY MINISTRY / FUNDING AGENCY / FARMER COMMITTEE)	• Tenders received • Contractor chosen and contracts agreed • Farmers' loan activated • Farmers' participation in construction • Training of farmers on cultivation, on-farm water management marketing and O&M • Hand-over of scheme to farmers	• Enable cost-effective choice • Assure payment for work and materials • Promote sense of ownership and acquire skills for future O&M • Promote effective use of water, good yields and sustainable activity • Farmers assume responsibility
MONITORING AND EVALUATION	• Regular review of performance • On-going training and extension	• Ensure targets are achieved and sustained • Encouragecontinued improvement

During project identification, stakeholders of an irrigation scheme should be identified first. Irrigation projects should ideally be developed on farmers' requests in order to ensure that development is demand-driven. However, government, donors, NGOs or other agencies may identify a need for them. In this case it is incumbent upon the institution spearheading the development to mobilize farmers and other stakeholders so that they appreciate the benefits of irrigation and will give their go-ahead for the project.

Meetings and continuous dialogue throughout the development process are necessary for the stakeholders to make contributions as well as to identify and defuse potential conflicts. There should also be agreements, preferably written and signed, that each party will execute its function throughout the planning, design, implementation, operation and maintenance of the scheme.

2.3. Definition of roles of stakeholders

There is a need to clearly define the role of each stakeholder in order to avoid the possibility of role conflict. Usually, the main players are the farmers and the irrigation agency, normally a government institution. The responsibilities of the agency are technical in nature. They include field surveys, such as water resources assessment, topographic, soil and socio-economic surveys, designs, technical and financial project appraisal, the supervision of construction and irrigation extension. On their part farmers provide the land for irrigation, organize finance for development (if not provided by the government or donors), provide labour for surveys and construction activities and any other assistance that the project may require. The farmers should form an Irrigation Management Committee (IMC) or a Water Users Association (WUA) to act as the contact between them and other stakeholders. Such committees operate based on bye-laws established and adopted by the farmers during general meetings, and also oversee the operation and maintenance of the irrigation infrastructure.

Government, donors and lending institutions are important, for development cannot take place without funding. Additionally, government and donors facilitate the adoption and implementation of appropriate policies and strategies to enhance irrigation development. Local authorities can also facilitate irrigation development by bringing to the attention of decision-makers the need for such development. The private sector, through suppliers of irrigation equipment and inputs, and buyers of agricultural commodities also have a positive role in irrigation development.

Of paramount importance are regular stakeholder meetings to update each other on developments and chart the way forward. Taking minutes of all meetings and approving and signing such minutes is important for use as reference when and if problems are encountered later. The presence of an extension agent during meetings can facilitate the process of taking minutes, especially if a large number of farmers are not literate.

2.4. Farmers' participation in scheme planning and development

Farmers' participation in irrigation planning and development is crucial for its success. Gender-sensitivity at all stages is equally important. For detailed guidelines on gender-sensitive irrigation planning, design and implementation the reader is referred to the guide on the integration of socio-economic and gender issues in the irrigation sub-sector (FAO, 1998). This guide has been developed within the framework of the joint FAO/ILO programme on Socio-Economic And Gender Analysis (SEAGA). Its purpose is to support participatory planning of irrigation schemes and the integration of socio-economic and gender issues in the planning process. Its ultimate aim is to improve irrigation scheme performance, while strengthening the position of rural women and disadvantaged groups. The guide is written for professionals who are involved in the planning, design and implementation of irrigation programmes. It is thus intended for irrigation engineers, members of multidisciplinary identification and formulation missions, staff of rural development projects, government employees, staff of NGOs, and engineering and consulting firms.

2.4.1. Farmers' participation in resource identification

Farmers normally have the resources land (be it owned or not) and labour at their disposal, but they need assistance in acquiring other resources such as capital and water. This section will limit itself to the issues related to land and labour because of the importance with which the farmers regard them. This is not to say that the other issues are not as important.

Land

The issues of land and communities are inextricably linked. Planners have to take into account the fact that any new development that alters traditional land use patterns is a potential source of conflict. Potential conflict areas should be identified and addressed from the outset. Therefore, there is a need to actively involve the affected communities in the decision-making process right from the outset.

The ownership of land offers immense incentives to invest in it. As a rule, if an irrigation scheme is privately owned, the owner will be only too willing to improve their scheme and carry out operation and maintenance as and when necessary. The same can not always be said in the case of communal land. When irrigation development is done on communal land, there is generally a disruption of the original communal land ownership pattern. Often some people lose their land when it is converted to irrigation. This land could have been used for cultivation, grazing, hunting etc. prior to the introduction of irrigation. At the same time, other farmers whose land may not be converted to irrigation, but will become plotholders, will make an apparent gain. In other cases, development cannot go ahead because of problems encountered with land redistribution. It is therefore necessary to hold meetings with all the farmers, their local leadership, government and other stakeholders in order to reach compromises on land redistribution or compensation arrangements. This should be done prior to the decision to go ahead with the project. It is also important to ensure that the parties involved fully understand the arrangements agreed upon and are committed to implementing them.

Labour

In most countries in Southern Africa, rainfed crop production utilizes family labour for about five months of the year. However, irrigated crop production is a year-round labour demanding enterprise. Hence, the issue of the labour demand of a particular irrigation activity is very important. Farmers normally have on-farm and off-farm activities prior to irrigation development. Irrigation will therefore introduce extra demands on the people's labour.

According to Chancellor and Hide (1996), some countries in sub-Saharan Africa experience labour shortages due to use of labour intensive technologies and the migration of male labour to urban centres. Consequently, women make up the bulk of labour for agricultural activities which result in them being over-burdened.

It is therefore necessary, during scheme planning, to evaluate the labour requirements of the planned irrigation design alternatives versus the estimated available labour in order to determine when and where shortages may occur (see also Module 11). Each alternative will have its own labour requirements and these should be discussed with the farmers. The assessment should also capture issues related to labour and gender so that the design minimizes over-working, especially of women who already have many other activities to attend to. Therefore, irrigation technology options should be gender-sensitive (FAO, 1998). For example, the use of a drag-hose sprinkler demands light work that is limited to moving the tripod and hose from one position to the next. This system has gained popularity amongst Zimbabwean smallholders to the extent that 30% of all smallholder schemes in this country have adopted this system (FAO, 2000).

2.4.2. Farmers' participation in scheme planning and design

Farmers participating in the planning process should be able to make well-informed decisions. It is therefore necessary that farmers be exposed to the various options of irrigation development and irrigated crop production before embarking on the participatory planning process. Farmer visits to several irrigation schemes using different technologies and discussion with the farmers using these schemes are considered as indispensable tools in initiating farmers into the process of participatory planning and informed decision-making. This approach, introduced in Zimbabwe during the late eighties, was found to be very useful in providing the openness and informed decision-making needed in participatory development. Farmers then play a significant role in scheme planning through participation in the following way:

- ❖ The farmers should select lands to be irrigated and the irrigation agency should assist farmers by assessing the suitability of those lands
- ❖ The communities within the area to be developed should participate in the Environmental Impact Assessment (EIA) for the project, through contributing vital information, such as current uses of their natural resources, ecology, human health, etc.
- ❖ Farmers should provide labour for topographic, soil and socio-economic surveys. They should, through their committees, decide who should do which activity
- ❖ Farmers could provide information on past experience with floods, point out areas with potential for flooding, and suggest to the planners locations for structures such as water abstraction from the river, hence preventing the pumping station from being flooded
- ❖ The farmers should select the crops to be grown in the project and the agency should guide them only on technical matters related to the suitability of such crops for the climate, soils, the cost of production and expected returns as well as the marketing potential of these crops
- ❖ The irrigation agency should facilitate the exposure of the farmers to various irrigation methods and enlighten them as to the advantages and disadvantages of each. The farmers then should propose the irrigation methods they would prefer to be considered during irrigation design
- ❖ The prospective irrigators should suggest the plot sizes they would prefer to irrigate and the irrigation agency should provide information on the management, labour and input costs required for different plot sizes, as well as on the potential of the land and water resources to satisfy the various sizes
- ❖ After completing the designs, the irrigation agency should explain the alternative designs to farmers and the implications of each vis-à-vis land redistribution, water resources potential, plot sizes and total area to be irrigated, cropping programmes, labour requirements, capital costs, operation and maintenance costs, environmental aspects, land use patterns and other considerations
- ❖ Finally, the farmers will decide which option to adopt.

Once the farmers decide on their preferred design option then the agency and the farmers should sign an agreement indicating the chosen option. What is important in the whole process is to help farmers appreciate the trade-off between what they want and what is technically feasible, economically viable and environmentally sound.

The duration of this process varies from group to group and is affected by the size of the scheme and the number of beneficiaries. Experience in Zimbabwe has shown that the preparation of feasibility studies with farmer participation can last from 3-4 months for small schemes (10-20 ha) to one year for schemes of 100 ha.

2.4.3. Farmers' participation in scheme implementation

The implementation of an irrigation project involves preparing tender documents for construction, evaluating the tenders, selecting the contractor and supervising construction. The farmers should be involved in all these processes, especially if they are contributing part of the finance, in cash or kind, for the project. The irrigation agency should provide technical information to assist the farmers in reaching decisions. The farmers should contribute their own labour for certain construction activities, such as trenching, back-filling, pipefitting, land levelling and concrete mixing. This will also assist them in gaining the experience needed later in the maintenance of the project. In this respect it is advisable to use labour intensive methods, where possible. The supervision of construction still remains the responsibility of the irrigation agency. Where the farmers contribute money for the project, they should also sign certificates authorizing payments to the contractor.

2.4.4. Scheme operation and maintenance responsibilities

The responsibilities of scheme operation and maintenance (O&M) should be clear to all parties from the outset. To assist farmers in selecting a design alternative, planners should estimate the O&M requirements at the planning stage and discuss them with farmers. If the irrigation agency is to pay for O&M for a specified time before hand-over to farmers, the farmers should be organized and prepared for take-over well in advance.

While the experience gained by the farmers during the course of planning and development is a valuable tool for the O&M of the irrigation scheme, farmers would still require assistance from the irrigation agency and the extension service in the form of training in the following areas:

- ❖ Crop production and protection
- ❖ Irrigation scheduling and on-farm water management
- ❖ Schedule of scheme maintenance
- ❖ Bookkeeping
- ❖ Access to markets and market information

Such training should be practical, in order to provide the hands-on experience needed, and should take into consideration that the background of most smallholders in Eastern and Southern Africa is in rainfed crop production.

The recently introduced Farmers Field School (FFS) methodology in the sub-region provides a good vehicle with which to continue the participatory process beyond the construction and follow it during the operation of the scheme. For this, FAO has developed a programme called "Participatory Training & Extension in Farmers' Water Management (PT&E-FWM)" (FAO, 2001). This programme provides guidelines, procedures and relevant material for the development of a participatory training and extension programme for technical staff, extension workers and other stakeholders, in order to assist farmers in taking charge of water management at field and scheme level and adapting, in a sustainable manner, appropriate water technologies. The programme is particularly relevant to irrigation management transfer programmes, assisting water users associations in the operation and maintenance of farmers irrigation systems, and to smallholder irrigation programmes, giving guidance to farmers in adopting efficient water control techniques.

2.5. Monitoring and evaluation of smallholder irrigation development

Once an irrigation scheme is implemented, there is a need to continuously monitor its performance, in order to identify constraints and opportunities for improved irrigation performance. There are a number of parameters that can be measured and assessed as performance indicators. These include technical irrigation system performance, which looks at performance in terms of water use efficiencies and other related parameters; economic analyses, which evaluate economic and financial performance; as well as socio-economic analyses, which evaluate the impact of economic performance on the social well-being of the people. Module 14 deals more in detail with monitoring the technical and financial performance of irrigation schemes.

Box 1 provides a typical case of the success that can result from the implementation of an irrigation project through farmer participation, as reflected by the socio-economic benefits that accrued to the community. This information, which highlights the success of Hama Mavhaire drag-hose sprinkler irrigation scheme in Zimbabwe, is a result of a study to assess the socio-economic impact of three smallholder irrigation schemes in Zimbabwe (FAO, 1997a).

Box 1:

Example of successful implementation of smallholder irrigation development with farmer participation (Source: FAO, 1997a and Savva, 1998)

Hama Mavhaire irrigation scheme in Zimbabwe is a 96 hectare drag-hose sprinkler irrigation project. The scheme is apportioned equally to 96 farmers, of which 70% are women. It is located in a dry agro-ecological area that receives about 450 mm of rainfall per year. Dryland cropping fails 3 to 4 years out of 5. The development of the scheme was initiated in 1989, following strong farmer requests to Government for irrigation development.

Participation of farmers in planning and design

The government dispatched a team of experts, comprising engineers, agronomists and economists, to the project site to carry out a feasibility study. Several meetings were held in order for planners to understand the farmers' expectations and to explain to the farmers the potential and requirements of the proposed development. This was followed by a baseline socio-economic survey. The local authorities then selected, from the many aspirant irrigators, those who showed the keenest interest in irrigation. The land chosen consisted of about 80% of non-cultivated bush, while the remaining 20% was arable land owned by the farmers who were selected for the scheme. The farmer group was to be the partner in irrigation development. It elected its own committee, which was tasked with liaising with the planners on all matters related to the new development.

To facilitate a process of making informed decisions, arrangements were made for farmers to visit different types of irrigation systems, surface and sprinkler. The farmers spent considerable time discussing issues with their counterparts at those projects. The issues discussed included the type of irrigation system, types of crops irrigated, fertilizer requirements, crop yields and marketing. This exposure proved useful to farmers when they eventually decide on the type of irrigation system they prefer and the crops to be grown. Once the experts completed design options, they took them back to the farmers and explained the pros and cons of each. Eventually the farmers settled on a drag-hose sprinkler irrigation system. This process took one full year.

Participation of farmers in construction

Upon the adoption of the design, tender documents were prepared with the condition that farmers would provide all unskilled labour required for construction. During construction the group provided labour for trenching and back-filling and assisted pipe fitters by carrying and placing pipes and fittings in position. As a result of their participation, the farmers were trained in pipefitting and other general repairs to their system. Additionally, the contractor trained one farmer per irrigation block on the repair of sprinklers. The irrigation engineers and extension staff trained the farmers on leadership, bookkeeping, scheme operation, improved agronomic practices and irrigation scheduling. This process took six months for the first 48 hectares and three months for the remaining 48 hectares.

Socio-economic impact of scheme development

The socio-economic impact study showed that on average, the net income per plot-holder quadrupled due to the introduction of irrigation, from a gross margin assessed at US$650 annually on 2.5 hectares of dryland crop production to a gross margin of US$2 775 for one hectare irrigated. The other benefit of the introduction of irrigation was that when electricity was brought into the Hama Mavhaire area to power the pump, the nearby shopping centre was also electrified. Before the scheme was constructed, there was only one general dealer, one bottle store and one grinding mill, which was powered by a diesel engine. Now there are three general dealers, two bottle stores, four electrically-driven grinding mills and a butchery. In addition, one of the plot-holders confirmed that a significant portion of the investment that he put into the shop he operates at a nearby shopping centre came from the proceeds of irrigation.

There are other indicators of a substantial rise in the standard of living of the irrigators. About 29% of the plot-holders are reported to have purchased between one and four head of cattle from the income earned through irrigation during the first five to six years of scheme operation. In addition, 13% of the plot-holders had put up brick under corrugated iron houses and 10% had installed solar panels during the same period. Women, who constitute the majority of the plot-holders and are represented at all committees, also confirmed that the other major benefit of irrigation was that they are able to pay for the costs of educating their children.

The success of the Hama Mavhaire irrigation scheme is largely attributed to the dedication and determination of the group to improve their standard of living. The participatory approaches adopted for the development of the scheme provided the opportunity to the group, planners and implementers to jointly plan and implement a scheme, making it both technically feasible and socially acceptable.

Chapter 3
Criteria for the selection of an irrigation system

There are many factors to consider before selecting a particular irrigation system. These include water resources, topography, soils, climate, type of crops to be grown, availability and cost of capital and labour, type and appropriateness of a particular irrigation technology to farmers and its associated energy requirements, water use efficiencies, as well as socio-economic, health and environmental aspects. It is not wise to use a single criterion for selection purposes. However, there are instances when one criterion can weigh heavily in favour of a particular irrigation system.

The socio-economic impact of an irrigation system largely determines the success of the project. This embraces the socio-economic benefits, for and against, that can be derived not only by the government but also, more importantly, by the communities in which the project is located, and how these affect the sustainability of the project.

Health and environmental aspects are also important. The introduction of irrigation in a particular area can not only improve health, but also introduce health hazards, if mitigation measures are not adequately addressed during the scheme design, implementation, operation and management. Irrigation development may also introduce other environmental risks, such as salinization and the deterioration of biodiversity.

It is therefore necessary to obtain all available information and data and to carry out an analysis of all the factors before possibly ranking the criteria for purposes of selecting an irrigation system. In order for a project to be sustainable, all technical, socio-economic, health and environmental information should be analyzed in such a way that the system chosen is technically feasible, economically viable, socially acceptable and environmentally sound.

3.1. Types of irrigation systems

In order to be in a position to select an irrigation system for a given area, it is important to look at the types of irrigation systems commonly used. Based on the method of applying water to the land, there are four broad classes of irrigation systems: (1) surface irrigation systems, (2) sprinkler irrigation systems, (3) localized irrigation systems and (4) sub-surface irrigation systems.

Surface irrigation systems apply water to the land by an overland water flow regime. Within this group are the furrow, borderstrip and basin irrigation systems. In sprinkler irrigation systems, water is conveyed and distributed through pressurized pipe networks before being sprayed onto the land. There are several sprinkler irrigation systems, which can broadly be divided into set systems and continuous move systems. In localized irrigation systems, a pipe distribution network is used to distribute and deliver filtered water (and fertilizer) to a predetermined point. The three main categories of localized irrigation methods are drip, spray and bubbler. More recently, drip irrigation systems have been developed whereby the laterals are buried in the root zone of the crop. Sub-surface irrigation systems rely on the raising or lowering of the water table in order to effect groundwater flow to the root zone. As such, they are drainage flow systems.

3.1.1. Surface irrigation systems

Surface irrigation systems are based on the principle of moving water over the surface of the land in order to wet it, either partially or completely. They can be subdivided into furrow, borderstrip and basin irrigation. The scheme layout up to field level, such as canals and drains, can be similar for each system. Low irrigation efficiencies are usually associated with poor land levelling, wrong stream size and change in soil type along the irrigated area both vertically and horizontally.

According to FAO (1989), 95% of the irrigated area in the world is under surface irrigation. Some of the major advantages of surface irrigation systems over other systems are that they are easy to operate and maintain with skilled labour, they are not affected by windy conditions and, with the exception of furrow irrigation, they are good for the leaching of the salts from the root zone. Generally, they are associated with low energy costs.

Surface irrigation systems do have several disadvantages, though. They are less efficient in water application than sprinkler or localized irrigation systems. The spatial and temporal variability of soil characteristics, such as infiltration rate and texture, make water management practices difficult to define and implement. It is also difficult to apply light, frequent irrigation required early and late in the cropping season. Another disadvantage can be the high labour demand, as compared to sprinkler and localized irrigation systems, in situations where labour is not abundant.

Below follows a description of the three surface irrigation methods, which are dealt with more in detail in Module 7.

Furrow irrigation

A furrow irrigation system consists of furrows and ridges, of which the shape, spacing and length depend mainly on the crops to be grown and the types of soils. Figure 1 shows furrow irrigation. Siphons are mostly used to take water from the field ditch to the furrows.

According to Kay (1986), the width of the furrows varies from 250-400 mm, the depth from 150-300 mm and the spacing between the furrows from 0.75-1.0 m, depending on soil type, crops and stream size to be applied to the furrow. Coarse soils require closely-spaced furrows in order to achieve lateral water flow in the root zone. Figure 2 show the general wetting patterns of sand and clay. There is more lateral water flow in clay than in sand. Typical furrow lengths vary from about 60 m on coarse textured soils to 500 m on fine textured soils, depending on the land slope, stream size and irrigation depth. The minimum and maximum slopes for furrows should be 0.05% and 2% respectively in areas of low rainfall intensity. In areas where there is a risk of erosion due to intensive rainfall, the maximum slope should be limited to 0.3%.

Most field crops, except very closely spaced crops such as wheat, as well as orchards and vineyards can be irrigated using furrows. However, with this type of irrigation there is a risk of localized salinization in the ridges.

Figure 1
Layout of furrow irrigation (Source: FAO, 1985)

Figure 2
Wetting parameter for coarse and fine textured soils (Source: Kay, 1986)

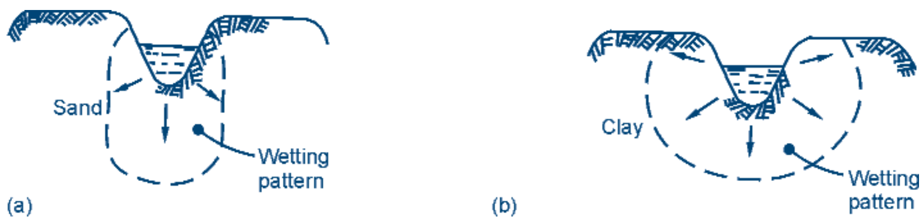
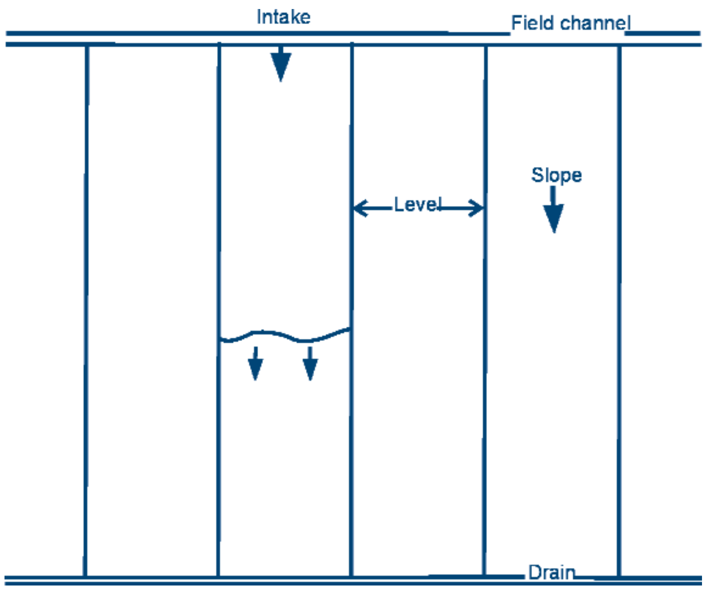


Figure 3
Layout of borderstrip irrigation (Source: FAO, 1985)



Borderstrip irrigation

Borderstrips, border checks or strip checks are strips of land separated by small earth bunds that guide the water as it flows down the field. They can have rectangular or contoured shapes, depending on the field. The borderstrip slopes uniformly away from the direction from the source of the irrigation water. They should be levelled across, in order to allow for the even wetting of the whole area, covered by a border and allow free drainage at the end. Figure 3 shows the layout of borderstrip irrigation. Normally, water is let onto the field from the canals through siphons. The siphoned water spreads across the width of the border when there is no cross slope, thereby facilitating uniform water application. Uneven borders slopes and cross border slopes are some of the most common problems that result in low irrigation efficiencies.

Borderstrips may vary in size from 60-800 m length and 3-30 m width depending on the soil type, stream size, irrigation depth, slope, field size and farming practices. Generally, border width becomes smaller as the soil becomes coarser for the same unit stream size, irrigation depth, and slope, as coarse soils have a higher intake rate than fine soils and consequently less lateral water flow.

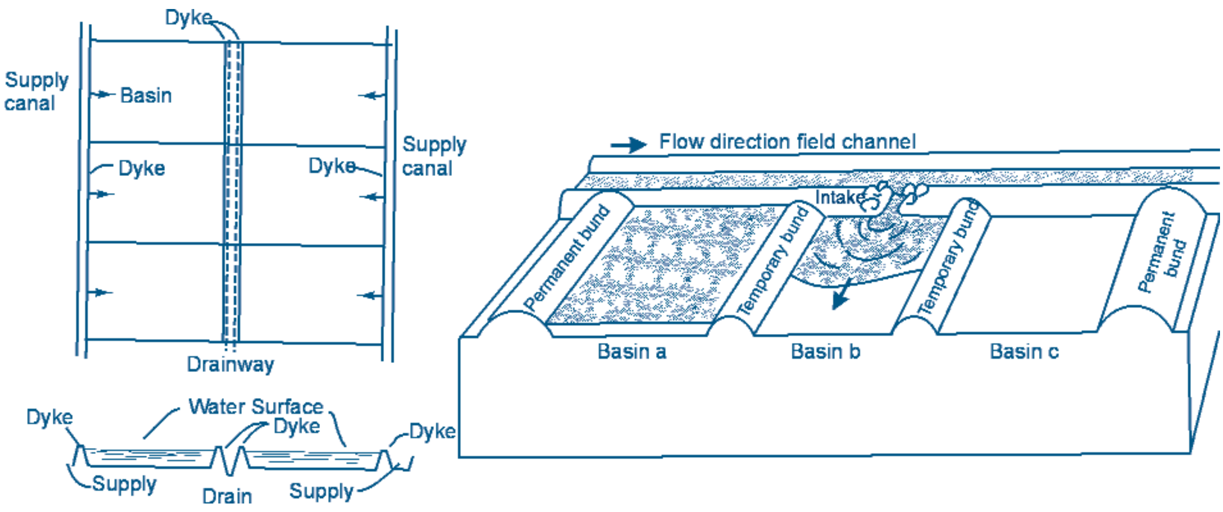
Border lengths for a width of 12 m vary from 60 m for an irrigation depth of 100 mm, a slope of 2% and a stream size of 15 l/s for sandy soils to 300 m for an irrigation depth of 200 mm, a slope of 0.4% and a stream size of 4 l/s for clay soils. The minimum slope of borders is 1% and the maximum is 2% in humid areas and 5% in arid areas, depending on crop cover. The greater the crop cover, the less the risk of erosion and the steeper the border can be. However, crop cover can only be a determining factor in case a permanent crop, such as pasture, will cover the borderstrip.

Basin irrigation

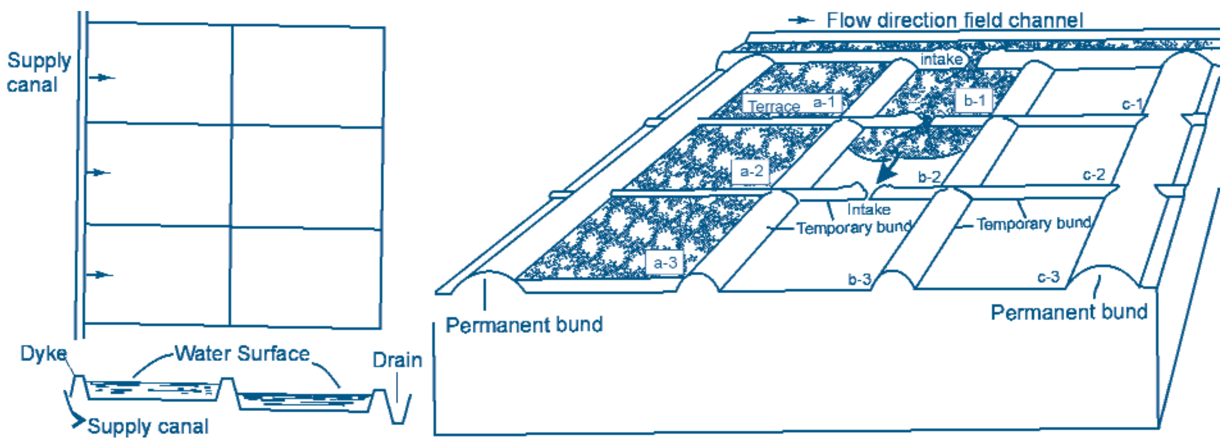
Basin irrigation is the most common type of surface irrigation and is particularly used in paddy rice irrigation. A basin is a leveled area of land, surrounded by earth bunds, that does not need directed and controlled flow (FAO, 1989). Basins should be quickly filled with water during irrigation, after which the water infiltrates evenly throughout the basin, in order to achieve high application uniformity. Basin irrigation can be a very useful way of leaching harmful salts. However, a good drainage system should also be put in place to dispose of the excess water.

Basins can be adapted to suit any crop, soil or farming practices. Crops grown under basin irrigation include rice, alfalfa, row crops and orchard crops. The basins vary in size from 1-2 m^2 to 3-4 ha depending on the irrigation depth, land slope and farming practices. Generally, for the same stream size and irrigation depth, basins should be smaller on light soils than on heavier soils. In cases where the land is considerably steep, terracing may be necessary in order to construct basins. Typically terrace width varies from 1.5 m for 4% land slopes to 150 m for 0.1% land slopes. Figure 4 illustrates rectangular basins being irrigated using water from the farm canal.

Figure 4
Layout of basin irrigation (Source: FAO, 1985)



Direct method of water supply to the basins with a drainway midway between supply canals. “Basin a” is irrigated, then “Basin b”, and so on.



Cascade method of water supply to the basins with a tier arrangement. Ideal on terraced land, where water is supplied to the highest terrace, and then allowed to flow to a lower terrance and so on.

3.1.2. Sprinkler irrigation systems

A sprinkler irrigation system consists of a pipe network, through which water moves under pressure before being delivered to the crop via sprinkler nozzles. The system basically simulates rainfall in that water is applied through overhead spraying. Therefore, these systems are also known as overhead irrigation systems. As such, the water distribution of certain sprinkler systems is affected to a large extent by the wind patterns and velocity in a particular area.

Sprinkler irrigation systems are suitable for most crops, except those whose leaves may be sensitive to prolonged contact with water or crops requiring ponding of water at some stage of their life. They are generally suitable for light, frequent irrigations, unlike most surface irrigation systems.

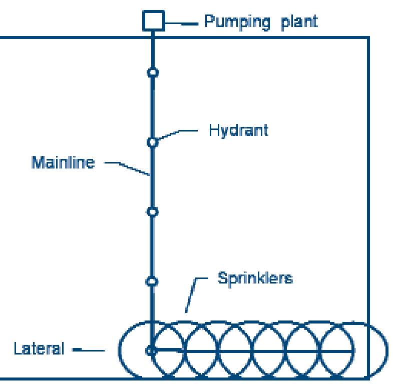
They have a large component of built-in management in that it is easy to apply the exact amount of water that one requires, unlike surface irrigation systems where the depth of irrigation desired at a given time can not be accurately applied. Sprinkler irrigation systems also require much less labour than surface irrigation systems. In contrast to these advantages, sprinkler irrigation systems are relatively high energy demanding and require fairly good water quality, in terms of sodium and chlorite. These systems are also susceptible to windy conditions.

There are several types of sprinkler irrigation systems, which can be broadly sub-divided into two groups: **set systems**, which operate with sprinklers in a fixed position, for some time at least, and **continuous move systems**, which operate while moving.

Set systems

Set systems can be further divided according to whether or not sprinklers should be moved through a series of positions during the course of irrigating a field. Those systems that must be moved are called ***periodic-move systems*** and those that do not require any movement are called ***fixed systems***. Periodic-move systems can be further divided according to the method of movement of sprinklers and laterals into hand-move systems, where laterals and sprinklers are moved manually, and mechanically-move systems, where the movement is done by mechanical means.

Figure 5
Layout of a periodic-move sprinkler irrigation system (Source: Keller and Bliesner, 1990)



Periodic hand-move sprinkler irrigation systems

The hand-move lateral systems are comprised of either portable or buried mainlines, sub-mainlines and hydrant valves at intervals for connecting the laterals (Figure 5).

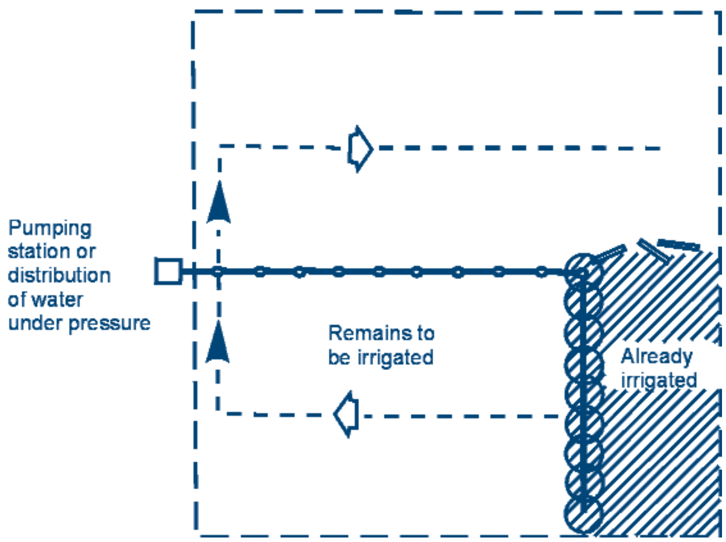
Hand-move lateral systems normally utilize quick-coupling laterals that are moved from one hydrant position to another by hand. Therefore, they are labour-intensive compared to other sprinkler irrigation systems. In fact they are the predecessors of mechanically-move systems, which were developed to reduce labour input. Hand-move systems are adapted to irregular field shapes, fairly steep topographies and are suitable for most field crops.

Due to their labour demand, they may be ideal where labour is available and cheap. A brief description of the various periodic hand-move systems (portable, semi-portable and drag-hose) is given below. The differences between the individual systems depend on which components are movable and which are not.

Portable systems

A portable sprinkler irrigation system has portable aluminum or light steel mains, submains, laterals and sometimes even portable pumps. This means that the equipment can be moved from one area to another in order to carry out irrigation events as required. It is, therefore, designed to irrigate different fields with different crops using the same equipment. It suits areas that border perennial streams or that have a number of sources of water in their vicinity or where supplementary irrigation is

Figure 6
Layout of a portable sprinkler irrigation system (Source: FAO, 1990)



required. They are extensively used in tobacco because of the 3-4 year rotation followed for this crop. Figure 6 shows a portable system, where only one lateral is operating. The shaded area indicates the area already irrigated. The lateral is moving towards the pump in a clockwise direction. When the lateral reaches the last position closest to the pump, it is flipped over to the other side of the mainline and continues moving away from the pump. After having finished this side the mainline can be moved to another position and the next part can be irrigated moving the lateral in the same way as explained above.

Semi-portable systems

The semi-portable or semi-permanent system usually has permanent AC or uPVC mains and submains, which should be buried, and portable aluminum or light steel laterals. This means that the mains and submains can not be moved. Both the portable and the semi-portable systems are common in many parts of the world. Figure 7 shows a semi-portable system in which the laterals together with the sprinklers are moved during irrigation. A more detailed description of semi-portable systems is given in Module 8.

Drag-hose systems

Drag-hose or hose-pull systems are composed of buried mains, submains and laterals. The hoses are attached to the hydrants or garden taps of the laterals on one end and to the risers, fixed onto tripod stands, on the other end. The sprinklers are fixed on tripod stands. Usually, one sprinkler is attached to each hose. Figure 8 is a schematic illustration of a drag-hose irrigation system in which sprinklers, connected to the supply line through flexible hoses, are shown in different positions. A prerequisite to the uniform wetting of the system is the systematic manner of movement of the sprinklers from one position to another, so that adequate overlap is achieved.

The hose and tripod stand are manually moved from one sprinkler position to the next. These systems were originally used to irrigate citrus trees and orchards. In Southern Africa they are now increasingly used for the irrigation of sugar cane, field crops and vegetable crops. The length of the hose varies with the desired ease of operation and initial capital investment required. A length of 30 m is considered as reasonable. The drag-hose irrigation system has been successfully implemented in Zimbabwe's smallholder irrigation sector since 1988. In 1997 it was estimated that more than 30% of all smallholder schemes in Zimbabwe were under this system. Other countries, such as South Africa, Swaziland, Malawi and Kenya, are using this system. A more detailed description is given in Module 8.

Periodic mechanically-move systems

Several mechanically moved sprinkler irrigation systems have been introduced during the last 30 years in an effort to reduce the cost of labour. The most popular mechanically moved systems are briefly explained below.

Side-roll and side-move lateral system

These systems are similar to the hand-move system, except that instead of people moving laterals it is done by a machine. The system is a rigidly-coupled lateral supported on a number of wheels, which are mechanically moved by a power source such as an engine at the center of the line or at the end. The number of wheels varies with the length of the lateral. The lateral is attached to the main line via a flexible hose or a portable aluminium pipe. When the system is operating, the wheels are stationary. When a change of lateral position is needed, an engine moves the wheels to the next position. Figure 9 shows a typical side-roll lateral layout and its wheel-mounted lateral.

The side-roll lateral system has the disadvantages of being only suited to short crops and mostly rectangular fields. Due to its long lateral, which extends to about 500 m, it is not suitable for rapidly changing topography or steep slopes. In the side-move lateral system, the lateral is raised to a height of 1.5 m from the ground, making it suitable for higher crops. The general disadvantage of both systems is that when they reach the end of the field they have to be towed back to the beginning of the field, a process that is time consuming.

Figure 7

Layout of a semi-portable sprinkler irrigation system based on a 12 m x 12 m spacing with tertiaries serving two plots

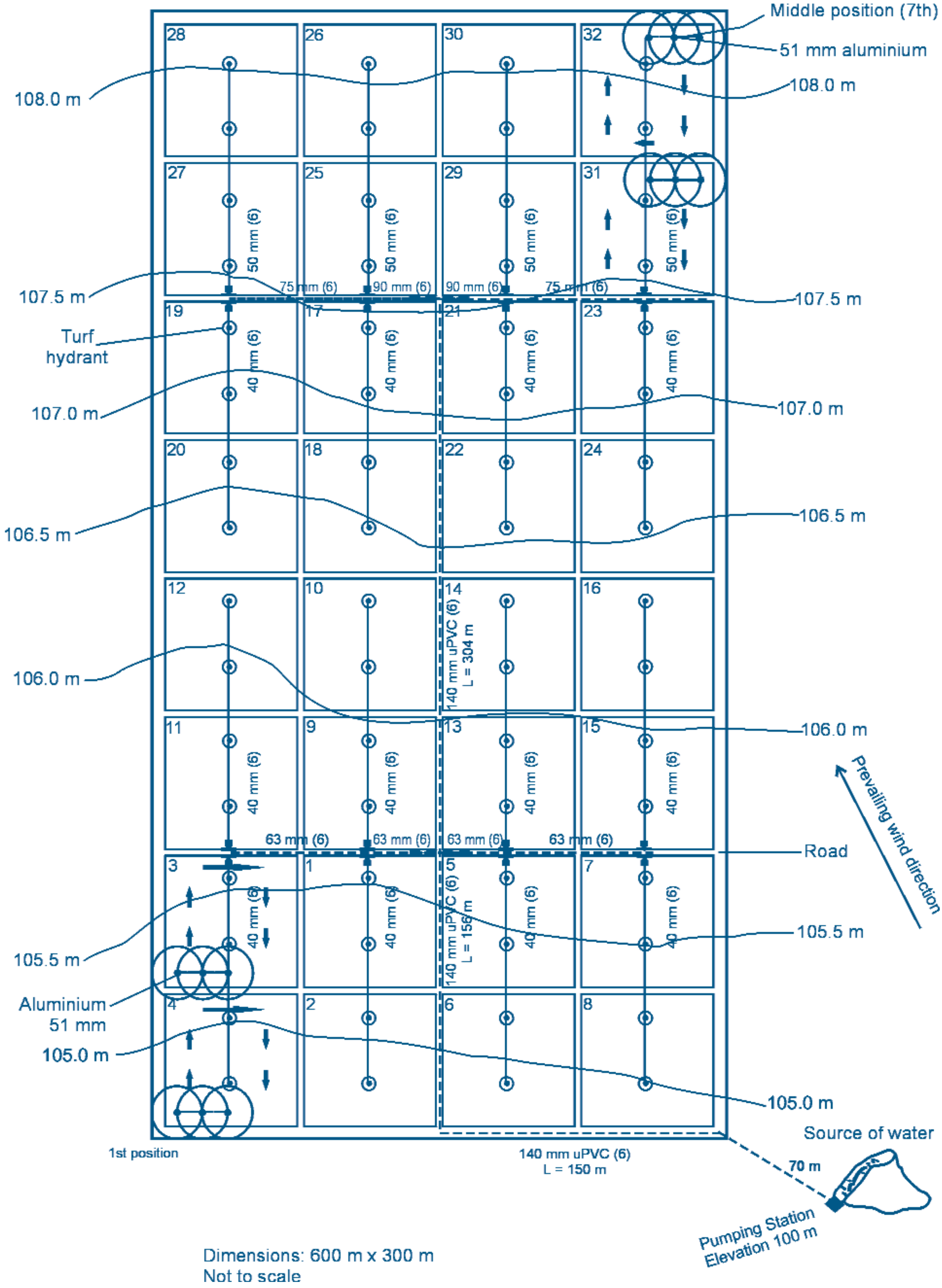


Figure 8
Layout of a drag-hose sprinkler irrigation system on a 12 m x 12 m spacing

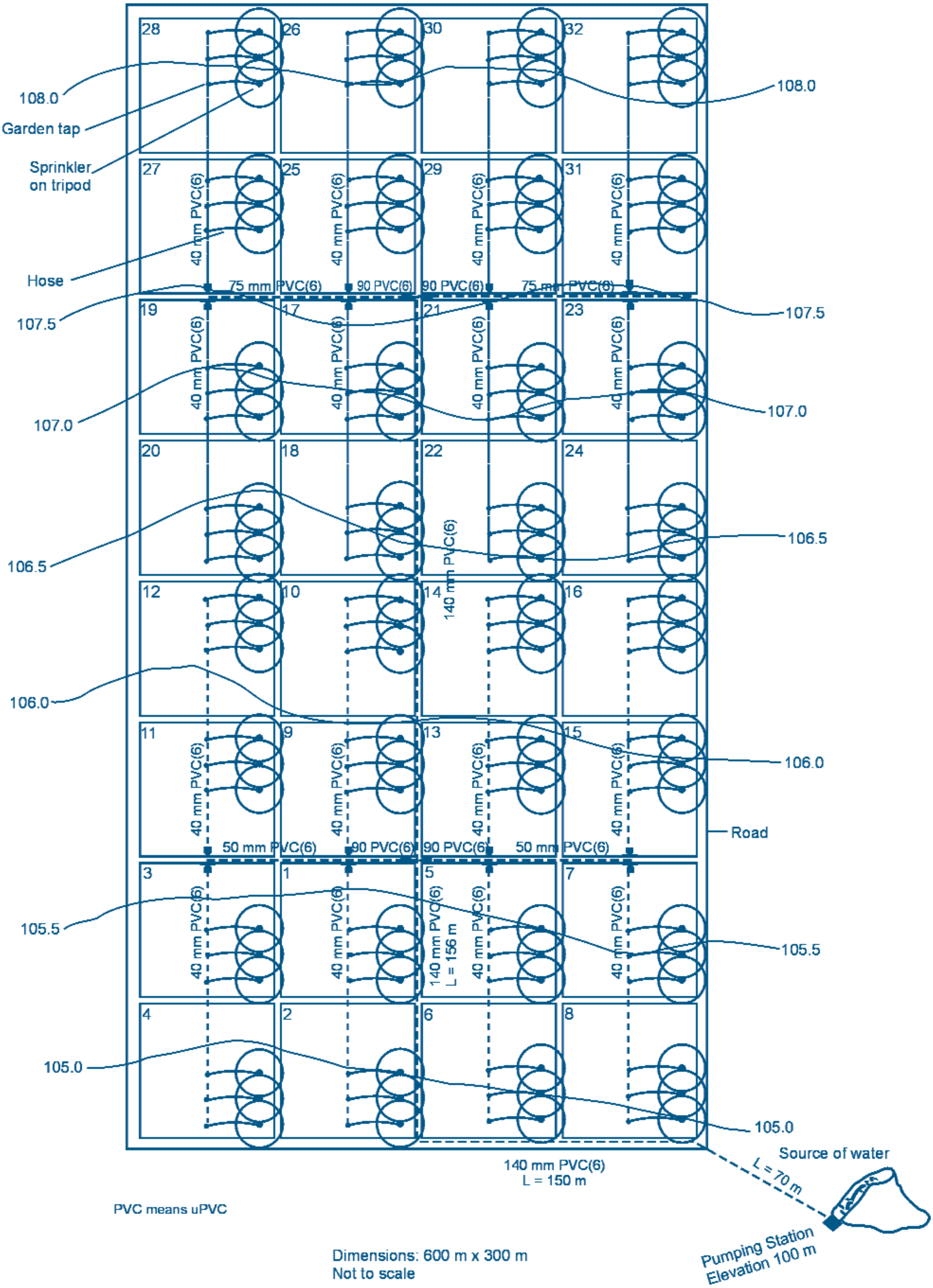
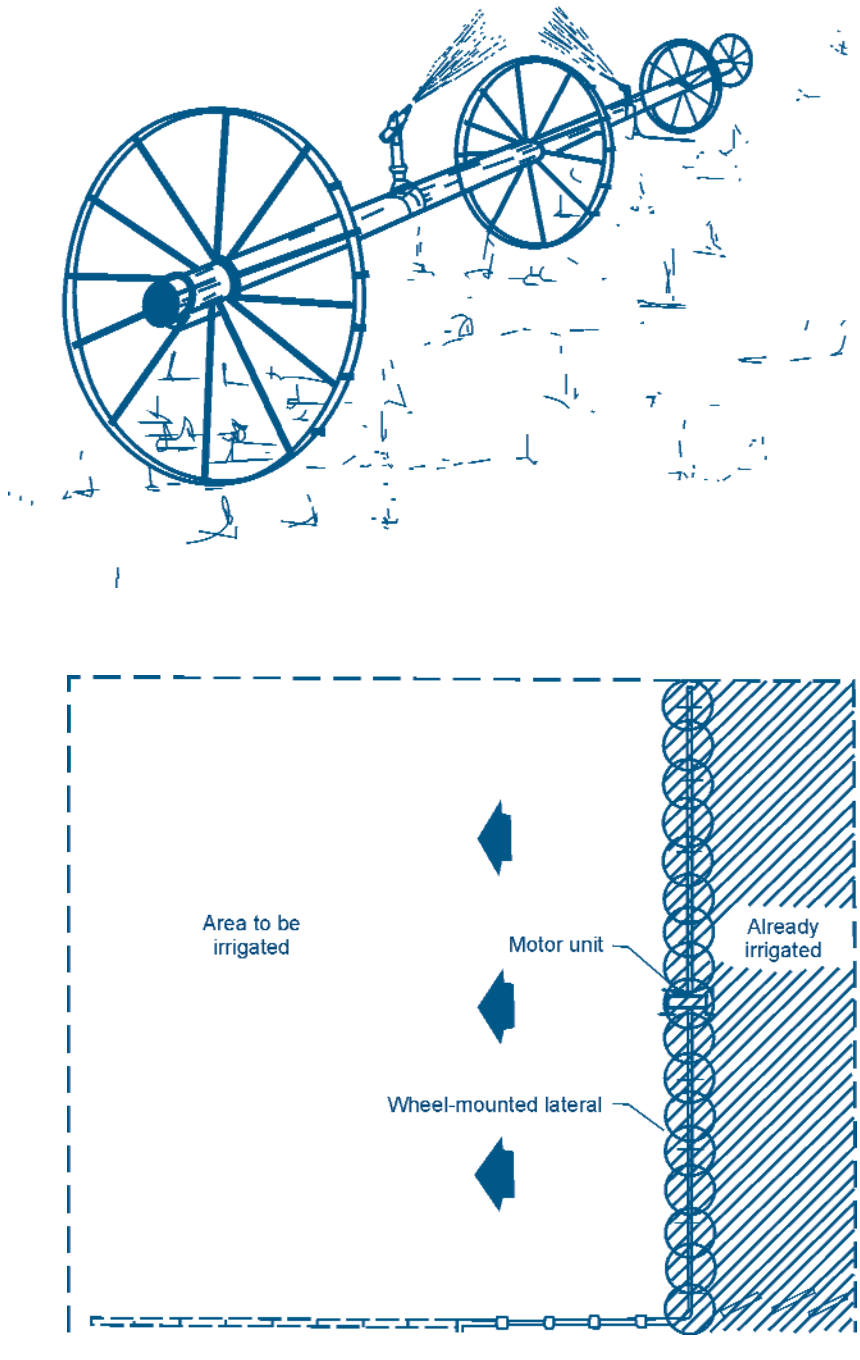


Figure 9

Layout of a side-roll lateral sprinkler irrigation system and wheel-mounted lateral (Source: FAO, 1982)

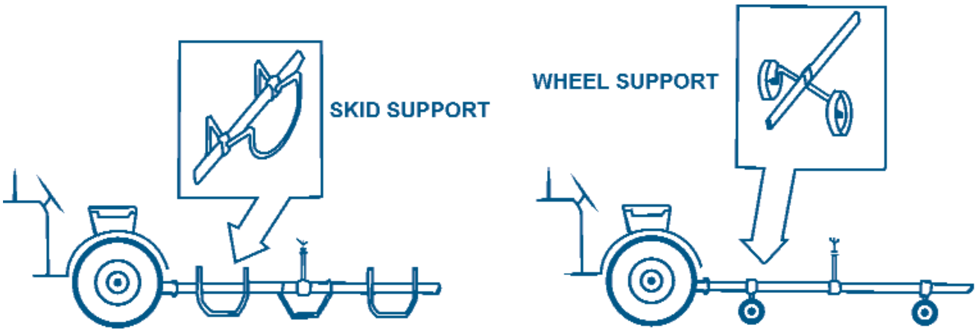


End-tow lateral systems

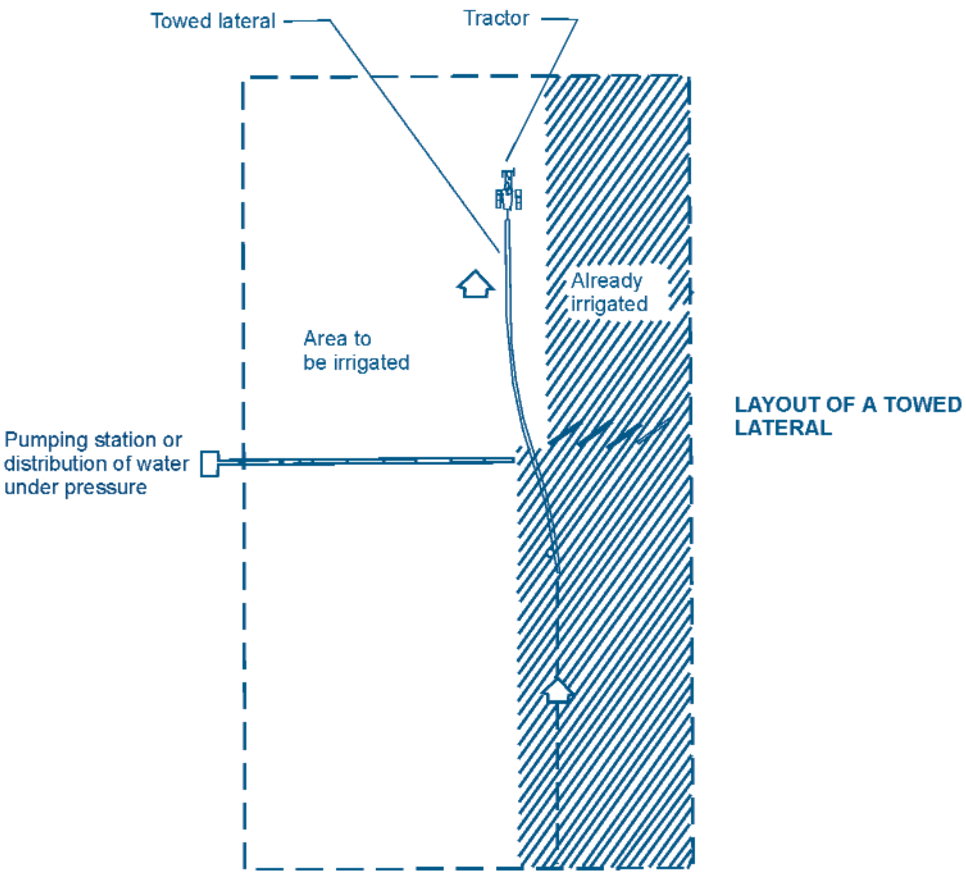
End-tow lateral systems are similar to hand-move systems except that they consist of rigidly coupled laterals, up to 400 m in length, connected to the mainline during operation. They also need to be towed from one side of the mainline to the next. The towing is normally done using machinery such as tractors rather than by hand. This system, by virtue of its long laterals, is not suited to irregular field shapes, rough and rapidly changing topography or row crops grown following the contours. Figure 10 is a schematic representation of the lateral on skid or wheel support and the sequence of moves of an end-tow sprinkler irrigation system.

Figure 10

Layout of an end-tow lateral sprinkler irrigation system and towed lateral on skid or wheel support (Source: FAO, 1982)



Skid or wheel support for towed sprinkler laterals



Gun and boom sprinkler irrigation systems

Gun sprinklers have large nozzles, 16 mm in diameter or larger, that are rotated by a rocker arm. Boom sprinkler irrigation systems have rotating arms on which sprinklers are positioned. The gun and boom sprinklers operate at up to 62 metres (or 6.2 bars) head and discharge approximately 31.5 l/s (Keller and Bliesner, 1990). The systems are used on most crops, mainly for supplementary irrigation. Their use is limited to coarse textured soils because heavier textured soils have low intake rates that are incompatible with the high application rates of these systems.

The gun and boom sprinklers are normally mounted on trailers or skids, which have to be towed from one position to the next. Figure 11 shows two typical layouts for gun sprinklers. In one instance the gun is pulled towards the fixed winding machine by the pipe supplying water, while in the other the gun is self-hauled on the pipe supplying the water. In the latter the winding machine is moving towards the pipe anchorage as the pipe winds onto the drum.

Figure 11

Layout of a gun sprinkler irrigation system and irrigation machine (Source: FAO, 1982)

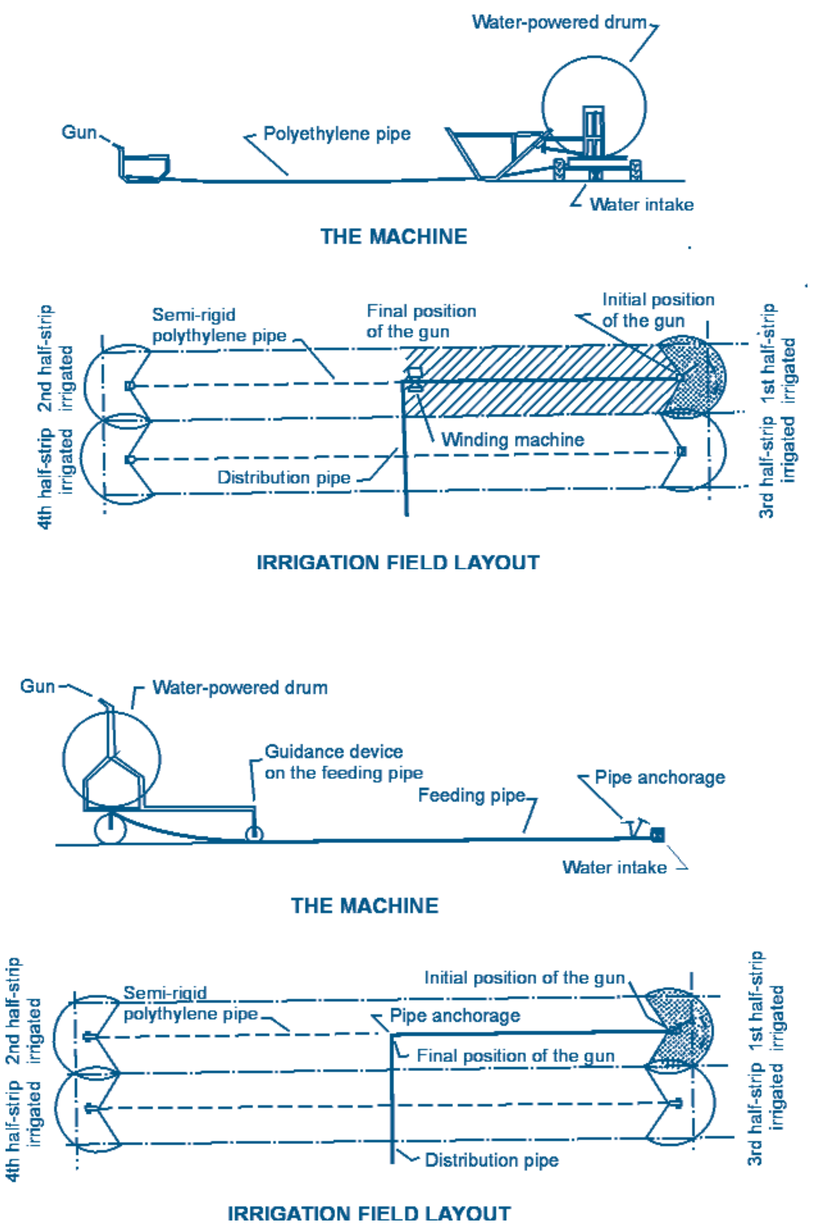
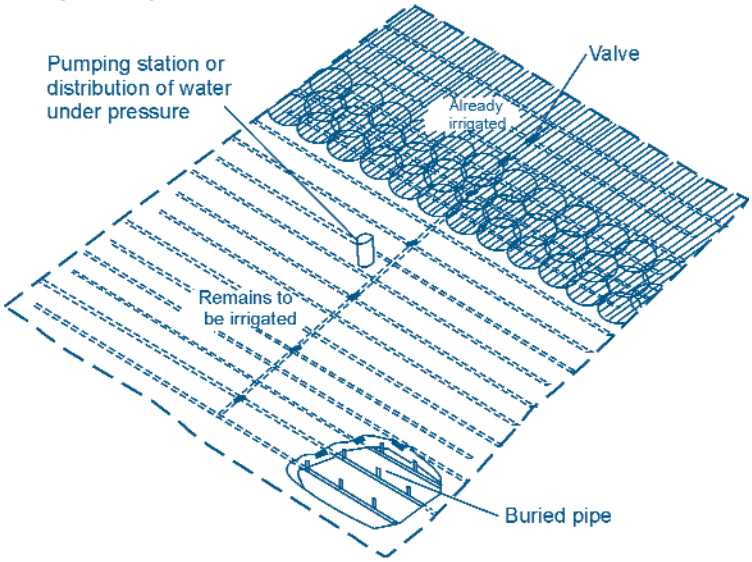


Figure 12
Layout of a fixed sprinkler irrigation system (Source: FAO, 1982)



Fixed sprinkler irrigation systems

Fixed sprinkler irrigation systems can be sub-divided into solid-set systems and permanent systems as described below. These systems are 'on and off' in terms of their operation and therefore require very little labour. However, they do require high capital investment.

Fixed systems can be automated, in which case the automatic control system can be programmed for irrigation, cooling and frost protection. Figure 12 shows a typical layout of a fixed sprinkler irrigation system. In this particular case, the whole system is entirely fixed.

Solid-set systems

These systems have enough portable laterals for their movement to be unnecessary. The mains and submains may be either buried or portable. The number of sprinklers may be sufficient so that no movement during irrigation is necessary. However, sometimes sprinklers may be moved within the area covered by laterals. These systems are used for high value crops and are suitable for light, frequent irrigation, such as the germination of small seeds.

Permanent systems

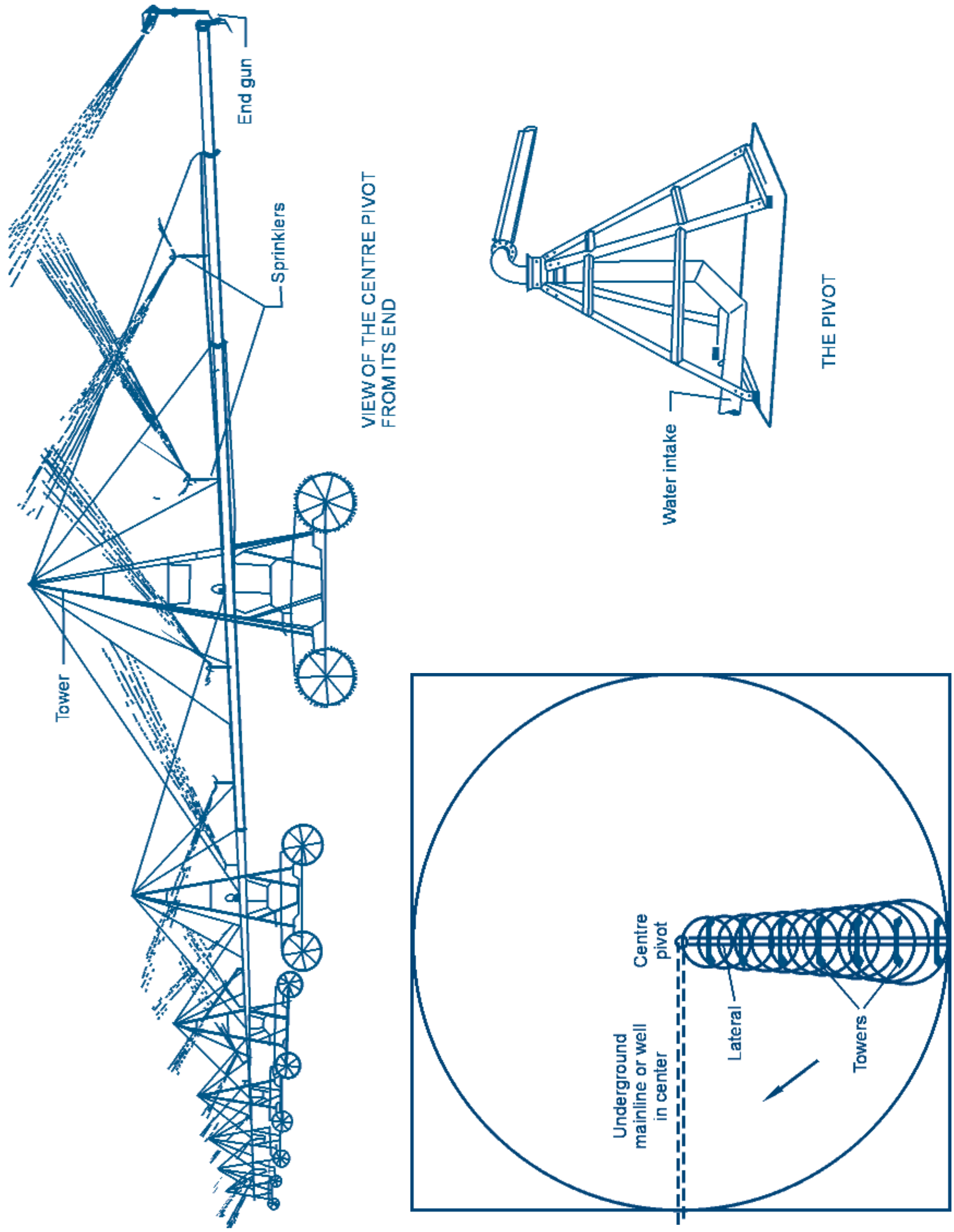
These systems have permanent buried mains, submains and laterals with sprinklers permanently located on the laterals. Often only the riser pipe and sprinkler are above the ground. These systems can satisfy the need for light frequent irrigation, be used for frost protection and cooling, and are best suited for automation. They are also often used to irrigate orchards, vineyards and other special crops. They have high irrigation efficiency and a very low labour requirement.

Perforated pipe sprinkler irrigation systems

Perforated pipe sprinkler irrigation systems utilize holes, drilled on the lateral pipe, for spraying water (Figure 13). The holes are uniformly spaced along the top and sides of the lateral pipe and are typically 1.6 mm in diameter. According to Keller and Bliesner (1990), this system is mainly used on home lawns and is generally suited to coarse textured soils because of its high water application rates. The minimum practicable application rate is about 13 mm/hr, making it unsuitable for heavy textured soils. In

Figure 13
Perforated pipe sprinkler irrigation system (Source: Farmelectric Handbook)

Figure 14
Centre pivot and field irrigation layout (Source: FAO, 1982)



Zimbabwe this system has been used for vegetable and tobacco seedling production. However, its use is gradually declining because of the rising popularity of micro-sprinkler irrigation systems.

Continuous-move systems

Continuous-move systems have motorized laterals or sprinklers, which irrigate and move continuously at the same time. Their innovation was prompted by the need to minimize labour inputs. They basically comprise a centre pivot, linear moving laterals and travelling irrigators.

Centre pivot

This is one of the most popular irrigation systems. The centre pivot system consists of a pipe lateral mounted on steel towers. The fixed end of the lateral, the pivot, is connected to a water supply (Figure 14). The pipe carries different sizes of impact, spinner or spray sprinklers. The steel towers, also called spans, have wheels that rotate continuously around a centre pivot point. The speed of movement varies from tower to tower. The closer the tower is to the centre of the pivot the slower the wheels move.

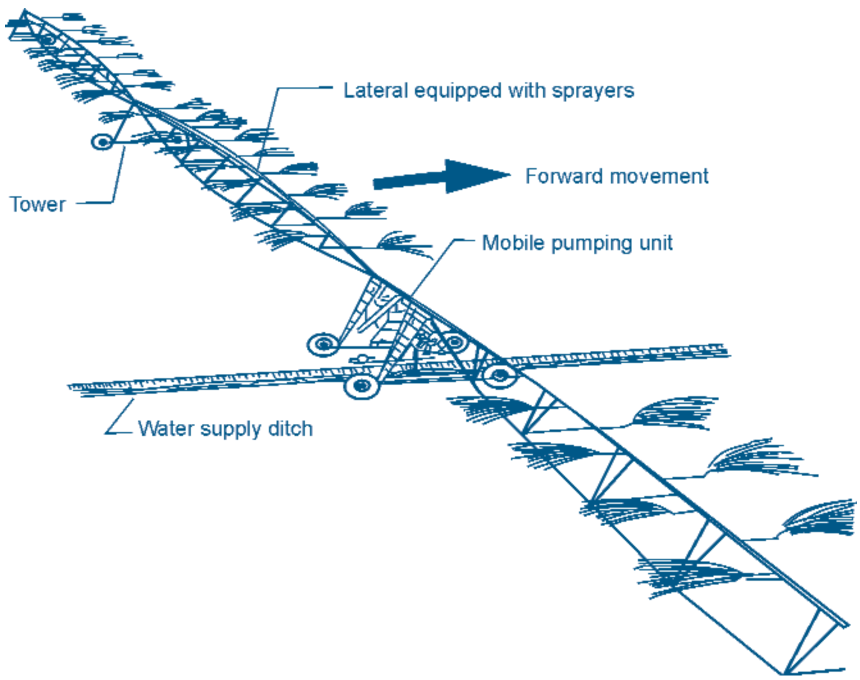
Centre pivots vary in length depending on the design area and can irrigate up to 120 ha. Centre pivots vary in height; they can be of low, standard or high clearance (from 3-5 m). The laterals can be fitted with end guns to irrigate irregular areas at the periphery of the circle. These systems are suitable for most field crops. They are best suited to soils that can take up high infiltration rates, and areas without obstructions such as power lines and buildings.

The use of centre pivots is increasingly gaining popularity among commercial farmers in Eastern and Southern Africa. The low per hectare cost of large centre pivot systems, the limited labour requirements and the low energy requirements of pivot systems using spray nozzles are the main reasons for the popularity of these systems. Centre pivot systems equipped with nozzles and drop pipes, placing the nozzles just above the crop canopy, are very useful under windy conditions.

Linear-move laterals

Linear-move systems are similar to centre pivots except that instead of the water being supplied from a central point and the lateral rotating around that point, a water supply system, such as an open channel or hose, is provided over the whole length, along which the lateral travels. Therefore, the lateral travels linearly as it irrigates. As a result this system irrigates rectangular fields. The fields, however, have to be free of obstructions. This system has to be brought back to the starting point once it reaches the end of the irrigated field. Figure 15 shows a linear-move lateral irrigation system, taking water from a water supply ditch as it moves forward.

Figure 15
Linear-move lateral system (Source: FAO, 1982)

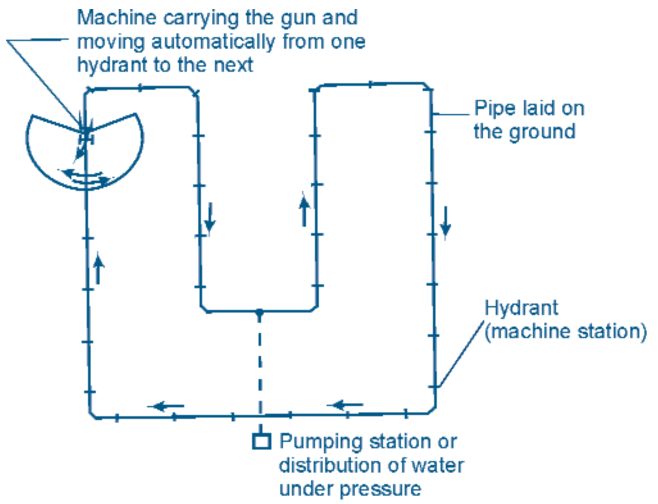


Traveling irrigators

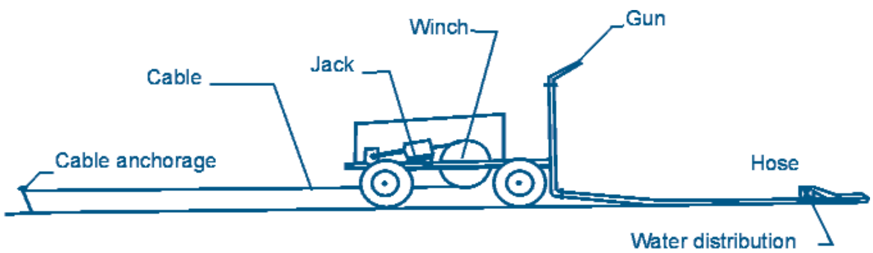
One of the most recent variations of the continuous-move systems is the continuous travel wheel, whereby the lateral, mounted on wheels, moves continuously while irrigating. A long flexible hose provides the lateral with water from the main pipe. The lateral is a gun or a boom with low-pressure sprayers, mounted on a wheeled irrigation machine. Figure 16 illustrates the components of a cable-drawn machine and the typical layout.

Gun sprinklers can also be hose-pulled during irrigation, as shown in Figure 11. In the latter case, the irrigating machine can be self-hauled or pulled by the pipe supplying the water. In contrast to the gun travelling irrigators, the boom with low-pressure nozzles is comparable to the centre pivot system and has been successfully used for the irrigation of several crops grown on different soils.

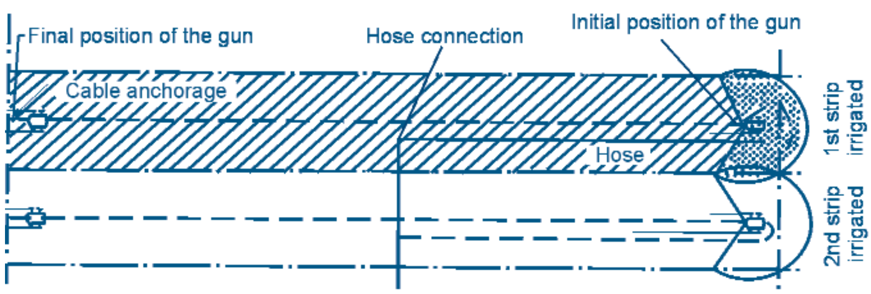
Figure 16
Cable-drawn travelling irrigator and layout (Source: FAO, 1982)



Field layout of a machine moving automatically between irrigation stations



THE MACHINE



IRRIGATION FIELD LAYOUT

3.1.3. Localized irrigation systems

Localized irrigation is a system for supplying filtered water (and fertilizer) directly onto or into the soil. The water is distributed under low pressure through a pipe network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. There are three main categories of localized irrigation:

- *drip irrigation*, where drip emitters are used to apply water slowly to the soil surface
- *spray irrigation*, where water is sprayed to the soil near individual trees
- *bubbler irrigation*, where a small stream is applied to flood small basins or the soil adjacent to individual trees

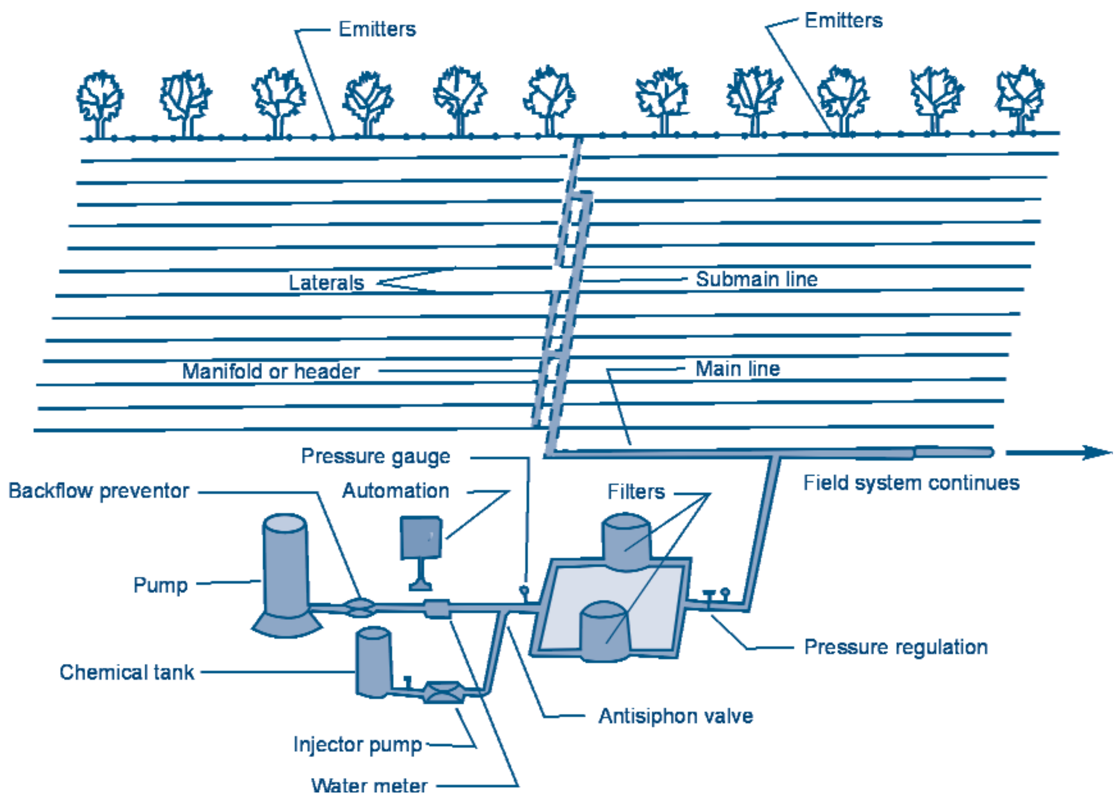
A localized irrigation system consists of the head of the system that filters and controls the supply of water and fertilizers to the network, the plastic buried pipes that supply the water to the laterals, the polyethylene laterals, usually 16-20 mm in diameter, that supply the water to the emitters, and the emitters that discharge the water to the pre-determined points and at pre-determined flows. Figure 17 shows the basic components of a localized irrigation system. It is a capital-intensive system with built-in management that requires very little but skilled labour.

The main advantage of localized irrigation is its potential to reduce water requirements and achieve a very high efficiency, while at the same time increasing crop yield and quality. The system has been successfully used on tree and vegetable crops, and high yields attributed to it. Localized irrigation provides the means for very frequent irrigation, daily if needs be. Hence it is particularly suitable for light shallow soils, irrespective of slope, and for shallow-rooted crops. It has also proved suitable for most row crops. The main disadvantages of localized irrigation systems are their high capital cost, a susceptibility to clogging and a tendency to build up localized salinity, especially in low rainfall areas. As such, this category of system requires careful management for its maintenance. Module 9 deals with the planning, design, operation and maintenance aspects of localized irrigation systems.

3.2. Irrigation efficiencies

There is an ever-growing demand on water resources, which emanates from an increasing human population.

Figure 17
Basic components of a localized irrigation system (Source: FAO, 1997b)



This means that there is increasing competition for the use of water for agricultural, industrial, domestic and environmental purposes. This calls for more efficient use of finite water resources in order to minimize conflict between the sectors. This section provides some basic information that can be used by planners for the selection of an irrigation system based on levels of their efficiencies. For more precise information the reader is referred to literature dealing more specifically with this subject.

In the process of applying irrigation water to crops, water losses occur. These losses have to be taken into account when calculating the gross irrigation requirements of an irrigation project. This can be done through the use of an efficiency factor, which has to be estimated at the planning stage. Different types of irrigation systems have different levels of efficiency. The higher the irrigation efficiency, the larger the area that can be irrigated from a given finite water source, and the less the leaching of nutrients and damage to the soil the more environmentally friendly the irrigation system. The water that is saved can be used for other productive purposes.

The overall efficiency, also known as project efficiency (E_p), comprises conveyance efficiency (E_c), field canal efficiency (E_b) and field application efficiency (E_a). According to FAO (1992):

- Conveyance efficiency (E_c) is the ratio of the water received at the inlet of a block of fields to the water released at the headwork
- Field canal efficiency (E_b) is the ratio between water received at the field inlet and that received at the inlet of the block of fields
- Field application efficiency (E_a) is the ratio between water directly available to the crop and that received at the field inlet
- Project efficiency (E_p) is the ratio between water made directly available to the crop and that released from the headwork, or $E_p = E_c \times E_b \times E_a$.

Conveyance and field canal efficiencies are sometimes combined and called distribution system efficiency, E_d, where $E_d = E_c \times E_b$. Field canal and field application efficiencies are also sometimes combined and called farm efficiency, E_f, where $E_f = E_b \times E_a$.

Table 2

Conveyance, field canal and field application efficiencies (Adapted from: FAO, 1992)

Irrigation System and Type Of Efficiency	USDA	US (SCS)	ICID/ILRI
Conveyance efficiency (E_c)			
- Continuous supply with no substantial change in flow			0.9
- Rotation supply in projects of 3 000-7 000 ha and rotation areas of 70-300 ha, with effective water management			0.8
- Rotational supply in large schemes (> 10 000 ha) and small schemes (< 1 000 ha) with respective problematic communication and less effective management:			
Based on predetermined schedule			0.7
Based on advance request			0.65
Field canal efficiency (E_b)			
- Blocks larger than 20 ha : unlined			0.8
: lined or piped			0.9
- Blocks up to 20 ha : unlined			0.7
: lined or piped			0.8
Field application efficiency (E_a)			
- Surface methods			
light soils	0.55		
medium soils	0.70		
heavy soils	0.60		
Graded border		0.60-0.70	0.53
Basin and level border		0.60-0.80	0.58
Contour ditch		0.50-0.55	
Furrow		0.55-0.70	0.57
Corrugation		0.50-0.70	
- Subsurface		Up to 0.80	
- Sprinkler : hot dry climate		0.60	
: moderate climate		0.70	0.67
: humid and cool		0.80	
- Rice			0.32

The conveyance efficiency is affected by several factors among which are size of irrigated area, size of rotational unit, number and types of crops grown, type of conveyance system and the technical and managerial facilities for water control. The field canal efficiency is affected by the way the infrastructure is operated, type of soils in respect of seepage losses, size of canals and irrigated blocks. Distribution system efficiency is particularly influenced by the quality of technical and organizational operations. Farm efficiency is dependent on the operation of the main farm delivery system and the irrigation skill of the farmers. Tables 2, 3, 4 and 5 present typical irrigation efficiencies according to the experiences of four different references.

Table 2 shows the conveyance, field canal and field application efficiencies for different irrigation systems, as proposed by different institutions under different conditions of water conveyance and distribution infrastructure and management.

Farm irrigation efficiencies of sprinkler irrigation systems vary under different climates. FAO (1982) proposed the figures of farm irrigation efficiencies provided in Table 3 on the basis of climate.

Table 3

Farm irrigation efficiencies for sprinkler irrigation in different climates (Adapted from: FAO, 1982)

Climate/Temperature	Farm irrigation efficiency E_f *
Cool	0.80
Moderate	0.75
Hot	0.70
Desert	0.65

** Assuming no losses in the distribution system (E_c and E_b = 1)*

Table 4 shows some typical field application efficiencies of well-managed sprinkler irrigation systems. The efficiencies are based on the type of sprinkler irrigation system as well as the type of climate.

Table 5 presents project efficiencies (E_p) that can be used for calculating gross irrigation requirements for localized irrigation systems.

Table 5

Project efficiencies for localized irrigation systems (Adapted from: Rainbird International, 1980)

Climate	Project efficiency E_{p^*}
Hot dry	0.85
Moderate	0.90
Humid	0.95

** Assuming no losses in the distribution system (E_c and E_b = 1)*

Each type of irrigation system affects the means used for water conveyance and distribution. For this, the conveyance (E_c) and the field canal efficiencies (E_b), and thus the distribution system efficiency (E_d), vary between pressurized and non-pressurized systems. It is, however, mainly the field application efficiency (E_a), which varies considerably from one type of irrigation system to another. Generally, localized irrigation systems are the most efficient (E_a is 85-95%), followed by sprinkler irrigation systems (E_a is 60-85%) and surface irrigation systems (E_a is 55-80%). On the basis of this, a localized irrigation system could irrigate 12-42% (95/85 x 100 to 85/60 x 100) more area than a sprinkler irrigation system and 19-55% (95/80 x 100 to 85/55 x 100) more area than the surface irrigation system.

Table 4

Field application efficiencies for well-managed sprinkler irrigation systems (Source: Keller and Bliesner, 1990)

Systems and environmental conditions	Field application efficiency E_a
Moving and set systems with excellent uniformity in cool or humid climates and low winds	0.85
Typical efficiency for moving systems in most climates and winds; and set systems with medium to high application rates and good uniformity in most climates and low winds	0.80
Typical efficiency used for average set systems in most climates and winds; and for moving systems in desert climates and high winds	0.75
Set systems with high application rate in the desert climates with high winds or low application rates in other climates with high winds; travellers	0.70
Set systems with moderately low application rates in desert climates and high winds or low application rates in high desert climates and high winds	0.65
Set systems with low application rates with small drops operating in low desert climates and medium to high winds; and gun or boom sprinklers	0.60

Key for set systems:
1) Low application rate : 2.5-5.0 mm/hr
2) Medium application rates : 5.0-10 mm/hr
3) High application rates : over 10 mm/hr

In discussing the sprinkler field application efficiencies (E_a), there is generally good agreement in the data published by different sources. Therefore the designer can use any of the sources, depending on which one describes local conditions best. There are, however, differences among application efficiency values provided by different sources, especially for the surface irrigation systems. This is attributed to the different climatic, soils and management conditions prevailing in the different countries. It also makes the availability of local data very important.

Looking at the overall project efficiency (E_p) and assuming an E_c of 0.9 for lined canal and continuous flow and an E_b of 0.8 for lined canals, the E_p for surface irrigation systems would be between 0.40 (0.9 x 0.8 x 0.55) and 0.58 (0.9 x 0.8 x 0.8). The E_p for pressurized systems, assuming an E_c and E_b of 1, would be between 0.60 (1 x 1 x 0.6) and 0.85 (1 x 1 x 0.85) for sprinkler irrigation systems and between 0.85 (1 x 1 x 0.85) and 0.95 (1 x 1 x 0.95) for localized irrigation systems. This simple calculation shows that under localized irrigation the irrigated area can be doubled as compared to surface irrigation. The increase in area for sprinkler irrigation can be over 50%.

The efficiency of an irrigation system is dependent on the level of management during operation as well as on the level of built-in management in the system. In general, sprinkler and localized irrigation systems have better built-in management than surface irrigation systems. Therefore, they can apply water for pre-determined duration, thereby achieving high irrigation efficiencies. This is especially the case for automated irrigation systems, but also applies to simple types of sprinkler irrigation systems, such as the semi-portable and portable systems, so long as the farmer knows the duration of irrigation. Under surface irrigation it is often difficult to apply water with the same degree of precision as in the localized and sprinkler irrigation systems. Consequently, the systems are less efficient. However, their efficiencies can be greatly improved if fields are regularly well graded, the system operator applies correct flows and if built-in management is enhanced through system automation.

3.3. Parameters affecting the selection of an irrigation system

With the different types of irrigation at the disposal of the irrigation engineer and the client, the next stage is to choose which system to adopt. The choice is affected by a number of considerations, all of which need to be taken into account as part of the decision-making process. These are:

1. Water
2. Soils and topography
3. Climate and crop
4. Capital and labour
5. Energy
6. Social aspects and policies
7. Socio-economic aspects
8. Health aspects
9. Environmental aspects

An analysis, based on the above factors, should be carried out and promising alternative systems should be designed (feasibility study). After that, an economic and financial analysis should be undertaken in order to determine the most economically and financially viable alternative for adoption. The economic and financial analysis is covered in Module 11.

3.3.1. Water

A number of critical questions related to water need to be addressed to facilitate irrigation system selection:

1) What is the cost of delivering the water at the needed flows from the source to the farm and what irrigation system would go well with that cost?
2) Is the flow large enough for surface irrigation? If not, is there a need to adopt a more efficient irrigation system or would it be desirable to reduce the area planned for surface irrigation?
3) Is the flow available at the needed quantity throughout the growing season and if not how does that affect the choice of the irrigation system?
4) Would the salinity of the water affect the choice of irrigation system?
5) Would the sediment content of the water affect the choice of irrigation system?

Sources of water

The source of irrigation water can be surface water, groundwater or non-conventional water (desalinated water, treated wastewater, etc.). The first two types of sources of water are the most commonly used worldwide.

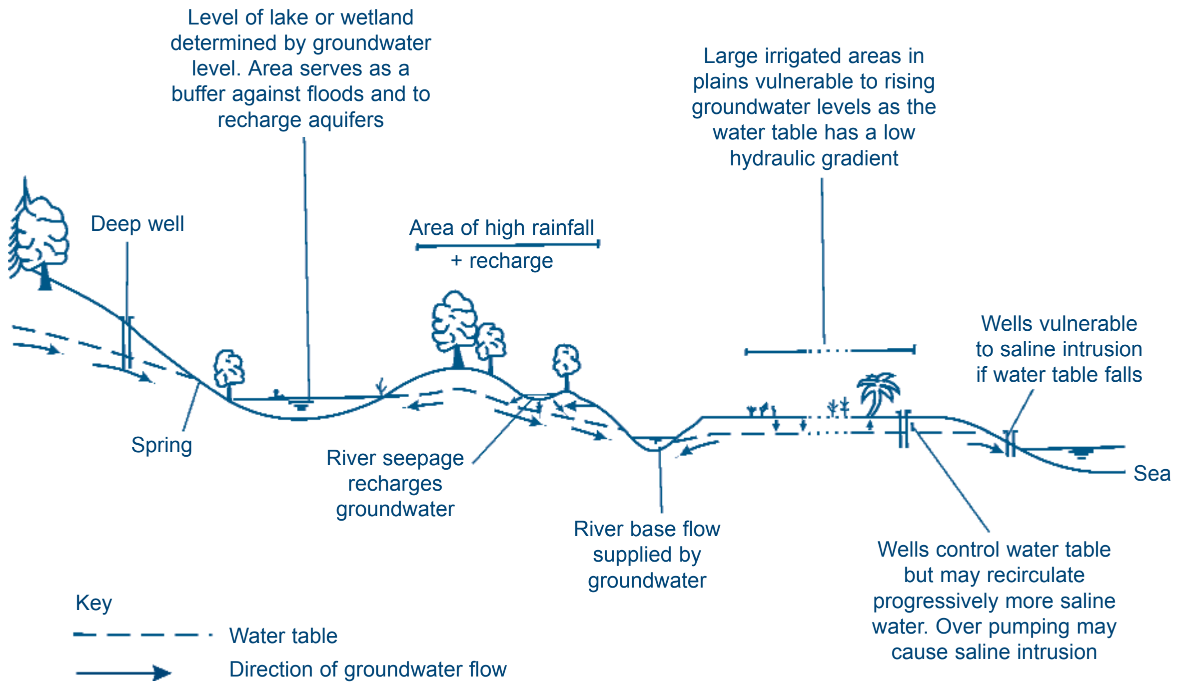
Surface water consists of river flows and water from dams, ponds and lakes, as well as recharge from groundwater. River flow results from run-off and river base flow, the latter being supplied by groundwater. River flow can be a good source of clean water, although it may carry all sorts of sediment, depending on the flow regime in the river and the condition of the catchment area. It is important to regularly measure river flow in order to establish the flow in relation to the season and the irrigation requirements.

River gauging stations are established for these purposes. The stations usually have enough years of data to reliably predict the quantities of water that can be abstracted for irrigation purposes. In cases where there are no data, flow measurements would have to be carried out in order to establish the amount of water that can be abstracted for irrigation from the river. Dams, lakes and ponds store water for use during times of water shortage. This is often the case where there is seasonal river flow. Proper reservoir management studies would facilitate the development of irrigation to the extent that the source of water can meet the demand. Groundwater is water that is stored in aquifers, which are recharged by rainfall, river flow, lakes and dams. As a rule, this type of water has higher concentrations of dissolved solids than surface water, because the recharged water dissolves and carries minerals to the groundwater table. The interrelationship between groundwater and surface water is shown in Figure 18.

Non-conventional sources of water are used where irrigation water is not readily available in the quantities required and for the efficient protection of the environment. It comprises industrial and municipal wastewater, as well as desalinated seawater. Treated wastewater is used to irrigate plants that can tolerate the levels of salinity in irrigation water. Lawns and grass can be irrigated using this water. The use of treated wastewater is gaining popularity among southern African countries with Namibia already using it and Botswana and Zimbabwe following suit. The increasing costs of freshwater resources development and/or the unavailability of freshwater resources made this alternative attractive. In view of the high cost of desalinization, so far this water is mostly used for domestic and industrial purposes.

The distance and elevation differences between the water source and the field have a significant influence on the choice of irrigation system. The distance affects the cost of water, which means that water has to be utilized efficiently. As such, more water-efficient irrigation systems would have to be adopted. The elevation difference between the source of water and the field will dictate whether the water can be delivered under pressure. If, for example, the pressure is adequate for a pressurized system without the need for pumping, this may dictate the selection of a pressurized system ahead of a surface irrigation system. An example of such a case is a situation where water naturally falls from a high enough position to run sprinklers at the correct sprinkler operating pressure. If pumping is unavoidable, a similar decision may be arrived at, if by adopting a less efficient irrigation system, the benefits would not outweigh the pumping costs.

Figure 18
The inter-relationship between surface water and groundwater (Source: FAO, 1995)



Water quantity

The available discharge from the source and the timing are very important. Small discharges would suit an irrigation system that incorporates frequent applications with small quantities of water. Large discharges would suit systems that require irrigation with higher quantities of water. The seasonality of water supply also influences the choice of the irrigation system. For example, seasonal limited water supplies may dictate the adoption of the most efficient systems in order to maintain a desirable cropping pattern for a set area. Distribution systems, based on rotational delivery, provide large intermittent flows, thus favouring the selection of surface irrigation, where large irrigation depths are normally applied, rather than sprinkler or localized irrigation systems. When the water supply is from underground resources, the optimum well yield will be a deciding element not only for the size of the scheme, but also as to whether this flow can directly satisfy the required flows for surface irrigation. Additional cost for on-farm storage reservoirs also influences the choice of the irrigation system.

Water quality

Both the chemical compositions of the water and the sediment load can influence the choice of irrigation method. The presence of certain elements, like sodium (Na), Chlorine (Cl) and Boron (B), beyond a certain level, can cause leafburn and defoliation under sprinkler irrigation. Similarly, the total concentration of salts in the water affects the leaching requirements. Hence furrow irrigation for certain crops may not be the ideal system under these circumstances. Generally, poor quality water should be utilized more frequently and in larger amounts than good quality water. This affects the choice of the irrigation system. The sediment load of the water determines the filtration requirements of a drip irrigation system and the selection of the appropriate dripper, hence its applicability under certain conditions. Similarly, sediments increase the wear of pumps and other components of sprinkler irrigation systems. It is always advisable to carry out water quality tests before a decision is made to adopt the one system or another.

3.3.2. Soil and topography

A number of soil factors affect farm irrigation system selection. These are soil texture and structure, soil depths and profiles, drainage and soil salinity.

Soil texture and structure

Soil texture and structure affect the selection of the farm irrigation system through their effect on the available soil moisture (field capacity minus permanent wilting point) and the infiltration rate of the soils. The available soil moisture affects the frequency of irrigation and therefore the irrigation method to adopt. The infiltration rate affects the length of run and size of borders, furrows and basins as well as the application rates from sprinkler and localized irrigation systems. Generally, coarse textured soils have high intake rates and low soil moisture storage capacities. They therefore impose shorter lengths of run on surface irrigation systems (implying more canals and higher costs), but they can accommodate high water application rates. They also require more frequent water applications. Hence, light soils favour the adoption of sprinkler or localized irrigation. The reverse is true for heavier textured soils. Textural characteristics may also influence the traction ability of heavy irrigation systems such as centre pivot sprinkler irrigation systems.

Soil depth and profile

Soil depth and profile influence the water storage capacity of the soils and therefore the irrigation frequency. Deep, uniform medium soils of good structure permit high storage of water to sustain plants for long periods between irrigations. However, a lot of shallow soils, often with a depth of no more than 30 cm, are being developed for irrigation in the region. At times, such soils may be of light texture obliging very frequent irrigation. While the first type of soils can be irrigated either with surface or sprinkler or localized irrigation systems, the use of surface irrigation on shallow light soils can cause serious surface runoff and drainage problems. Stratification of soils can have substantial influence on the water movement through the soils as well as on the water storage capacity of the soils, hence its effect on design parameters and costs of the system.

Drainage and soil salinity

Drainage of irrigated soils, whether natural or by provision of the needed facilities, is an essential complement to irrigation. Drainage, in combination with adequate irrigation scheduling, allows for the leaching of excess salts and water from the plant root zone in order to maintain the right soil nutrients and water balance. Surface and subsurface characteristics of the soil will affect the ability of a soil to drain excess water away. Better-draining soils will suit irrigation systems that have a lot of drainage water, such as surface irrigation systems. The reverse is true for poorly drained soils. Such soils would require systems with less drainage water, for example localized irrigation systems. Within this context, irrigation systems that can provide a built-in mechanism for controlled water management can significantly reduce the drainage requirements and therefore affect the project cost as a whole.

Soil salinity is another consideration in selecting the appropriate irrigation system. Soils with salinity problems require leaching which, depending on the salinity level, would be required before and/or during cropping. Certain systems, such as furrow systems, do not provide for the basic requirements of uniform leaching and may even promote the concentration of salts within the most active part of the root zone depth.

Topography

Topography is one of the most important elements that affect the irrigation system selection process. Of particular importance are the location and elevation of the water source relative to the field, land slopes and uniformity. Land slopes may limit the selection of surface irrigation systems as it affects the length of run and the labour required for the operation of the system. Generally, surface irrigation systems require uniform field slopes within the 0-5% range. Steep lands are not favourable for surface irrigation. This is because a lot of land levelling, at a high cost and the possibility of removing fertile topsoil, will have to be done. If fertile soils are removed, higher fertilizer quantities will have to be applied to the crop, at a higher cost. Sprinkler and localized irrigation systems can cope with much steeper lands than surface irrigation systems. Micro-relief will affect the land grading requirements for surface irrigation. Shallow sloping lands would favour systems that require limited or no land grading.

3.3.3. Climate and crop

The cropping pattern for a project should be such that the selected crops can be successfully grown under the prevailing climate and soil conditions. Furthermore, these crops should be marketable at economic prices. It is therefore necessary that cultivating practices for these crops should be well understood and the planned irrigation system should be compatible with these practices as well as with the physical constraints prevailing at the farm.

Paddy rice, for example, requires partial submergence of the rice plants for most of the growing period. Therefore, surface irrigation using basins, either flat level or extremely well graded, would be required for this purpose.

As a rule, most vegetable crops have a shallow effective root zone depth and respond better to low moisture depletion levels. Consequently, irrigation systems that can provide small amounts of water at short intervals are preferred. In this respect it should be pointed out that through the introduction of localized irrigation to these crops farmers in several countries of the Near East and Africa have reported yield increases of up to 100%. Germination of seeds requires very frequent and light water applications. In this case, sprinkler or localized irrigation may be suitable, especially if the soils are light. The fruit quality of a number of crops, such as tomatoes and cucumbers, is negatively affected when the fruits rest on wet soils. In this case, furrow and drip irrigation are preferable to sprinkler and basin or borderstrip irrigation.

Ponding of water promotes diseases at the neck of trees such as citrus. In this case, systems applying water away from the tree trunk, such as drip and furrow irrigation are preferable.

Under warm and/or desert climates cooling may be required for certain crops, especially in some stages of their growth. In this case a sprinkler irrigation system may be the best alternative. By the same token, in certain climates where frost is a problem, the sprinkler irrigation system, if so designed, may be used for frost protection of part or all of the area under irrigation.

Some crops are sensitive to the way water is applied to them. Systems which wet the whole crop, as does sprinkler irrigation, may introduce undesirable consequences such as leaf burn, fruit spotting and deformation, crown rot etc. These considerations would influence the choice of the irrigation method for such crops.

3.3.4. Capital and labour

The availability and cost of capital and labour for the irrigation development and for the operation of the irrigation system are also major elements that influence the selection of the irrigation system. In general, the costs of irrigation systems increase with the level of sophistication of water control means and the provision of components reducing the labour requirements. However, the cost of the drainage system increases as the water control means of the irrigation system decrease. When there is a shortage of labour or the available labour is relatively unskilled or expensive, systems that have low labour requirements are usually selected.

3.3.5. Energy

The energy requirement of the different alternatives under consideration is another important criterion in the irrigation system selection process. Studies carried out in Washington State (USA) on the energy requirements of the different systems, including the energy required for the manufacturing, transport and installation of the various irrigation systems, have shown that these requirements increase in the following order: surface, drip, sprinkler. Nevertheless, it should be born in mind that surface irrigation generally requires more water because of lower irrigation efficiencies, and thus may require more energy if it is necessary to pump the water (see Module 5). From both an economic and environmental point of view, design options that utilize the minimum possible energy requirements are preferable.

3.3.6. Social aspects and policies

Historical tendencies

In developing countries, where resettlement of people from a dryland farming background to irrigated land is practiced, the usual dilemma of choosing the appropriate irrigation method for people without past experience often emerges. Not infrequently is the decision in favour of surface irrigation with the justification of simplicity of operation and maintenance by unskilled people. Unfortunately, this decision, usually biased because of past historical reasons, does not take into consideration the basic element of water management. Surface irrigation does not have a built-in mechanism for water management. Using their own judgement, the irrigator will apply what they consider the right depth of irrigation water. It must be remembered that, as a rule, in dryland farming better yields are obtained during the years of better rains. Hence, the psychology of the farmer is that the more water applied to the crops the greater the yields should be. It is therefore of paramount importance to either use, to some extent, systems with built-in water management elements or to train the farmers in the water management aspects of surface irrigation. For people without past experience, irrigation is a very difficult task that may result in very low application efficiencies, drainage problems and waterlogging.

In Zimbabwe, the Nyanyadzi and Exchange irrigation schemes are cases in point. Very low irrigation efficiencies, and waterlogging problems in the latter, arose through poor water management and inadequate maintenance. Therefore, the need for skilled people to operate and maintain surface irrigation systems cannot be overemphasized. More recently, water scarcity, environmental considerations and the increasingly high cost of water development have led to the need for better water management at farm level, the use of more efficient irrigation systems and the tendency to use treated wastewater for irrigation.

Farmer or farmer group preferences

Irrigation can be an individual or a community enterprise. The irrigation system to be designed should lend itself to the preferences of the user(s). Therefore, the user should have a considerable influence upon the irrigation method to be adopted. This can be achieved through participatory approaches to irrigation development, where the final user of the system is involved in all planning processes through to implementation (see Chapter 1).

Women

Experience shows that in many countries women contribute up to 70% of the labour required at smallholder irrigation projects. At the same time they are not adequately represented at irrigation planning meetings. Instead, men attend these meetings in large numbers and make decisions on behalf of women. An irrigation method that requires a lot of labour will only serve to worsen the burden of the smallholder woman. Therefore, the process of choosing an irrigation system should ensure that women participate as fully as possible and, if needs be, the system should avoid being too labour intensive. In this respect, training and exposure of both men and women to different technologies during participatory planning will facilitate more active participation of women. In some cases focus group discussions are advisable.

Institutional influences and policies

Conditions outside the immediate sphere of irrigation, and for that matter agriculture, may influence the type of irrigation system adopted. Such conditions are very complex and difficult to quantify. Land tenure issues, water rights, financial incentives by government, taxation and other regulatory and legal issues are some of the important conditions that should be understood right from the start of the selection process. If, for instance, certain irrigation system components are not readily available in the country or region and require substantial foreign currency to import, such irrigation technologies may not be adopted easily where foreign currency is in short supply. At the same time, many irrigation systems are financed by outside donors and lenders. This may result in specific irrigation technologies being precluded or preferred at the expense of all other criteria, because of the policies and attitudes of the donors.

Irrigation development is usually part of the national policy on development, which may also influence the type of irrigation system to adopt. As an example, governmental policies in some countries may encourage more employment in agriculture in order to reduce the unemployment problems. This may lead to reluctance to adopt labour-saving irrigation technologies. On the other hand, where availability and reliability of labour are limited, systems that can reduce the labour requirements may be advised.

Institutional aspects are especially important in developing countries, as the size of the land holding may limit the choice of different types of irrigation systems. A very small parcel of land, where a number of crops are grown at the same time, would be difficult to irrigate using a sprinkler irrigation system. A surface irrigation system or localized irrigation system may be more appropriate instead.

The durability of the equipment may be another important consideration, especially for small farmers with limited financial resources, or who are situated in areas remote from major centres.

3.3.7. Socio-economic aspects

Experience shows that under smallholder conditions, up to 80% of irrigation development cost is the cost of water resources development, such as the construction of a small to medium size dam. These costs have been increasing substantially since the best sites for dam construction have already been developed. Consequently, the cost per m^3 of water is growing. In parallel to this development, the population pressure on land is growing to the extent that marginal lands are being put to cultivation, resulting in land degradation and dam siltation, making the cost of irrigation water even higher.

One of the arguments for the necessity of irrigation development is to transform the subsistence farmer into a commercial farmer, moving into the mainstream of the economy of developing countries, hence the need to accommodate as many smallholders as possible in irrigation development. In this respect it should be noted that in Zimbabwe most successful smallholder irrigation schemes have long waiting lists of individuals who would like to enter the scheme when an existing member is no longer interested in irrigation and leaves.

Looking at both the high cost per unit volume of water and the need to satisfy the high demand for irrigation, systems with higher efficiencies proved to be the tool for addressing this matter, both in terms of economics as well as in terms of social and political desirability. As such, they deserve serious consideration in the process of selecting an irrigation system.

3.3.8. Health aspects

Often the issue of health risks related to one or another irrigation system is overlooked and the most sensitive part of the population (women and children) is negatively affected. Since rural women are the major users of irrigation infrastructure, the sensitivity of the different technologies to health aspects should be analyzed and taken into consideration during the decision-making process.

In many parts of Eastern and Southern Africa two waterborne diseases are cause for concern: malaria and bilharzia. It is therefore necessary to avoid or modify systems that promote these diseases. In this respect, surface irrigation with unlined canals provides ideal breeding grounds for snails that carry the bilharzia parasites. Through the introduction of concrete-lined, free-draining canals the risk from these diseases can be substantially reduced. The adoption of pressurized irrigation systems, such as sprinkler and localized irrigation, reduces the risks further. This is because no drainage system is required and water is pumped from well below the water surface, where the bilharzia parasite is not common. However, when going into the water themselves people are exposed to the disease. The trend of treated wastewater reuse for irrigation adds another dimension to the selection of an irrigation system in view of the additional hazards from the diseases such as parasitic worms, typhoid, cholera and salmonella. Health issues are dealt with more in detail in Chapter 4.

3.3.9. Environmental aspects

The environmental impact of different irrigation systems has to be taken into consideration when selecting an irrigation system. What should happen with the drainage water? Should it be disposed of in a nearby land depression, causing ideal conditions for mosquito breeding and thus malaria for the people of the project? Should it be discharged into the same stream from where it was originally extracted, thus increasing the salinity and chemical pollution downstream? Or should alternative systems with built-in water management and thus minimum drainage effluent be adopted? How would the one or the other choice affect fishing in the river on the short and long run?

These are some questions, that emerge if one is to avoid negative environmental and health impacts of irrigation development and ensure long term benefits and sustainability of irrigation. In order to predict environmental impacts of irrigation development, an Environmental Impact Assessment (EIA) should be carried out prior to the establishment of a project and be used as one of the criteria to approve the implementation of the project and to select the irrigation system.

When planning irrigation projects, one should always keep in mind the importance of biodiversity. The ecosystem is a self-contained and balanced system of inter-dependent living organisms and their physical development. A change, necessitated by infrastructure development, will unavoidably have consequences on the living organisms and their diversity. This is what the EIA seeks to establish and minimize. More detailed information on EIA can be found in FAO (1995).

Within a river catchment, there are upstream and downstream water users. There are habitats alongside the river where a diversity of species derive their livelihood. River basin planning is important in order to minimize within one catchment the negative impact of one project on another and on living organisms. Good planning and environmental management will protect the environment. As an example, Figure 19 shows some of the effects of reduced water quality within a river system. Environmental issues are dealt with more in detail in Chapter 4.

3.4. Methodologies used in the selection of an irrigation system

A number of criteria are used in selecting irrigation systems. Some of the most common (as explained in the previous sections) include: the efficiency of the system, the capital investment required, the suitability to different crops and different soils, the labour requirements, and the operation and maintenance cost. Field and Collier (undated) provide two classes of factors: technical factors and scheme development factors. Tables 6 and 7 present their selection criteria.

Unfortunately, these criteria are based on the infield irrigation method and do not consider irrigation systems where conveyance and distribution of water through various means is included. Moreover, Table 6, while differentiating between different types of surface irrigation, lumps together all types of sprinkler irrigation systems, hence the classification of high energy demand. Today, there are sprinklers operating at 10-15 metres (1-1.5 bar) at the nozzle outlet, very close to drippers' energy requirements.

Looking at Table 6, presenting a potential efficiency for surface irrigation of 60% combined with low capital cost is misleading. In Southern Africa, the cost of surface irrigation systems for smallholders is 20-40% higher than the drag-hose sprinkler irrigation systems, because of concrete lined canals and land grading in the case of surface irrigation. Regarding the overall efficiency, even with lined conveyance and field canals, it generally does not exceed 50%.

Looking at the labour requirements of surface and sprinkler irrigation systems, they appear to be almost identical. Experience in Zimbabwe, however, has shown that it takes six hours to irrigate one hectare under borderstrip irrigation while the same area under drag-hose sprinkler irrigation would only take one hour at peak water demand. Again, today there are various types of sprinkler irrigation systems to suit different soil and labour conditions.

Referring to Table 7, one gets the impression that the design and construction of surface irrigation schemes is simple. This is contrary to what practice has demonstrated. To establish the length of run and the appropriate stream flow, bearing in mind that most soils are not uniform horizontally or vertically, requires experience because of the unknown factors. Constructing lined canals and carrying out land levelling are equally complex and precise processes.

The design of sprinkler irrigation systems is rather straight forward, based on well-established engineering processes, and their construction in most cases amounts to trenching and pipe fitting.

Table 6

Technical factors affecting the selection of irrigation method (Source: Field and Collier, undated)

Irrigation method	Crops	Soils	Labour (hrs/ha irrigated)	Energy demand	Potential efficiency (%)	Capital cost
Surface:					60	Low
- basin	All crops	Clay, loam	0.5-1.5	Low		
- border	All crops except rice	Clay, loam	1.0-3.0	Low		
- furrow	All crops except rice and sown/drilled	Clay, loam	2.0-4.0	Low		
Sprinkle	All crops except rice	Loam, sand	1.5-3.0	High	75	Medium
Trickle	Row crops, orchards	All soils	0.2-0.5	Medium	90	High

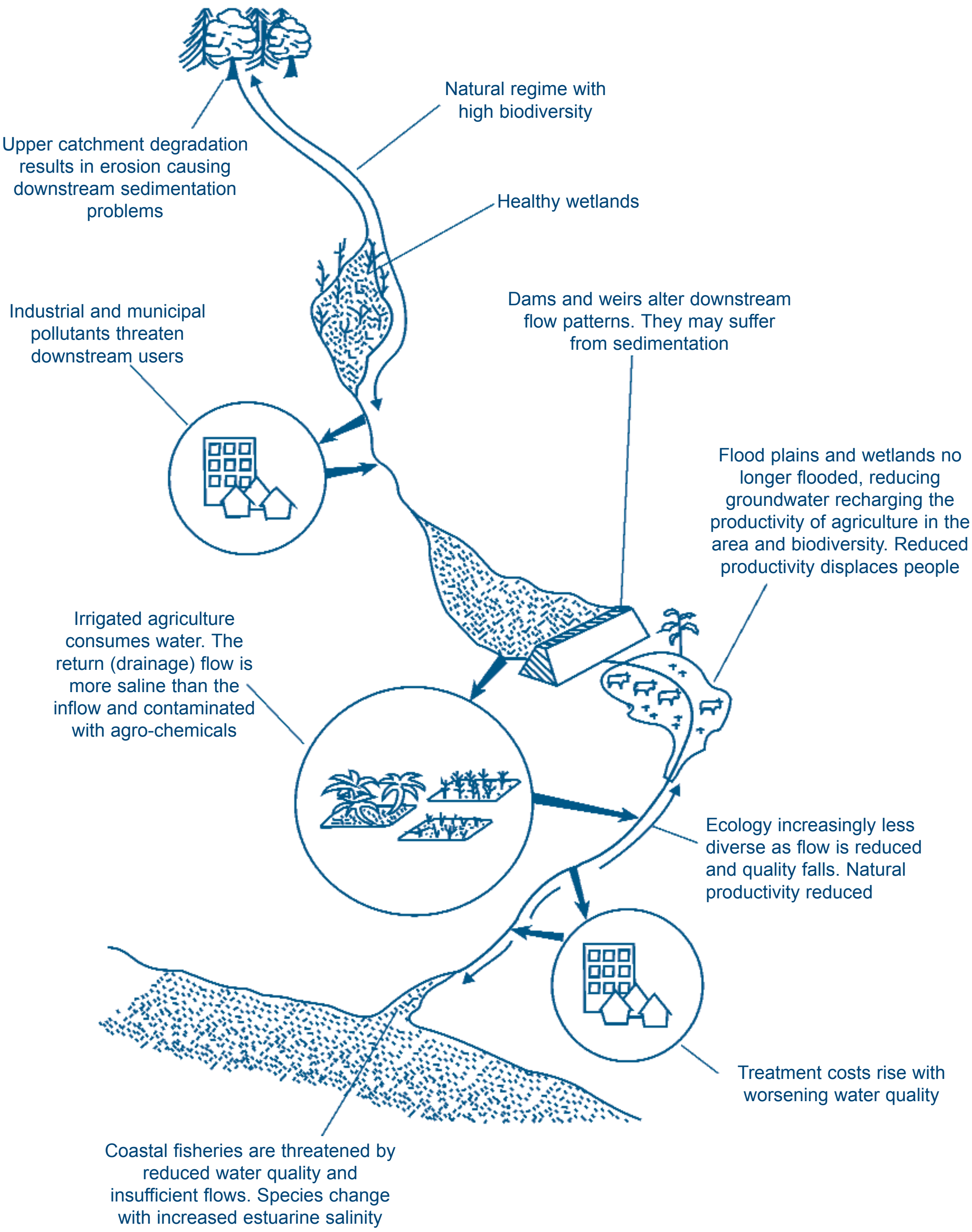
Table 7

Scheme development factors affecting the selection of irrigation method (Source: Field and Collier, undated)

Irrigation method	Design	Construction	Operation	Maintenance
Surface	Simple	Simple	Complex	Simple
Sprinkle	Complex	Complex	Simple	Complex
Trickle	Complex	Complex	Simple	Complex

Figure 19

Causes and impacts of reduced water quality in a river system (Source: FAO, 1995)



Keller and Bliesner (1990) provide a summary of the major institutional factors affecting the selection of different irrigation system types, for use in developing countries (Table 8).

Divisibility refers to the suitability of the technology to smallholdings, which are common in developing countries. The category of ***Total*** divisibility refers to the technology that can fit economically to any size of land. ***Partial*** divisibility refers to the technologies that can be adapted to smallholdings with difficulty or at high cost. The last category, ***No*** divisibility, refers to technologies that are not adaptable to smallholdings.

Maintained by is a category that gives a measure of the physical sustainability of the system. It indicates who can operate and maintain the system. ***Farmer*** is used for easily maintained equipment. ***Grower*** is used for equipment that can be maintained at the farm level. However, advanced skills are required. ***Shop*** indicates the need for local merchant with limited facilities for repairs. ***Agency*** indicates facilities with specialized equipment and skills to keep the irrigation equipment in operation, including engine-driven pumps.

Risk is a category addressing the issue of potential crop failure because of breakdowns in the system. The ***low*** risk category is used for systems not vulnerable to breakdown at farm level. The ***medium*** level risk is used for pressurized systems that can still operate even if some parts of the equipment at farm level can malfunction. The ***high*** risk level refers to systems requiring a high degree of filtration and to systems vulnerable to breakdowns at farm level. A breakdown in a critical stage of the crop development needs to be addressed immediately. Time-consuming repairs may cause the complete failure of a crop.

Table 8

Factors affecting the selection of modern irrigation systems for use in developing countries (Source: Keller and Bliesner, 1990)

Method & Type	Divisibility	Maintained by	Risk	Management and O&M Skill	Effort	Ruggedness
Surface: canal feed						
Basin	Total (1)	Grower	Low	Master	5	Lasting
Border	Total (1)	Farmer	Low	Master	6	Lasting
Furrow	Total (1)	Farmer	Low	Medium	10	Lasting
Surface: pump/pipe feed						
Basin-Level	Partial (1)	Shop	Medium	Master	3	Robust
Border	Partial	Shop	Medium	Master	3	Robust
Furrow	Partial (1)	Shop	Medium	Master	6	Robust
Sprinkler						
Hand-move	Total	Shop	Medium	Simple	9	Durable
End-tow	Partial	Shop	Medium	Medium	5	Durable
Side-roll	Partial	Shop	High	Medium	6	Durable
Side-move	No	Agency	High	Master	5	Fragile
Hose-fed/pull	Total (1)	Farmer	Medium	Simple	10/7	Durable
Travelling gun	Partial	Agency	High	Master	4	Sturdy
Centre pivot	No	Agency	High	Complex	1	Sturdy
Linear-move	No	Agency	High	Complex	2	Sturdy
Sprinkler solid set						
Portable	Total (1)	Shop	Medium	Medium	5	Durable
Permanent	Total (1)	Farmer	Medium	Medium	1	Durable
Localized point-source						
Drip	Total (1)	Grower	High	Complex	2	Fragile
Spray	Total (1)	Grower	Medium	Complex	2	Durable
Bubbler	Total (1)	Grower	Low	Complex	4	Robust
Hose-basin	Total (1)	Farmer	Low	Simple	10	Robust
Localized line-source						
Reusable	Total (1)	Grower	High	Complex	5	Fragile
Disposable	Total (1)	Grower	High	Complex	3	Fragile

(1) well-adapted for irregular shape fields

Management, Operation and Maintenance (O&M) of on-farm irrigation systems require skill and effort related to the type of system. Under **Skill** reference is made to the complexity of management required in order to achieve reasonable application efficiencies. The nature of the skills, the level of support for services, and spare parts to keep the system in good working order fall also in this category. ***Simple*** indicates elementary skills. ***Medium*** indicates considerable skill for the proper operation and management of the system. ***Master*** refers to considerable practical field experience to manage the flows and achieve the expected efficiencies. ***Complex*** implies sophisticated technical skills to operate and service the equipment properly. **Effort** refers to the time required to manage, operate and maintain the system. It is given in hours per hectare per month.

The last category, **Ruggedness**, indicates the durability of the distribution and on-farm equipment. ***Lasting*** is used for surface irrigation systems that are canal-fed. As a rule, these systems do not break down. ***Robust*** systems are those with few mechanical or intricate parts. They also do not break down as a rule. ***Durable*** indicates systems that require some spare parts and service facilities, but seldom break down. They also do not require very careful handling. ***Sturdy*** is used for systems that require careful

Table 9

Additional factors affecting the selection of irrigation systems for developing countries

System and type	Soils	Crops	Potential efficiency[1]	Labour demand (hrs/ha irrigated)	Energy demand	Capital cost	Design and construction	Operation	Maintenance
Surface:	Clay, loam								
* Gravity supplied									
- unlined canals			30%	6	Low	Low	Moderately complex	Complex	Simple but labour intensive
Basin		All							
Border		All except rice							
Furrow		All except closely-spaced crops							
- lined canals			45%	6	Low	High	Complex	Complex	Simple, moderately labour intensive
Basin		All							
Border		All except rice							
Furrow		All except closely-spaced crops							
* Pump supplied									
- lined canals			45%	6	High	High	Complex	Complex	Moderately complex, moderately labour intensive
Basin		All							
Border		All except rice							
Furrow		All except closely-spaced crops							
Sprinkler:	Most								
* Semi-portable and drag-hose		All except rice	75%	3-4	High	Moderately high	Relatively simple	Simple	Moderately complex
* Centre pivot and lateral move		All except rice	90%	0.5	Medium	Medium	Complex	Simple	Complex
Localized:	All								
* Drip, spray, micro-sprinkler		All except closely-spaced crops (under drip)	90%	0.5	Medium	High	Moderately complex	Simple	Moderately complex

[1] Refers to the overall or project efficiency, which includes conveyance, field canal and application efficiencies

handling and maintenance to continue functioning, such as irrigation machines. ***Fragile*** systems, like drip, require proper handling and considerable spare parts, as they have delicate components.

While this is a more detailed methodology, still it does not incorporate the areas of capital cost, energy requirements, etc. Table 9, based on experience in the Middle East and Africa, provides additional information to complement the criteria of Table 8.

3.5. Conclusion

The selection of on-farm irrigation systems is a complex process whereby technical, socio-economic, environmental and health elements are involved. The analysis of all facts related to these elements is a necessary process through which a viable solution can be found on a case by case basis.

Having gone through all the criteria, one has to rank each promising system against the various parameters discussed in order to prioritize options for screening, the preparation of detailed designs and cost estimates. The relative importance of each parameter in deciding which system to adopt varies from case to case.

Economic considerations will play an important role in the final system selection. Some of the data required to carry out a financial and economic analysis of the pre-selected options include interest rates, labour cost, land rents, water cost, energy costs, as well as crop production costs of each of the irrigated crops. The other data required include the capital costs of the irrigation infrastructure, the life and costs of different irrigation system components, and the labour and energy required for the maintenance of each system under consideration.

Chapter 4
Health and environmental aspects of irrigation development

Irrigation water may carry pathogens of communicable diseases for human beings. It can also provide the right environment for the breeding and propagation of their vectors. The creation of open water bodies and irrigation and drainage infrastructure can lead to the introduction of disease vectors in areas where they did not exist before, or encourage a rapid increase in their original densities. The high human population densities associated with these projects create an environment conducive to the proliferation of communicable diseases. Indeed, irrigation may also introduce disease agents through human migration. Water-related diseases may be avoided or reduced by good engineering practices and appropriate environmental management. It is therefore important for planners to have a sound understanding of disease vectors, their habitats and behaviour, as this is of relevance to their control.

Environmental management of water-related diseases is aimed at reducing the human-vector contact through sound environment control measures, such as proper location of villages, provision of safe drinking water and toilets. It is also equally important during irrigation scheme planning to focus on ecological changes that come about because of the project. Apart from changing land use patterns around the project, an irrigation project also has an effect on the biodiversity of the catchment in which it is located. An environmental impact assessment (EIA) is the planning tool used to assess the potential effect of a project on the ecology of an area. It provides planners and decision-makers with vital information about the effects of planned projects. Irrigation projects modify river hydrology, water and air quality, soil properties and salinity, erosion and sedimentation and the entire ecology within and around the project locality (see Section 4.4).

4.1. Types of diseases related to water and ways of transmission

Table 10 presents a list of water-related diseases and a brief description of their categories. The classification of the diseases is based on conditions that prevail in most developing countries where such diseases are common. The conditions are:

- ❖ insufficient domestic water supplies, sanitation and solid waste disposal services
- ❖ inadequate housing and lack of hygienic conditions
- ❖ general lack of good health due to poor economic circumstances
- ❖ increase in the number of vector habitats resulting from development of water resource projects such as irrigation schemes

Table 10
Environmental classification of water-related infections (Adapted from: ILRI, 1994)

Category	Some of the infections/diseases	Mode of transmission
1) Faecal-oral (water-borne or water-washed)	* Diarrhoeas and dysenteries (amoebic dysentery, cholera) * Fevers (typhoid) * Hepatitis A	Through contaminated drinking water
2) Water-washed (skin and eye infections; other)	* Skin sepsis	Through poor personal hygiene and contact with contaminated water
3) Water-based (penetrating skin; ingested)	* Schistosomiasis (bilharzia) * Guinea worm	Through an aquatic invertebrate organism (snail)
4) Water-related insect vector (biting near water; breeding in water)	* Malaria * Lymphatic filariasis (elephantiasis) * Onchocerciasis (river blindness) * Japanese encephalitis (brain fever)	By insects that depend on water for their propagation
5) Infections	* Ascariasis (roundworm) * Anchylostomiasis (hookworm)	Through inadequate/infective sanitation

According to ILRI (1994) about 200 million people in the tropics are infected by bilharzia. According to FAO (1999) the same number of people are infected with malaria and between 1 and 2 million people die of the disease annually. Most cases of these diseases occur in Africa. In order of decreasing importance globally, the water-related vector-borne diseases shown in Table 10 (category 3 and 4) are listed as follows:

- Malaria
- Schistosomiasis, also known as bilharzia
- Japanese encephalitis, also known as brain fever
- Lymphatic filariasis, also known as elephantiasis
- Onchocerciasis, also known as river blindness

Some of these diseases are, of course, locally more predominant. Brain fever occurs in epidemic outbreaks with high mortality rates among children. It is most common in irrigated rice production in South, Southeast and East Asia. Elephantiasis is mainly an urban disease but is also linked to irrigated lands in Central Africa and weed-infested reservoirs as well as latrines in South and Southeast Asia. River blindness is a common disease in West and Central Africa as well as Central America.

This chapter will not go into details about all the diseases described above. It will deal with only two major diseases, malaria and bilharzia, in more detail since they are very common to irrigation schemes, are globally the major diseases and are of major concern to Africa. Knowledge of the favourable conditions for the hosts of the two categories of diseases helps in considering the engineering and environmental measures necessary to take into account in scheme design and operation. The measures are categorized under disease preventive measures, which relate to design considerations, and disease post-construction control measures, which relate to environmental management safeguards in scheme operation. These measures are described in section 4.2 and 4.3 respectively.

4.1.1. Malaria

Malaria is caused by protozoan organisms of the genus Plasmodium. The plasmodial parasites are transmitted to human beings by the female anopheles mosquito through mosquito bites. Water is an essential component of the mosquito environment. Anopheles mosquitoes breed on sheltered edges of lakes, ponds, rivers, reservoirs and canals. Weed, in combination with water, provides an ideal habitat.

The difference in time between deposition of mosquito eggs and the emergence of the flying adult is about one week at temperatures between 30°C and 32°C and two weeks at temperatures between 20°C and 25°C. It has to be remembered that malaria is responsible for high morbidity and mortality in tropical and sub-tropical countries of the world.

4.1.2. Bilharzia

Human beings are infected with bilharzia when they make contact with water that has been contaminated by infected aquatic and semi-aquatic snails. These snails are used as intermediate hosts in the life cycle of the schistosoma, the parasite causing bilharzia. The interruption of the life cycle can be used as a way of controlling the schistosoma and hence the disease. Some of the characteristics of snails, which can be used as key control pointers in irrigation engineering design for vector control, are the following:

a) Semi-aquatic snails, such as oncomelania, may survive in drying water bodies even where water is present for only three months of the year. They are adapted to ditches, irrigation canals, drains, marshes and rice fields.

b) Snails prefer dense vegetation, which protects them from direct sunlight and water currents, and moderately polluted water with faeces or organic material.

c) Snails can tolerate a wide range of pH, from 5-10.

d) Snails do not tolerate:

   - water velocities of about 0.6 m/s or more for flows of 1 to 50m^3/sec (Table 11)
   - turbulent waves
   - depths greater than 1.5 m

4.2. Disease preventive measures

Surface irrigation projects may pose more disease-related problems than sprinkler irrigation systems. This is due to the fact that the infrastructure of surface irrigation schemes can present more disease vector habitats compared to the closed pipes used in sprinkler irrigation systems. This is attributed to the nature of surface irrigation infrastructure. However, both sprinkler and surface irrigation systems may be associated with mosquito breeding sites, if there is over-application of water that leads to the ponding of water in the fields. The following sections will deal with health safeguards mostly related to surface irrigation systems, because this is where most health and environmental problems occur.

4.2.1. Hydraulic measures to prevent diseases

There are opportunities during the design and construction of irrigation projects to incorporate health safeguards in order to reduce the risk of infection. These include:

- Increase of water velocities in canals and drains and, where possible, elimination of night storage reservoirs
- Canal lining
- Free draining hydraulic structures
- Good drainage systems
- Land levelling
- Proper irrigation scheduling and water application

Water velocity

Low water velocities in canals and drains create a good habitat for parasites and vectors. To dislodge a snail from a canal or other surface, a drag force must be produced on its shell to pull the snail from its position. According to ILRI (1994), laboratory research carried out on the Biomphalaria glabrata snail, common in the Western Hemisphere, indicated that a velocity of 0.94 m/s would completely dislodge all sizes of snails from smooth solid surfaces and a velocity of 0.36 m/s would do the same on loose granular surfaces. Generally, on smooth surfaces the snails were pulled loose from the surface at velocities around 0.60 m/s. This was considered a dislodging velocity. The snails would be completely immobilized at a velocity of 0.20-0.30 m/s. These results were compared with static force tests which showed that a velocity of 0.33 m/s would immobilize snails, while a velocity of 0.65 m/s would cause dislodgment.

From these findings, mean velocities that could produce immobilization or dislodgment were calculated. Table 11 presents the estimated velocities for immobilizing snails in a wide range of channel geometrics. At values below the ones given the snails will be immobilized.

On average, snails do not tolerate velocities of about 0.6 m/s and above, depending on the surfaces they cling to and canal discharge. These velocities can be used as guidelines for design. It has also been established that the design velocities used for devices that flush mosquitoes in natural streams in Asia and the Caribbean Islands are 0.4-0.5 m/s for intermittent discharges, which is lower than the velocity required for immobilizing snails.

The higher velocities are desirable and should be designed for wherever possible. Structures within the canal system, such as night storage dams, tend to lower velocities in canals and should therefore be avoided wherever possible. Besides which, and more importantly, these structures can offer open water bodies conducive for vector borne diseases. However, in the case of unlined canals care should be taken that no erosion because of too high a velocity occurs in the canals. The experience of Mushandike irrigation scheme in Zimbabwe provides more information with regards to velocities in concrete lined canals and structures (Thomson *et al.*, 1996; Chimbari *et al.*, 1993). A canal gradient of 0.2% was selected for the standard size of secondary canal. This gave a maximum water velocity of 0.85 m/sec.

Canal lining

From the engineering point of view, the main reason for lining canals is to improve the conveyance and distribution system efficiencies by eliminating or minimizing water seepage.

From a vector point of view, the major advantages of canal lining are:

- it allows for increased water velocities
- if well maintained, it discourages rooted weed growth
- the lower seepage reduces ponded water and waterlogging
- lined canals dry faster than unlined canals
- hard canal surfaces discourage sheltering by snail vectors
- it facilitates easier control of vectors by water management and chemicals

Table 11
Mean velocities in trapezoidal channel for controlling Bilharzia snails in the Western Hemisphere (Source: ILRI, 1994)

Canal discharge (m^3/s)	Immobilizing mean velocities in the canal(m/s)
1	0.58
5	0.67
10	0.71
20	0.75
30	0.78
50	0.81

Figure 20
Typical cross-section of trapezoidal field canal for smallholder irrigation schemes

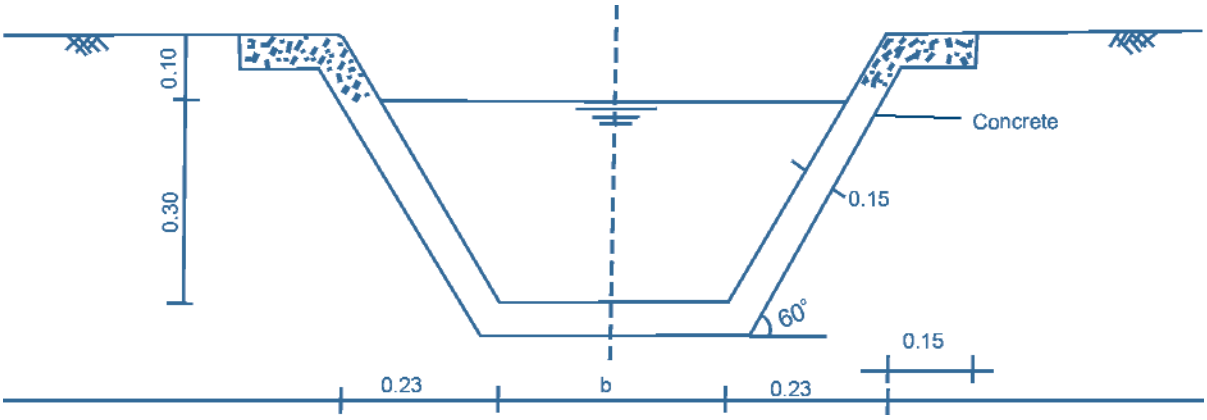


Table 12
Flows through a standard Agritex canal

Bed width (m)	Longitutional slope	Flow (m^3/s)	Cross-sectional area (m^2)	Velocity (m/sec)
0.25	1:1000	0.058	0.127	0.46
0.30	1:1000	0.068	0.142	0.48
0.35	1:1000	0.077	0.157	0.49
0.40	1:1000	0.087	0.172	0.51
0.45	1:1000	0.097	0.187	0.52
0.50	1:1000	0.108	0.202	0.53
0.25	1:300	0.105	0.127	0.83
0.30	1:300	0.123	0.142	0.87
0.35	1:300	0.140	0.157	0.89
0.40	1:300	0.158	0.172	0.92
0.45	1:300	0.177	0.187	0.95
0.50	1:300	0.195	0.202	0.97

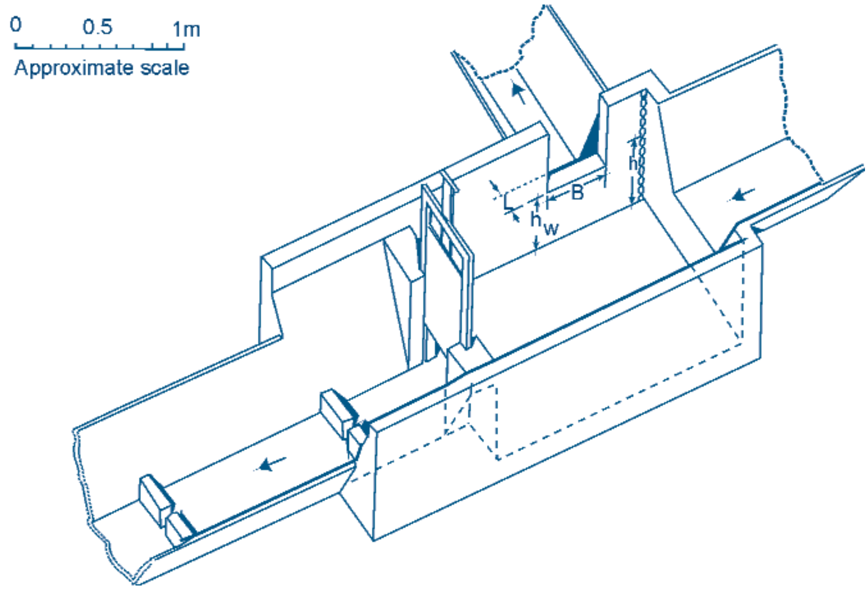
Canal lining alone does not automatically increase water velocities to the desirable level for vector control. The velocities also depend on the longitutional slope of the canal. Table 12 shows the effect of canal slope on velocities for concrete-lined trapezoidal canals constructed by the Department of Agricultural, Technical and Extension Services (Agritex) in Zimbabwe for its smallholder irrigation projects.

The steeper the canal the faster the water moves and therefore the less favourable the habitat. Comparing Tables 11 and 12 reveals that there could be a problem with snails for the smaller canals at 1:1000 slope whereas the same problem is eliminated by constructing the canals at 1:300 slope. However, it has to be remembered that the general slope of the area largely dictates the canal slopes. Nevertheless, by using canal embankment combined with drop structures, the objective of high velocities can be attained and sufficient water depth maintained.

Free draining hydraulic structures

Structures retarding flow and not allowing complete draining are good habitats for bilharzia snails and mosquitoes. Examples of such structures are duckbill off-take weirs and structures with sunken stilling basins, such as distribution boxes (see Module 7). Most of these structures can be substituted with free draining structures, which means that there is no standing water under normal working conditions. These improved structures are not necessarily more expensive. For example, the duckbill weir could be replaced by a free draining off-take structure, as shown in Figure 21. This type of structure, however, requires a drop of at least 0.35 m and is therefore unsuitable for flat land, unless the upstream canal elevation is artificially raised, which is expensive.

Figure 21
Free draining off-take structure



Drop structures are very common in surface irrigation schemes. Small drops do not necessarily need stilling basins. However, large drop structures should be designed to dissipate excess energy. Rather than using a sunken basin, a stilling basin flush with the downstream canal and with block baffles to dissipate energy and induce the hydraulic jump is proposed. More details on drop structures are discussed in Module 7.

Drainage system

Surface irrigation systems require drainage systems to remove excess irrigation water. Drainage channels are a favourable habitat for the mosquito parasite. If the drainage system is well-designed and maintained, the hazard can be reduced. Taking into account the life cycle of the mosquitoes, the design of the drainage system should cater for the disposal of the water before the mosquito completes its larvae cycle. The recommended design time for draining off water from drains for mosquito control is one and two weeks respectively for the two temperature ranges mentioned in Section 4.1.1. Drainage systems for snail control should remove water in one to two months, which means that a drainage system designed for mosquito control will suffice for snails. This criterion can be used to size the drains during design. The drainage system should be designed in such a way that field drains lead to collector drains at the bottom end of the field where water is then delivered completely outside the irrigated area. In the absence of flowing rivers in the vicinity of an irrigation scheme, the drainage water can be re-used for production purposes.

Land levelling

Land grading is done to even out land to allow for more efficient use of irrigation water. It also removes depressions, which would be potential breeding ground for mosquitoes and bilharzia snails. The design of irrigation schemes, especially surface schemes, should incorporate calculations of the necessary cuts and fills for land levelling. It has to be noted, though, that land levelling is expensive and can lead to removal of the fertile topsoil if not done properly.

4.2.2. Measures to reduce human-vector contact

Minimizing the human-vector contact in the following ways can reduce the transmission of the disease vector.

Location of villages

Plot holders in smallholder irrigation schemes and farm labourers in commercial irrigation schemes are particularly vulnerable to water-related diseases, especially if their villages are located too close to open water bodies. Villages should be located at least one kilometre away from open water bodies such as canals, drains and night storage reservoirs. In order for villagers to accept this scenario, a safe water supply should be provided close to the homesteads so as to discourage the farmers from using irrigation and drainage water for bathing and other domestic purposes. It has to be acknowledged that the siting of villages in this manner may not always be possible. In this case other disease control measures, such as chemical control, would have to be employed.

Provision of domestic water

Boreholes, equipped with hand pumps or motorized pumps, are generally considered to provide safe drinking water. The official recommendation in a country like Zimbabwe is one borehole per 20 families. The boreholes should not only be provided near the villages, but are also needed within the irrigated area, in order to discourage farmers from using canal and drain water while in the irrigated area. The boreholes should have adequate drainage so as to avoid the accumulation of water in ponds and muddy places. They should be fenced in order to prevent animals from drinking water from any wet areas around the boreholes. Washing slabs should be provided and connected to the drainage facilities.

Pit latrines

It is imperative to provide and locate a number of ventilated pit latrines within the scheme area. In Zimbabwe it is recommended that one toilet unit be provided for every 6 ha or for every 50 people. Pit latrines should also be provided in the villages.

Cattle troughs

Cattle troughs should be provided at strategic places outside the irrigation scheme to discourage farmers from taking their cattle to dams, irrigation canals and drains. The troughs could be designed, wherever possible, in such a way that they could utilize gravity or manual pumping to fill up in order to avoid energy costs. A provision should be made for periodic flushing of the troughs.

4.3. Disease post-construction control measures

There are a number of post-construction measures that can be applied in order to reduce diseases related to water. These include biological, chemical, physical and environmental controls. The environmental issues will be discussed in Section 4.4.

4.3.1. Biological and chemical control

Biological control is normally established by introducing or increasing biological control agents within the target area. These agents increase at the expense of disease agents. Once biological control is established it is self-perpetuating. It is not, however, effective against weeds and considerable skill is also required in utilizing this technique.

Chemical control measures are an effective means of controlling parasites, but are often expensive and can lead to environmental degradation if not well applied. The use of pesticides and herbicides requires considerable understanding on the part of the user. Moreover, they may have adverse effects on non-target organisms and may limit the use of water for some time after application. In some cases, new agricultural pests or vectors may be triggered by the application of pesticides.

In light of the above, integrated pest management strategies and programmes should be drawn up in such a way that vectors can be monitored and early warning systems for disease outbreaks be put in place (see Module 3). There should be close liaison with health authorities on this.

4.3.2. Physical control

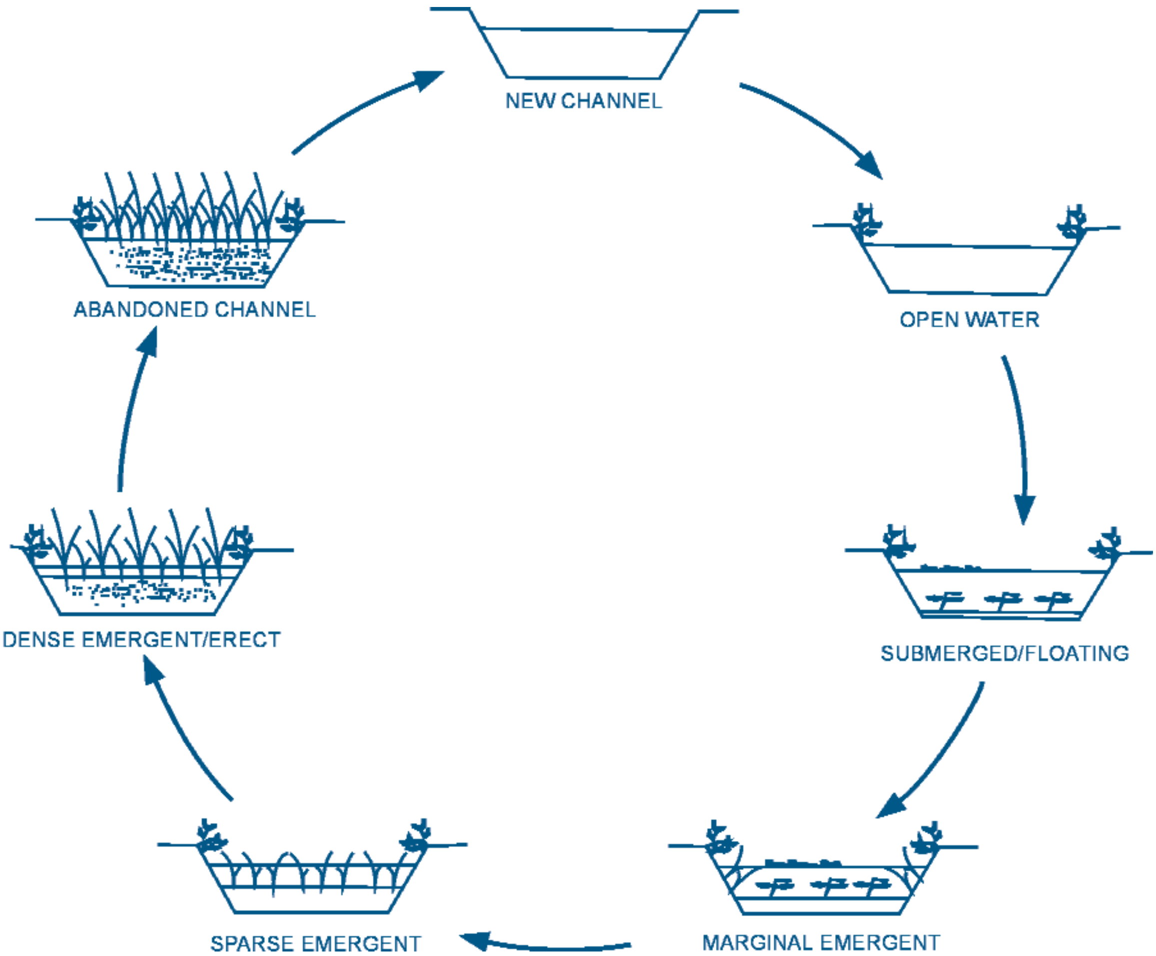
The control measures that are within the domain of engineering are physical control measures. These are geared towards the reduction of silt, aquatic weeds and other vegetation using manual or mechanical methods. Knowledge about the types of weeds helps in establishing how to control them. For the purpose of this module, it suffices to mention that there are four categories of aquatic weeds: submerged weeds, free-floating weeds, floating-leafed weeds and emergent weeds. Figure 22 shows a schematic presentation of these weeds growing in canals.

Depending on the area and type of weed, the density of the weeds in a canal will dictate when weeding should be done. Since canal siltation often takes much longer than weed infestation, weed clearing will have to be done more frequently than maintenance for silt removal. The process of irrigation system maintenance for silt removal also removes weeds.

The irrigation system, once established, will require maintenance so as to discourage the formation of water bodies that would otherwise become habitats for snails and mosquitoes. Canals, drains, night storage reservoirs and other related hydraulic infrastructure have to be cleaned of silt and weeds regularly. For this, a maintenance programme has to be drawn up. The maintenance programme for vector control is a part of the overall maintenance of irrigation infrastructure. It will be discussed in detail within the context of the operation and maintenance of irrigation schemes in the modules dealing with surface irrigation (Module 7), sprinkler irrigation (Module 8) and localized irrigation (Module 9).

Pressurized irrigation systems, in view of the piped distribution of water and the absence of open water surfaces at field level, have the inherent advantage of controlling the vectors of diseases related to water. The absence of drainage systems in this type of irrigation, combined with better water application, is added advantage. However, major outbursts of pipes become potential health hazards when left unattended.

Figure 22
Schematic presentation of weed types (Source: University of Zimbabwe, 1995)



4.4. Environmental Impact Assessment (EIA)

According to FAO (1995), an EIA is a formal process for predicting environmental consequences of human development activities and planning appropriate measures to eliminate or reduce adverse effects and augment positive effects. An EIA is therefore a management tool for planners and decision-makers that complements the other engineering and economic considerations. EIA comprises the following steps:

Screening	:	This leads to the decision whether or not a particular project warrants a full EIA to be carried out. It depends on project size or site specific information.
Scooping	:	A process of determining the most critical issues to study. It has to involve community participation.
Prediction & Mitigation	:	The central part of an EIA intended to look at different realistic and affordable mitigation options.
Management & Monitoring	:	This involves drawing up an environmental action plan based on the mitigation options assessed as well as institutional requirements for implementation.
Auditing	:	This is a process of carrying out an environmental audit, based on experiences gained after project implementation.

Some of the important effects of irrigation schemes that emerge in an EIA are briefly discussed in the following sections.

4.4.1. Hydrology

Irrigation schemes change the hydrology of rivers and groundwater due to their consumptive use. The ecology of the area, prior to the project, may not be able to cope with changes that may result from new irrigation projects or the rehabilitation of the old ones. The changes in river hydrology also have an impact on the users downstream. Therefore, present and future users of the water need to be clearly defined and matched to the current and future base flows within a given river catchment. The lowering of the water table also affects other users, as well as flora and fauna, especially in wetlands. Continued, uncontrolled mining of groundwater can have severe economic and environmental consequences and should be given particular prominence during planning.

4.4.2. Water quality

Water is essential for human beings, agriculture, industry and the environment. Polluted water may contain intolerable levels of toxic substances for human beings, animals and plants. As the hydrological regime changes, so does the water quality. Agrochemicals used in irrigated crop production and chemicals discharged from industry into watercourses have harmful effects on the environment. Proper planning has to be put in place to minimize these effects. The reader is referred to FAO (1995) for guidelines on water quality for irrigation.

4.4.3. Soil properties and salinity

Irrigation is associated with intensive crop production, which has a marked effect on soil fertility, erodibility and possible salinity. At irrigation schemes, salts carried in irrigation water, as well as fertilizers, pesticides and groundwater may increase soil salinity. The accumulation of salt leads to irreversible soil damage. Therefore, proper planning and use of irrigation is essential for sustainable irrigation development.

4.4.4. Biodiversity

By changing the land use pattern of the immediate and surrounding areas, irrigation schemes have a major impact on the biodiversity of the river or groundwater in their respective catchment areas. The EIA of potential irrigation schemes should assess the effects of the scheme on mammals, fish, reptiles, insects and other endangered species that may be affected by the change in their habitat. Wetlands and plains are among some of the most productive lands in the world. They support a wide range of species, including waterfowl and migratory birds, and besides being a buffer to reduce floods, they are ideal for relatively cheaper water purification facilities and also protecting the coast from erosion. Wetlands require consistent recharge of fresh water. However, if the inflow is saline or reduced, both of which may result from poorly planned irrigation and other projects upstream, this will have devastating effects on soil fertility not to mention the fresh water needs of the people, fish, birds, animals and other species whose lives are based on the wetlands (FAO, 2002).

Chapter 5

Checklists for the socio-economic, agro-technical, health and environmental impact assessments of irrigation development

Below, non-exhaustive checklists for socio-economic, agro-technical, health and environmental impact assessment are given. More information on checklists can be found in Field and Collier (1998), which deals with checklists to assist preparation of small-scale irrigation projects in sub-Saharan Africa.

5.1. Checklist for the socio-economic impact assessment of irrigation development

In order to facilitate quick reference to the socio-economic impact assessment of irrigation development, the following non-exhaustive checklist can be used as a guide:

- ❖ Has a PRA been applied?
- ❖ Will the project involve a change of living conditions for the residents? If yes, have these been mapped and documented?
- ❖ Have traditional preferences been considered when designing the system?
- ❖ Is the planner aware of all the groups' expectations of/from the project?
- ❖ Are the potential conflict areas mapped?
- ❖ Is the land tenure situation taken into account for men and women farmers?
- ❖ Are all persons or groups affected by the scheme fully aware of the new development and their new roles?
- ❖ Are all the responsibilities, obligations and rights clear for all parties? Are they in writing and signed?
- ❖ Have time, labour and financial constraints for all parties been taken into account in the proposed activities?
- ❖ Have women farmers' needs been taken into account and/or how do the proposed activities affect women's time and labour?
- ❖ Have all parties had opportunity to express their opinions?
- ❖ Have all the parties' opinions been documented?
- ❖ Is there any proof that peoples' opinions have been considered and incorporated in the planning?
- ❖ Have farmer interests groups been formed, for example through Irrigation Management Committees?
- ❖ For each identified critical issue or potential conflict area have alternative ways to reduce or avoid the expected conflicts by using participatory approaches been studied?
- ❖ If the impacts of the new construction are not acceptable or viable from a social aspect has the project been cancelled? Who has the authority to decide upon continuation or cancellation?

5.2. Checklist for the agro-technical assessment for the selection of an irrigation system

In order to facilitate quick reference to the agro-technical assessment for irrigation system selection, the following non-exhaustive checklist can be used a guide:

Is the irrigation system adapted to the following agro-technical characteristics at the site:

- ❖ Water resources: accessibility, quantity and quality?
- ❖ Soils: soil texture, structure, profiles and depths, salinity and drainage?
- ❖ Topography: slope?
- ❖ Climate and crop: top or root watering crops, shallow rooted crops, etc.?
- ❖ Capital and labour: availability and cost?
- ❖ Energy: availability and cost?

For each question for which the answer is NO, study and present alternative technical solutions to adapt the system.

5.3. Checklist for the health risk assessment of irrigation development

In order to facilitate quick reference to the health risk assessment of irrigation development, the following non-exhaustive checklist can be used a guide:

Will the project:

- ❖ Lead to an increase in favourable breeding sites for water-related diseases?

- Involve change in drinking water quality?
- Increase transmission of diseases through the animal-vector contact?
- Increase the transmission of diseases through the human-vector contact?
- Involve the use of toxic substances?

For each question for which the answer is YES, go to Table 13 to find a solution to mitigate or reduce the damages.

Other important issues to consider regarding health parameters are:

- Are relevant departments within the Ministry of Health and other appropriate health sector institutions involved and consulted at the earliest stage of the project?
- What is the level of understanding of preventive measures and knowledge of how diseases are transmitted?
- Do the residents have access to health extension workers and treatment facilities?
- Has a person responsible for monitoring been appointed?
- If so, are they sufficiently qualified to handle the functions of the job?

Table 13

Management and mitigating steps for public health risks

Potential negative impacts	Mitigating measures
Public health risks	**• Minimize increase in water-related diseases and vulnerability of rural communities within and around projects**
• Introduction or increase in water-related diseases (schistosomiasis, malaria, etc.) and vulnerability of rural communities within and around projects	- Line all unlined canals or use pipes in the delivery and distribution system, in order to minimize water seepage, as standing water would be a habitat for disease vectors - Incorporate free draining structures in the design of the water delivery, conveyance and field canal system - Install gates at canal ends to allow for flushing - Fill up or drain depressions along canals and roads or in and around irrigated area to discourage water from ponding - Maintain drainage system by regular de-silting and weeding. Level irrigated area to avoid ponding of water during irrigation - Regularly de-silt and weed night storage reservoirs and canals and weed canal banks - De-silt and weed other hydraulic structures of the irrigation system, such as division boxes, weirs, flumes, drops etc. - Replace bitumen on canal joints to reduce water seepage through canals - Repair canal embankments, canals and other structures - Where possible, fluctuate water levels in the night storage dams in order to desiccate aquatic snail and anopheles mosquito larvae - As much as possible allow canals to dry regularly, by the rotating water supply between them in order not to keep them continuously wet. - Carry out disease prophylaxis - Treat diseases
• Injury or death associated with accidents such as during construction, and drowning in canal, night storage reservoir, etc.	- Enforce safety regulations relating to construction - Use qualified machine operators and adhere to regulations regarding use and disposal of hazardous materials - Use appropriate technology - Protect people from structures that could pose dangers for example, by fencing reservoirs and canals in which humans, especially children, and animals could drown
Pollution of water and soil	
• Contamination of and accumulation of toxic concentrations of heavy metals and agrochemicals in surface water, groundwater and soil	- Protect wellheads from potential contamination: (a) Periodically inspect and maintain acceptable well construction guidelines as needed (b) Install backflow prevention devices and non-return valves (c) Stay at least 30 m away from well when mixing, loading and storing agrochemicals (d) Periodically monitor well quality by sending water samples for quality tests in order to ensure adherence to recommended standards (e) Know site-specific variables affecting aquifer vulnerability - Manage irrigation to minimize transport of chemicals, nutrients or sediment from soil surface or root zone: (a) Schedule irrigation according to crop water needs and soil moisture depletion, and apply water accordingly (b) Upgrade or maintain irrigation equipment and system to improve water application efficiency (c) Time the leaching of soluble salts to coincide with low residual soil nitrate levels (d) Reduce water application rates to ensure no runoff or deep percolation occurs during or immediately after agrochemical application

Potential negative impacts	Mitigating measures
	- Manage nitrogen applications to maximize crop growth and economic return while protecting water quality: (a) Sample soil to at least 0.6 m or the crop rooting depth in order to determine the residual NO3 - N (b) Establish the yield versus N application rate for the previous 5 year period at least (c) Take account of all N sources in determining the N fertilizer requirement. These sources can be organic matter and previous crop residues, irrigation water nitrate, soil nitrate and manure (d) Use slow-release N fertilizers and nitrification inhibitors as required (e) Split N application into as many applications as is economically and agronomically feasible (f) Avoid fall application of N fertilizers, especially on sandy soils and vulnerable aquifers (g) Prepare a yearly nitrogen management plan for each crop - Employ pesticides judiciously and minimize off-target effects: (a) Provide thorough training to all applicators of chemicals and possibly certification prior to use (b) Select pesticides based on site and management variables to minimize potential groundwater contamination (c) Make sure that applicators of chemicals know the characteristics of the application site, including soil type, depth to groundwater and erosion potential (d) Compare chemical leaching hazards, persistence and toxicity to the specific conditions to determine suitability of the pesticide at that location (e) Inspect, calibrate and maintain application equipment on a regular basis (f) Minimize pesticide waste and storage by purchasing and mixing only enough chemicals to meet needs. Utilize refillable containers to minimize container disposal problems - Maintain records of all pesticides and fertilizers applied: Keep records on: (a) Irrigation water analysis (b) Soil tests results (c) Projected crop yields (d) N fertilizer recommendations (e) Fertilizers and/or manure applied (f) Amount of irrigation water applied (g) Actual crop yields (h) All pesticides applied including: brand name, formulation, registration, amount and date applied, exact location of application, name, address, and certification number of applicator (i) Records should be kept for 3 years at least - Manage phosphorus requirements for crop production to maximize crop growth and minimize degradation of water resources: (a) Implement standard SCS (any local) soil erosion practices and structures (b) Carry out soil tests of tillage layer and apply fertilizer according to soil test recommendations (c) Take account of all P from manure and other sources in determining P application rate (d) Spread grass filters around erosive crop field to catch and filter P in surface runoff (e) Incorporate surface applied P into soil - Utilize Integrated Pest Management (IPM) approach in pest control decision-making: (a) Monitor pest and predator populations (b) Select varieties that are resistant to pest pressures (c) Time planting and harvesting dates to minimize pest damage (d) Rotate crop sequence to break up pest cycles (e) Spot treat or band pesticides instead of applying broadcast treatment (f) Utilize beneficial insects and other biological controls
• Transport of pathogens resulting from use of excreta as fertilizer	- Animal wastes should be properly collected, stored and applied at agronomic rates for crop production in order to avoid discharge to surface or ground water. This can be done as follows: (a) Analyze manure for nutrient content and percent dry matter (see if there are recommendations for this) (b) Reduce N fertilizer according to the amount of available N in the manure (c) Avoid manure applications on saturated soils and incorporate it after application

5.4. Checklist for the Environmental Impact Assessment (EIA) of irrigation develoment

The guidelines on how to carry out an EIA are well-documented in other references such as FAO (1995) and the World Bank Guidelines on Environmental Impact Assessment. Thus they do not need elaboration here. This section is intended to provide general information on some of the important aspects that must be addressed by an EIA, as well as the potential negative impacts of irrigation projects and their mitigating measures. The information is provided in the form of checklists, which planners and communities can use during the development and operation of irrigation projects. The following checklist is an example of the questions that need to be addressed during the planning of an irrigation project. Table 14 provides potential negative impacts and their mitigating measures.

Will the project:

❖ Have any impacts on sensitive biological areas susceptible to erosion or pollution, for example wetlands and fresh drinking water sources? Is there a risk of eutrophication?

Table 14

Management and mitigating steps for soil degradation

Potential negative impacts	Mitigating measures
• Waterlogging	• Minimize and control waterlogging through: (a) Regulating the water application to avoid overwatering (b) Installating and maintaining an adequate drainage system, including installing a sub-surface drainage system where the need arises (c) Using lined canals or pipes to prevent seepage (d) Choosing efficient irrigation systems, for example sprinkler or drip, at design stage
• Increase in soil salinity, alkalinity, sodicity, acidity	• Management strategies for reducing salinization and its effects on crops are: (a) Leaching of salts by regular flushing (b) Using proper irrigation schedules with leaching requirements incorporated (normally 10-20% added onto the irrigation requirement), or allowing for leaching in rainy season (c) Installing an adequate drainage system (d) Changing tillage techniques (e) Adjusting cropping patterns through the cultivation of crops with salinity tolerance and avoiding monocropping (f) Incorporating soil ameliorates, such as incorporating gypsum in irrigation water to reduce sodium content of soils (g) Safe disposal of salty drainage water into unused land (if such land is not threatened) or evaporation ponds (where impacts can be contained) (h) Using good quality water
• Soil loss/accumulation due to water erosion in irrigated lands	• Minimize soil erosion in irrigated lands through careful design (considering field size, stream size (drop size), soils, slope and field layout) and by: (a) Using lined canals or pipes for water conveyance (b) Providing adequate drainage and soil conservation structures in irrigated lands (c) Selecting the correct stream flow for furrows, borders and basins (d) Using the correct command between field canals and the irrigated land, usually between 15 and 30 cm (e) Using plastic or other materials to reduce the impact of water coming from the siphons onto the irrigated land (f) Using siphons, checks, gates, and canal escape structures for water application, control and disposal (g) Selecting sprinklers with an application rate less than the infiltration rate of the soil for use for that type of soil (h) Land levelling and construction of conservation structures (i) Ensuring proper cut and fill operations through water course embankments (j) Establishing vegetation in cleared areas after irrigation construction work
• Soil erosion due to intensified human activity in surrounding areas such as more rainfed agriculture, increase in livestock and need for firewood • Loss of soil fertility	• Measures include: (a) Well-planned settlement to avoid surpassing carrying capacity of surrounding area (b) Allowance for villages, livestock, fuel wood, and vegetable gardens within or around irrigation scheme.

- ❖ Contribute to a change of soil structure or fertility?
- ❖ Contribute to salinization of soils or waterlogging?
- ❖ Have large impact on the availability of surface water and groundwater, at local and regional scale? Is there a risk of groundwater mining? Or salt intrusion?
- ❖ Contribute extensively to pollution of land and water, in the short term and long term?
- ❖ Have considerable impact on and change areas with unique or sensitive species of vegetation?
- ❖ Imply an evident increase in the use of chemicals, such as fertilizers and pesticides?
- ❖ Involve use of chemicals/products that do not decompose through natural processes?
- ❖ Involve risk for unintentional spreading of pollution beyond the controlled project area through air, water or the food chain?
- ❖ Involve unskilled people handling hazardous chemicals?
- ❖ Increase the use of fossil natural resources?

Other important issues to consider are:

- ❖ Has a person responsible for monitoring been appointed?
- ❖ What is the level of understanding of the residents regarding environmental causes and effects at global, regional and local scale?
- ❖ Does the area have any zones of vegetation or trees to prevent soil erosion?

Chapter 6
Principles and guidelines on the preparation of feasibility studies for irrigation projects

Feasibility studies provide the means for assessing developmental options for investment, in this case investment in irrigation. A feasibility study for irrigation development would assess the physical aspects of land, water and climate, and evaluate crop production potential and cropping programmes within the context of the physical aspects. The same study reviews and assesses alternative engineering options in terms of benefits and costs, operation and maintenance, compatibility with the available land and water resources, their impact on the environment, the health of the users and the social life and welfare of the irrigators. Finally, market potentials and access to markets are critically reviewed through such studies and the financial and economic aspects of the development are evaluated. In summary, the feasibility study is expected to provide options for the client with recommendations for the best option combining technical feasibility, financial and economical viability and social desirability and environmental sustainability.

For irrigation projects, the feasibility study is expected to cover the following areas:

1. Climate and natural resources
2. Agriculture
3. Credit and marketing
4. Engineering aspects of the project
5. Social aspects of the project
6. Organization and management aspects of the project
7. Health and environmental aspects of the project
8. Economic and financial analysis

In the previous chapters the multifaceted process of irrigation development has been discussed. This chapter briefly outlines the presentation of this process thought the elaboration of a feasibility study.

6.1. Climate and natural resourses

As a rule, climate and the assessment of the potential and availability of natural resources (land and water) are among the first areas to be addressed in the preparation of a feasibility study.

6.1.1. Climate

The most important climatic data are rainfall, maximum and minimum temperatures, maximum and minimum relative humidity, wind and sunshine hours.

Climate is an important factor in crop production. Different crops have different requirements in terms of temperature, humidity and light. Also, occurrence of frost at certain times may exclude a number of crops from the cropping programme. All in all, the analysis of climatic data with respect to crop production is needed before a cropping programme can be prepared.

Accurate estimates of crop water requirements also rely heavily on the availability of accurate meteorological data. Errors of only 20% in crop water requirement estimates can significantly affect the economics of the project, especially in Africa where the water development cost is high. Hence the need for long-term accurate meteorological data, especially long-term rainfall data.

6.1.2. Land

The topography of the land when combined with the soil characteristics will provide the means of assessing the irrigability of the land and select the most suitable areas for irrigation. In this respect, soil and topographic surveys, discussed in detail in Modules 2, provide the means for this assessment.

6.1.3. Water

Long-term data of river flow and water quality are needed to assess the potential of the water resources. In the absence of hydrological data, rainfall records or flows of nearby streams are used for estimates. In the case of groundwater resources, hydrogeological studies are carried out and records from existing wells and test wells are used to establish long-term and short-term yields of the aquifer (Module 2).

Nevertheless, irrespectively of water availability, the right to using the water should be investigated. This is becoming very important with the establishment of water boards, water strategies and policies as well as water legislation in many countries in Africa. Hence, a water right should be obtained from the relevant authorities that permits the use of the water. Since the use of transboundary water resources is bound by agreements between the states sharing the same river basin as well as international law, the feasibility study should deal with such matters as and when they arise.

Wherever a new scheme is planned, existing established demands for water upstream and downstream should be investigated and taken into consideration. A formal system of water rights might be in operation, or local people may have an agreement by traditional custom over the way in which water for irrigation is allocated. Proposed changes in water demand must be fully discussed with the national authority responsible for regulating abstraction (Field and Collier, 1998).

Water quality and flow rates are very important for the selection of crops to be grown and the irrigation method to be adopted. As such they should be included in the water resources surveys to be undertaken. Of particular importance is the potential siltation of water reservoirs and the need to protect the catchment areas, in order to avoid the rapid decline in the yield of dams.

6.2. Agriculture

As irrigation development aims at agricultural production the engineering works should be designed for this purpose. The objective is not the conveyance of water but the irrigation of crops. Thus the engineering approaches used should be considered as part of a broader system (irrigated crop production) for which the designed scheme will be constructed to serve.

6.2.1. Existing farm practices

The existing agricultural practices are assessed to analyze the without-project situation. Data is gathered from the baseline socio-economic survey. The data is aggregated to reflect the average production cost and gross margins and incorporated in the financial and economic analysis. The same surveys will provide information on the availability of family labour for use under rainfed farming and irrigation in the future, and assess the need for hired labour.

6.2.2. Land tenure

The land tenure for smallholders varies from country to country in Sub-Saharan Africa. In some countries smallholders have the right to use the land, while in others smallholders have title deeds of their land. How one or the other type of land tenure affects the various aspects of the project should be elaborated in the feasibility study.

6.2.3. Proposed agricultural system

Based on the climate and the natural resources potential, crops are selected for consideration and alternative cropping programmes and rotations are developed for discussion with the smallholders. The cultural requirements of each crop and expected yields should be elaborated and the crop water requirements estimated for alternative cropping programmes. Crop budgets for these crops will be prepared and presented later on in the feasibility study, under financial and economic analysis. The marketing potentials of these crops will also be discussed under the relevant chapter of the study.

6.3. Credit and marketing

As a rule, irrigated crop production is a high-input high-output system. Smallholders therefore need to procure seeds, fertilizers and chemicals in order to optimize their production system. However, the poor cash flow from conventional rainfed farming is too low for such an investment. Consequently, the need for credit is great indeed. It is therefore necessary that the study reviews potential options and makes recommendations under the prevailing land tenure in the scheme.

The choice of crops to be grown and the cropping patterns influence the field layout and irrigation method. However, the choice of crops as well as the cropping programmes are influenced by their marketing potentials. Therefore, an assessment of the existing markets and transport system and road infrastructure, as well as their potential for development, should be made. Market prices, transport costs and farm prices must be predicted, as related to the expected increased volume of production. Processing and/or storage facilities should be considered as part of a marketing strategy.

6.4. Engineering aspects

This part of the feasibility study covers the rehabilitation and/or extension of existing irrigation schemes, as well as the development of new schemes. It deals with the water development, the distribution system, the water storage and control structures and measuring devices, the on-farm irrigation works and the drainage. For these and other engineering works preliminary designs are made and cost estimates prepared.

The same chapter of the feasibility study discusses water duties as relate to the water availability, the selection of the on-farm irrigation system and drainage requirements. Engineering aspects are covered in detail in Modules 7, 8 and 9.

6.5. Social aspects

The project's objectives and expectations can not be realized unless farmers' considerations on benefits and costs, feasibility and desirability and their priorities in life match that which the project requires of them. At times, smallholders' priorities differ from the project's priorities. Hence the need to assess the acceptability and desirability of the farmers to participate in the development of the irrigation scheme. The nature of the population must be understood in order to match the rate of development with the absorptive capacity. Elements such as the level of literacy, farming knowledge and skills, past experience with irrigation, gender issues and attitudes to change are among the several parameters to be considered when analyzing the social aspects of the project.

As a rule, irrigation development brings cultural shock to a smallholder community. With monomodal rainfall conditions, smallholders work for a few months in a year under rainfed conditions. In a sense they are under-employed and have ample time to attend to their social aspects of the society. In contrast to this, irrigated crop production requires almost daily attention throughout the year if it is to be profitable. How able the community is to adjust to these and other changes becomes critically important and should be thoroughly discussed with the farmers.

6.6. Organization and management aspects of the project

An analysis of the structures and competence of the agencies or bodies responsible for the organization and management of the project is necessary. A number of problems or difficulties should be expected to arise during the planning, construction and operation of a fairly large project. Hence the need for the presence or establishment of competent agencies to manage the planning and implementation of the project.

6.6.1. The organization of planning and construction

The planning and construction of a smallholder irrigation scheme involves several stakeholders. Rural authorities, traditional leaders, farmers, relevant Department or Ministry at central level, consultants and contractors are the major stakeholders. At times, sub-contractors are also involved with the construction of some parts of the project. Hence the need for a competent agency to coordinate and supervise the work of all involved in the planning and implementation of the project. The same agency, through established procedures, would be responsible for the selection of the contractor and sub-contractors. As a rule, selection of inexperienced contractors on the basis of a cheaper offer does not always cost less. Delays from one contractor can have snowball effect on other contractors, and the on project as a whole.

6.6.2. The organization of operation, maintenance and management

Irrigation development, especially in sub-Saharan Africa, is very costly. It is therefore necessary for this investment to be utilized productively as soon as possible. Thus, provision should be made from the feasibility study stage onwards for the needed trained engineers, agronomists and technicians to be available on time. Equally important is the assessment of the farmers' training needs, which will enable them to make well-informed decisions and to undertake the operation, maintenance and management of the infield part of the system.

6.6.3. Extension services

The training of farmers and the adoption of new farming practices is the mandate of the country's extension services. However, most extension agents in sub-Saharan Africa are not familiar with irrigated crop production. Hence the need to assess the level of extension know-how and provide for the training needs of the extension staff. While the success of achieving the desirable results will greatly depend on the adaptability of farmers, no effort should be spared in developing and implementing the appropriate training for the smallholders. Establishment of on-farm research, demonstrations, farmers' field schools and the provision of advisory services with back up from specialists are some of the means to be considered.

6.7. Health and environmental impact assessment

Very often the health and environmental aspects of irrigation development are not given deserved attention in the feasibility studies. Water-related diseases affect the health of the irrigators and thus the overall performance of the scheme. Measures to reduce such problems through engineering and other solutions should be incorporated in the feasibility study. The impact of irrigation development on the environment is equally important, as it affects the quality of the water resources and thus downstream water users as well as the ecosystem at large. For details the reader is referred to Chapter 4.

6.8. Economic and financial analysis

Economic and financial analyses are carried out in order to appraise a project. The economic analysis provides the justification for an irrigation development. The financial analysis evaluates the project's capability to repay the investment and the operation costs of the project. In other words, the economic analysis assesses the economic viability of different alternatives and assists with the selection of one. The financial analysis evaluates different financial alternatives with respect to interest rates, repayment schedules and length of the loan period. For more details the reader is referred to Module 11.

6.9. Presentation of the feasibility study

Following is an outline of the content of a feasibility study for smallholder irrigation development:

Chapter 1 : Summary

Chapter 2 : Background

Chapter 3 : Location

Chapter 4 : Land resources

Chapter 5 : Water resources

Chapter 6 : Climate

Chapter 7 : Agriculture

Chapter 8 : Irrigation

Chapter 9 : Social environment

Chapter 10 : Credit and marketing

Chapter 11 : Engineering requirements

Chapter 12 : Health and environmental impact analysis

Chapter 13 : Organization, maintenance and management

Chapter 14 : Capital cost

Chapter 15 : Operation and maintenance cost

Chapter 16 : Economic and financial analysis

Chapter 18 : Conclusions and recommendations

References

Chancellor, F.M. and Hide, J.M. 1996. *Smallholder irrigation: Ways forward. Guidelines for achieving appropriate scheme design*. Volume 1: Guidelines. 91 p. Volume 2: Case studies. 92 p. Draft Report OD 136. HR. Wallingford. Volume 1. 91 p.

Chimbari, M., Chandiwana, S.K., Ndlela, B., Ndhlovu, P.D., Chitsiko, R.J., Thomson, A.J. and Bolton, P. 1993. *Schistosomiasis control measures for small irrigation schemes in Zimbabwe*. Final report on monitoring at Mushandike irrigation scheme. Report OD 128. HR Wallingford. 82 p. + appendices.

FAO. 1982. Mechanized sprinkler irrigation. *FAO Irrigation and Drainage Paper No. 35*. By L. Rolland. Rome. Italy. 409 p.

FAO, 1985. Irrigation methods. *Irrigation water management training manual No. 5*. By C. Brouwer, K. Prins, M. Kay and M. Heibloem. Rome, Italy.

FAO. 1989. Guidelines for designing and evaluating surface irrigation systems. *FAO Irrigation and Drainage Paper No. 45*. By W.R. Walker. Rome. Italy. 137 p.

FAO. 1991. *Water harvesting: a manual for the design and construction of water harvesting schemes for plant production*. By Will Critchley and Klaus Siegert. Rome, Italy. 133 p.

FAO. 1992. Crop water requirements. *FAO Irrigation and Drainage Paper No. 24*. By J. Doorenbos and W.O. Pruitt. Rome. Italy. 144 p.

FAO. 1995. Environmental impact assessment of irrigation and drainage projects. *FAO Irrigation and Drainage Paper No. 53*. By T.C. Dougherty and A.W. Hall. Rome, Italy. 75 p.

FAO. 1996. *Development of a national watershed management programme*. Prepared by T. Marghescu. Rome, Italy.

FAO. 1997a. *Assessment of the socio-economic impact of irrigation development on smallholder farmers: Case studies of Hama-Mavhaire, Hoyuyu 5 and Nyadire irrigation schemes*. Prepared by Rabson Dhlodhlo. FAO-SAFR. Harare, Zimbabwe. 28 p.

FAO. 1997b. Small-scale irrigation for arid zones: principles and options. *FAO Development Series No. 2*. Rome. Italy.

FAO. 1998. *Socio-Economic And Gender Analysis Programme (SEAGA): Sector Guide Irrigation*. Prepared by: Eva Jordans. Rome, Italy. This document is also available in FAO Land and Water Digital Media Series No. 12: Irrigation Guidelines. http://www.fao.org/ag/agl/

FAO. 1999. *Comparative assessment of the malaria and schistosomiasis risks associated with surface and sprinkler irrigation schemes in Zimbabwe*. (in preparation)

FAO. 2000. *Socio-economic impact of smallholder irrigation in Zimbabwe. Case studies of ten irrigation schemes*. FAO-SAFR. Harare, Zimbabwe. 142 p.

FAO. 2001. *Participatory Training & Extension in Farmers' Water Management (PT&E-FWM)*. FAO Land and Water Digital Media Series No. 14. http://www.fao.org/ag/agl/aglw/farmerwatertraining

FAO. 2002. *Wetland development and management in SADC countries*. Proceedings of a sub-regional workshop, 19-23 November 2001, Harare, Zimbabwe. Editors: Karen Frenken and Isiah Mharapara. FAO-SAFR, Harare. 190 p.

Farmelectric Handbook. *Pumping and Irrigation: A guide to the design of simple pumping systems*. Warwickshire. 61 p.

Field, W.P. and Collier, F.W. undated. *Guidelines for water management and irrigation development*. HR. Wallingford, Institute of Hydrology. FAO/DFID/ICID. 169 p.

Field, W.P. and Collier, F.W. 1998. *Checklist to assist preparation of small-scale irrigation projects in sub-Saharan Africa*. ICID, HR Wallingford, DFID, FAO. This document is also available in FAO Land and Water Digital Media Series No. 12: Irrigation Guidelines. http://www.fao.org/ag/agl/

ILRI. 1994. *Health and irrigation; incorporation of disease-control measures in irrigation, a multi-faceted task in design, construction, operation*. By Oomen, J.M.V., de Wolf, J. and Jobin, W.R. ILRI Publication 45. Volume 1. Netherlands. 304 p.

Kay, M. 1986. *Surface irrigation: systems and practice*. Bedford. 141 p.

Keller, J. and Bliesner, R. 1990. *Sprinkle and trickle irrigation*. Chapman and Hall, New York. 739 p.

Rain Bird International. 1980. *Design manual drip irrigation systems*.

Rockstrom, J. 1996. *Green water security for the food makers of tomorrow: windows of opportunity in drought prone savannas*. RELMA.

Savva, A. 1998. *Study assesses socio-economic impact of Hama Mavhaire – largest of three FAO developed schemes*. A paper in Farming World Magazine, February 1998. Harare. 2 p.

Thomson, A.J., Chimbari, M., Chandiwana, S.K., Ndlela, B. and Chitsiko, R.J. 1996. *Control of schistosomiasis: a practical guide for irrigation development*. Report OD/TN 78. HR Wallingford. 37 p.

University of Zimbabwe. 1995. *Management of weeds in irrigation and drainage workshop, 8-9 March 1995*. Research project by Water, Engineering and Development Centre (WEDC), Loughborough University of Technology and Agricultural and Rural Development Association (ARDA). Harare.