DFID Department For International Development

Smallholder Irrigation: Ways Forward

Guidelines for achieving appropriate scheme design

Volume 1: Guidelines

F M Chancellor
J M Hide

TDR Project R5830
Report OD 136
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Contract

This report summarises work carried out by the Overseas Development Unit (ODU) of HR Wallingford in collaboration with:

- Irrigation and Drainage Branch of the Ministry of Agriculture, Livestock Development and Marketing (IDB), Government of Kenya
- Water Research Centre of the Ministry of Public Works and Water Resources (WRC), Cairo, Egypt
- AGRITEX of the Ministry of Agriculture, Harare, Zimbabwe

The work was carried out for the Department for International Development (DFID) formerly the Overseas Development Administration (ODA) of the British Government. The Technology Development and Research No. and project details are as below:

Theme	Improve availability of water for sustainable food production and rural development
Theme No.	W 5
Project	Minor Irrigation Design
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Prepared by .... *(name)* .... Socio-economist *(Title)*

Approved by ....

Date 5/8/97

Summary

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Programmes of small irrigation scheme development have become popular with governments and funding agencies. By comparison with large projects, small schemes potentially involve lower total capital investment; less time for project development and implementation; less complex design. They provide the opportunity for participatory development and for orderly devolution to farmers of costs and responsibilities for operation and maintenance. However, many development initiatives have been unsustainable over the long term.

Very little practical material has been published to help designers of small schemes with the technical and social issues which affect design and the long-term sustainability of projects. To meet the need, the Overseas Development Unit of HR Wallingford undertook a collaborative programme quantifying small scheme technical and socio-economic performance, with the support of the UK's former Overseas Development Administration (ODA) - now the Department of International Development (DFID). Thirteen small schemes in Africa were investigated jointly with the irrigation ministries of Zimbabwe, Kenya and Egypt, under DFID's Technology Development and Research (TDR) programme.

The Guidelines are a principal output of the work. They are primarily intended to assist designers in Africa, probably based at provincial government level, who are responsible for identifying, detailing and implementing small, surface irrigation developments based on rivers and springs. Groundwater development is not included. The Guidelines complement the MIDAS software for small scheme design, also developed under the research programme and described elsewhere (HR Wallingford, 1994). Design is included amongst the issues dealt with, but detailed aspects of design are not covered, as they may be found in many existing references. The bibliography includes a selection of design texts along with other references.

The Guidelines are entitled "Smallholder Irrigation: Ways Forward" to correspond with the topic of a workshop in Nairobi in October 1996, organized on behalf of the Kenyan Government with funding from the Dutch and UK Governments, and attended by representatives from many sub-Saharan countries. They consist of two volumes:

Volume 1 Guidelines
Volume 2 Summary of Case Studies

Volume 1 is a structured guide for identifying and dealing with technical and non-technical issues which can affect the viability and sustainability of small scale irrigation developments. The document deals with essential issues including : scheme identification; establishing the adequacy of the available resources; identifying beneficiaries; promoting consultative processes between farmers and irrigation staff; identifying and implementing appropriate designs ; anticipating and planning for scheme operation and maintenance.

Summary *continued*

Volume 2 summarizes the results of the field studies. Thirteen schemes, mostly growing both cash and staple crops, were investigated, including 10 projects in Kenya, 2 in Zimbabwe and 1 in Egypt. Schemes varied in size between 50 and 500 ha. Five were managed by an irrigation agency, and the others by farmers.

Of the farmer-managed schemes, 5 were found to be technically sustainable, financially and economically viable, as planned. On the remaining three schemes, which were strongly affected by problems including shortage of water at source, it appeared that farmers would continue to irrigate a reduced area, although the systems were long past their design lifetime and in poor condition. On the better schemes, farmers were successfully selling fresh vegetables to the European market via intermediaries. On a few long-established schemes, farmers' incomes did not fully cover the true economic costs, yet they continued to farm, presumably because agriculture was their traditional livelihood and alternative occupations were not available.

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1 Introduction

1.1 Background

Irrigated agriculture must provide a substantial part of the increase in world food production needed to feed a population rising until well into the next century. In many African countries, irrigation plays a vital role in:

- Providing security against drought
- Allowing year-round cropping
- Increasing grain yields by three to four times compared with rain-fed production
- Promoting development in areas where rain-fed potential is poor
- Generating income from cash crops for small farmers

Large irrigation schemes in the developing world have often failed to fulfil the targets set by planners and designers. Funding agencies and governments have been attracted to small scheme developments by the prospects for lower total capital investment, a shorter development lead time, devolution of costs and responsibilities for operation and maintenance to farmers, and less complex design in comparison with large schemes. However, there is concern that many development initiatives have been unsustainable over the long term.

Many small scheme development programmes have been supported by the international funding agencies, by governments and by NGOs. However, there is little published information on small scheme design and performance which is directed at designers, to identify the determinants of success and failure, and evaluate design options. Design manuals prepared under internationally-funded programmes tend to be specific to countries and generally make little reference to socio-economic issues. In practice, it is unrealistic to expect that an engineer can devote much time to detailed socio-economic investigations of small schemes. The Guidelines are intended to identify principal socio-economic issues, and ways of improving the implementation process, so that designers fully understand the background to a development and can commission necessary further work and investigations, as appropriate.

There are both positive and negative aspects to small scale developments. Under favourable social, technical and economic circumstances, small schemes function effectively, yielding a reasonable income for farmers, contributing to nations' needs for increased food production and helping to stabilize rural populations. However, small schemes can also suffer all the problems in operations, maintenance, and management, which are experienced on larger schemes.

Issues particular to small schemes are:

Ownership. Irrigation is a co-operative activity involving many individuals, with considerable potential for conflict. Small schemes potentially encourage a sense of ownership by their members. Under such circumstances, co-operation between scheme members is likely to be good. However, disputes between farmers on small schemes can sometimes seriously disrupt the functioning of the entire distribution system. On large schemes, the management agency controlling the main distribution system will normally mediate to reduce conflict. If the farmers' groups on small schemes are weak, the performance of the whole scheme can suffer.

Participatory Design. The limited scale of small schemes potentially allows designers to gain a good understanding of entire projects, to agree proposals and necessary actions with farmers. However, government designers of small schemes may lack experience to make the most of the opportunity because the more skilled staff are attracted away by better terms and conditions in the private sector. The financial resources available to design individual small schemes are also limited. Suitably-designed schemes will include small irrigation blocks and a few, simple, structures so as to limit the number of individuals who must co-operate, and to simplify operation and maintenance. Groups consisting of no more than 15 –20 individuals are recommended in the Guidelines.

Location. Small schemes are often located away from centres of population. Isolation can help promote a sense of community and stability within the scheme. However, there are accompanying disadvantages. Goods and services, particularly crop inputs, are likely to be less readily available and more expensive. Lengthy transportation over poor roads can limit farmers' ability to exploit favourable markets, reduce the quality of their produce, and make it less competitive. Government extension workers may visit rarely, if at all, so farmers may lack essential assistance in agriculture practices, scheme operation, and maintenance.

1.2 Scope of Guidelines

The present Guidelines have been based in the main on investigative field work carried out in sub-Saharan Africa, also on one study in Egypt. The work was carried out in collaboration with the Governments of Zimbabwe, Kenya and Egypt under the former ODA's Technology Development and Research Programme (TDR), now managed by the Department for International Development (DFID). Particularly close liaison was maintained with the Smallholder Irrigation Development Project (SIDP) of the Kenyan Ministry of Agriculture, supported by the Dutch Government, throughout the work in Kenya. The detailed findings of the investigations are supplemented by published information on small schemes throughout the world.

Design practices tend to vary around the world, depending upon tradition and local circumstances. The Guidelines, which are based principally on experience in Africa, therefore cannot be general in all respects. However, there are important issues affecting scheme performance and sustainability, connected with project identification, development, management, and maintenance, which are quite generally not given detailed attention by designers. The field studies confirmed that accurate assessment of resources and good engineering are basic to the success of schemes, but also that social, economic and financial issues may determine long-term performance. These issues are covered in some detail in the document, which is primarily aimed at designers of small irrigation schemes in Africa, who will probably be government employees based at provincial level. The Guidelines deal with schemes drawing their water from surface sources, primarily gravity irrigation schemes, though experience was also drawn from two sprinkler systems, one of which was served by a pumped supply, and also from a pumped low pressure pipe distribution system. Groundwater developments are not included within the scope of work.

The present **Volume 1** of 2

- Emphasizes issues which must be investigated and appropriately addressed in progressing from identification of small schemes through to detailed design.
- Assists by identifying ways of acquiring background information basic to the scheme development process.
- Provides guidance on appropriate design.
- Recommends procedures for gaining participation of farmers, both male and female, throughout the scheme development process and, subsequently in operation and maintenance.

After the Introduction, Section 2 of this volume provides background to the issues involved in scheme identification, in studies for feasibility, and in project development and design. The consultative processes for scheme development which have been adopted under the Smallholder Irrigation Development Project (SIDP) of the Ministry of Agriculture, Kenya, supported by the Dutch Government, are presented as a working model. The resulting covenants between farmers and the irrigation agency, which set out the responsibilities of each party, are included in summary form.

Section 3 prompts the designer to ensure that there are adequate resources for a proposed development. The term resources is taken to include water, land, labour, infrastructure and capital. Methods for acquiring the necessary information for pre-feasibility and feasibility studies are presented.

Section 4 requires designers to confirm the development potential identified in the pre-feasibility stage. Scheme promoters must ensure that prevailing economic and social conditions favour the proposed project.

Section 5 concentrates on factors which must be correct for long-term success of the project. Designers must take realistic account of the way the scheme is to be managed and maintained over the long-term and allow for possible changes in assumed cropping pattern. Suitable designs take account of farmers' expressed preferences, available skills and resources.

Technical and institutional aspects to be addressed during preliminary and detailed design, are identified. Necessary elements of design are set out, but detailed designs are not included. Instead, leading design texts are listed in the bibliography, along with other references.

Section 6 includes overall conclusions and recommendations. Principal findings are also summarized at the end of each section.

Volume 2 summarizes the results of thirteen collaborative field studies of small scheme performance. Ten schemes were investigated together with the Irrigation and Drainage Board (IDB), Ministry of Agriculture, Kenya; two, with AGRITEX in Zimbabwe; and a single scheme with the Water Research Centre (WRC) in Egypt. The studies in Zimbabwe and Egypt extended over periods of three years. Those in Kenya lasted a full calendar year, and were phased to take account of climate and cropping.

A number of more detailed reports giving the results of socio-economic and hydraulic performance studies on individual schemes, were produced during the course of the work. They are listed in the bibliography.

Section 2 contains a brief summary of the methodologies used in the investigations.

Section 3 is devoted to brief accounts of the characteristics and performance of individual schemes.

Section 4 compares the performances of schemes, which are categorized according to physical and socio-economic parameters. Most of the schemes involve surface irrigation, in furrows, basins, ridged basins or border strips. One project employs locally-made sprinklers, one depends on gravity irrigation from a low pressure pipeline, and one includes sprinklers introduced by tail-end farmers on a surface system. Water supply parameters, including adequacy, efficiency, equity, and timeliness, are given for each scheme. Schemes are ranked in terms of the averaged net income per hectare.

There were many common elements in the situations and performances of schemes:

- Almost all schemes suffered recurrent water shortages. Catchment planning appears essential in many countries where the exploitation of water resources for new developments, whether for irrigation or other purposes, increasingly jeopardizes the viability of existing projects.
- Farmers appeared skilled at matching the irrigated area to available supply. Their crop choice and income generally reflected the relative security of the water supply. They frequently possessed both small irrigated plots and dryland holdings. Yields tended to be below national averages.
- The engineer has an essential role to play in ensuring that land and water are available for development, that design is correct and suited to small scale irrigation, and that schemes are financially and economically viable. However, given such conditions, many of the constraints on performance are not primarily technical in nature. A holistic approach to the design process is therefore essential.
- The wide variation in financial performance between schemes was determined primarily by the skills and experience of farmers, by market opportunities, and by availability of labour, rather than by the water supply, which was generally less than theoretically needed but not very seriously short. The overall economic returns would reflect the extent to which the full designed command area was successfully irrigated. Within any single scheme financial performance was strongly influenced by the adequacy of the water supply which showed the normal, strong correlation with location relative to the head of the scheme.

- At times when the supply was sufficient for the cropped area, overall efficiency on farmer-managed schemes was 40-45%, comparable with the performance of small, centrally-managed schemes which carry heavy management overheads. By contrast, large schemes may operate at 30-40% efficiency, or less.
- Locally-made, gravity-powered sprinkler systems introduced by farmers were associated with substantially better water–use than surface methods, though performance was not up to the standards of proprietary equipment on commercial farms. The sprinklers are robust, cheap and easily maintained.
- System maintenance was frequently not well carried out on the farmer-managed schemes. Shortage of labour for maintenance tasks delayed irrigations and reduced output. No charges for water were made on these schemes. Despite severe constraints on funding, the centrally-managed schemes were better maintained. The finding needs to be set in a context of government policies aimed at devolving responsibilities for O&M to farmers.
- Medium-term success and long-term sustainability can be improved if farming communities are involved in project identification and planning. Under procedures in place in Zimbabwe and Kenya, farmers are encouraged to approach government for assistance with proposals for scheme development. Governments may then act either as executive or enabling agencies. It is essential that farmers take a meaningful stake in the project, preferably by investing cash, but also labour. Formal contracts define the responsibilities of the parties.

2 The Development Process

2.1 General

The Guidelines are intended to assist the engineer through the various stages of project development from identification through to detailed design. Development has been assumed to include both a pre-feasibility stage, at which proposals are screened for suitability and compared on the basis of outline estimates of economic and technical viability, and a feasibility stage when estimates are refined on the basis of semi-detailed planning.

In practice, small scheme developments are not likely to justify studies of the type and scale of those conventionally carried out by consultants for large irrigation projects. In the first place, much greater emphasis needs to be placed on socio-economic aspects of proposed developments, for which purpose the active participation in the studies of intended beneficiaries is essential.

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

Figure 2.1 shows the stages in project identification and development.

Stage	**Alternative Outcomes**
• Identification	
• Pre-Feasibility	Proceed to feasibility stage/stop
• Feasibility	Proceed to design stage/stop
• Detailed design	Proceed to implementation
• Implementation	

Table 2.1 sets out principal activities at each stage of the cycle, the type of information which will be needed by the designer at different stages, and the purpose of acquiring it. The final column in the table directs the user to the relevant section of the Guidelines.

Section 2.2 describes procedures to formalize the investigative process, including a checklist for schemes in sub-Saharan Africa recently developed for the International Commission on Irrigation and Drainage (ICID). Appendix 1 includes a table linking the topics in the present Guidelines to the appropriate section in the ICID checklist.

Many of the basic decisions involved in scheme development are affected not only by the physical and socio-economic parameters characteristic of the area, but also by other design/development choices. Figure 2.2 is intended to help the designer identify linkages so that appropriate choices, taking account of the various influencing factors, are made at each stage of a development.

Major items which will require decisions from the scheme developer are shown across the top of Figure 2.2. Issues which will affect the choice are shown down the side of the figure. For example, the choice of crop is fundamental to the viability of a proposed scheme. In the pre-feasibility stage the designer must identify and investigate those issues affecting the choice, in order to decide whether the crop(s) proposed by farmers is/are likely to be technically and economically feasible. Sufficient water must obviously be available. Other factors, ranging from the quality of the water to the skills and knowledge of the farmer, are also involved, as indicated in the figure.

The lower part of the diagram shows so-called ’cross-linkages’. For example, the choice of application method (upper part of the figure) is influenced not only by the ’given’ issues but also by other development/design choices, namely the crop and distribution method.

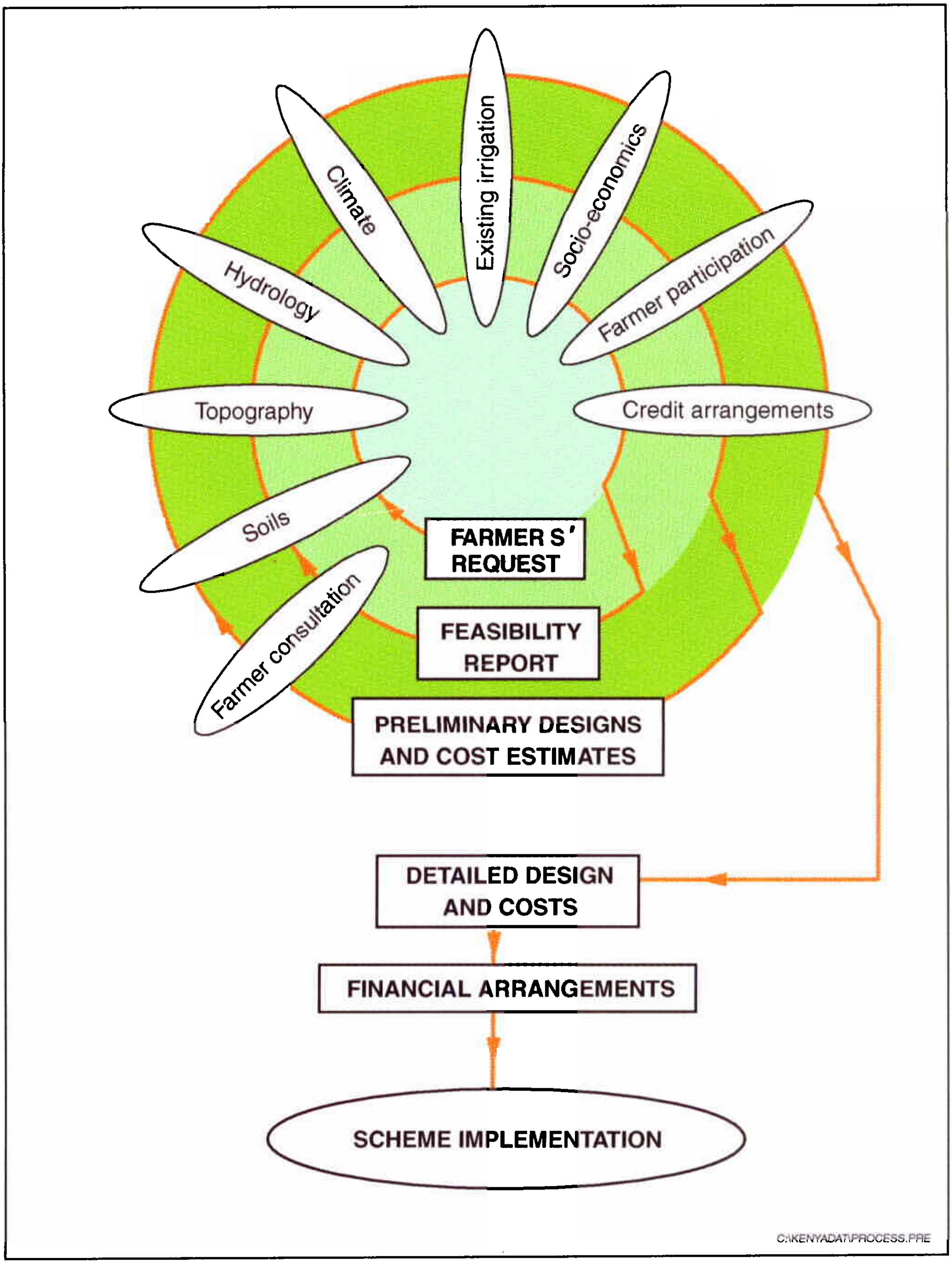

Figure 2.1 **Process of scheme development. (After IDB, Kenya)**

● Strong influence
○ Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Water source		●							
Water availability	●		○	○	●				
Water quality	●								
Sediment		●	○			○	●		○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

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Figure 2.2 Linkages between resources/issues and development choices

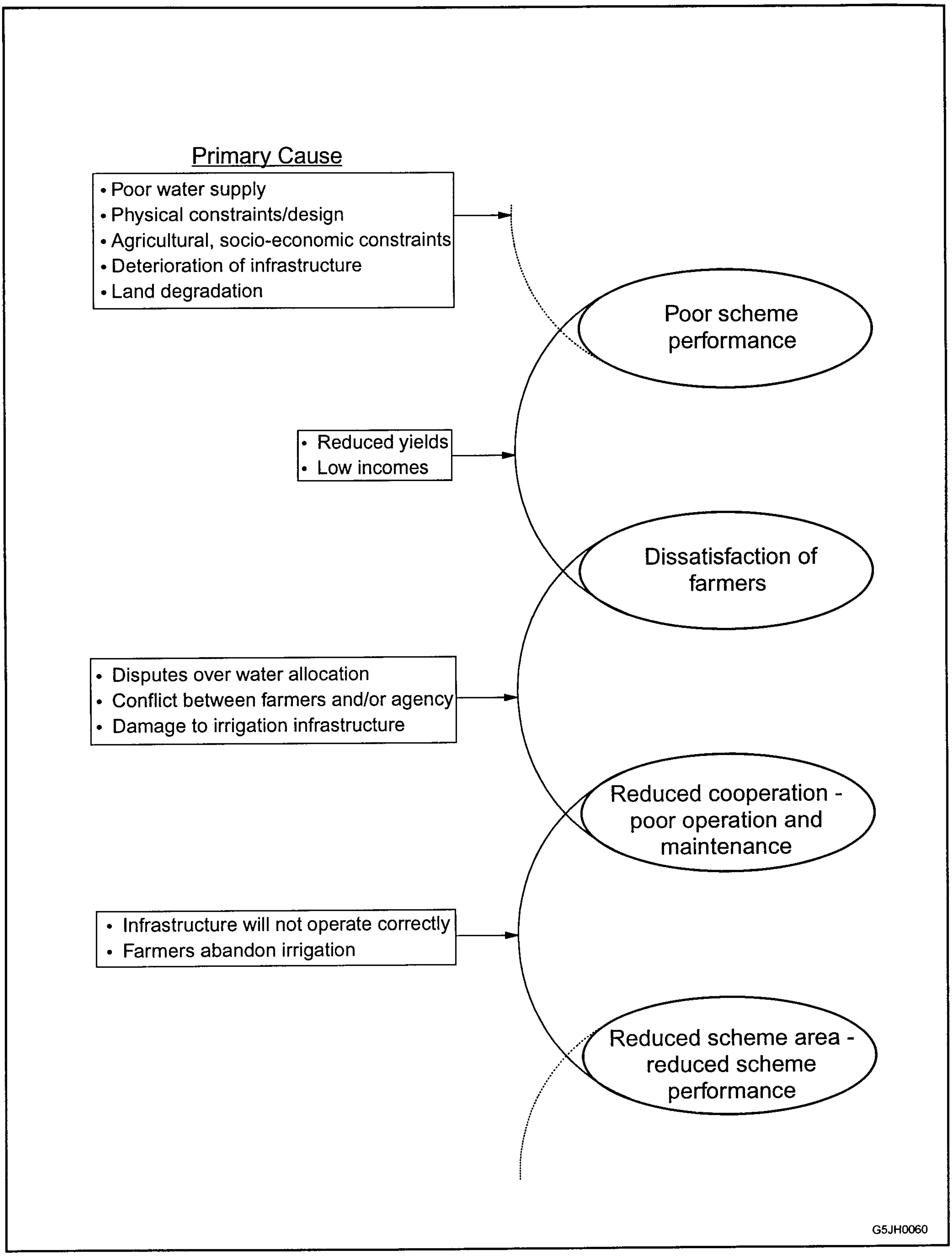

Figure 2.3 The "downward spiral" of scheme performance causes and effects (after IDB, Kenya)

Table 2.1 Project development stages and activities for smallholder irrigation

Project stage	Main activities	Purpose	Section
Project identification	• perceived need by farmers • farmers' request for assistance	– ensure development is demand driven	2
Pre-feasibility	• initial field visit • collect existing physical and socio-economic data • stakeholder analysis • first appraisal	– first-hand assessment of irrigation potential – identify farmers' objectives, requirements and capabilities – provide background for informed decisions – identify stakeholders, determine their roles and interests, highlight potential conflicts and strengths – use existing data and findings to indicate preliminary feasibility	– 2.1, 3 2.3 –
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' organisation • prepare project feasibility report including economics	– ensure adequate resources to meet farmers' objectives – ensure resources available for proposed development – determine farm budgets, organisation, needs for assistance – provide basis for discussion with farmers – provide opportunities to modify design or withdraw request – provide basis for loans, management, O&M – enable comparison of projects competing for funding	3.1, 3.2 3.3 – 3.5 4.1 – 4.4 5.1 2.4 5.12 4.2.3, 4.3
Priority ranking	• rank irrigation projects in district/region • select project(s) with highest potential	– selection of potentially sustainable investments – identify best returns to farmers and nation	2.2.2 4.2.3, 4.3
Conditional approval	• approval by irrigation professionals and district officials	– ensure quality of design	2.2.3
Detailed design	• review O&M capability and needs • final data assessed and final farmer choices • detailed design, quantities and contract documents prepared • funding arrangements organised • farmers' contributions clearly determined and agreed by contract	– match design with farmer capabilities – allow informed commitment of farmers – finalise details and costs – assure farmers of credit availability and cost – enable farmers to take responsibility for financial and practical commitment	Ch 5 Ch 5 3.4 2.4, 5.2
Final approval	• approval by all major stakeholders	– multi-directional responsibilities implemented	
Implementation (overseen by Ministry/funding agency/farmer committee)	• tenders received • contractor chosen and contracts agreed • farmer loan activated • farmer participation in canal construction • construction of structures and intake by contractor • training of farmers for cultivation, marketing and O&M • hand-over of scheme to farmers	– enable cost-effective choice – assure payment for work and materials – promote sense of ownership – ensure quality of major works – promote effective use of water, good yields and sustained activity – farmers assume responsibility	Ch 5
Monitoring	• regular review of progress • on-going training and extension	– ensure targets are achieved and sustained – encourage continued improvement	5.2, 5.3 3.5.4, 5.2

Section 3 deals in detail with the identification and quantification of available resources and with issues which influence design/development choices. Resources are taken to include water, land, labour, infrastructure and capital. Each section of the Guidelines commences with a matrix based on Figure 2.2 to highlight issues and the linkages between them.

The Guidelines promote a collaborative development process between designers and farmers which is already practised in the implementation of new farmer-managed schemes in Kenya and to some extent in Zimbabwe. Sections 2.3 and 2.4 describe the working of the process. Governments can no longer provide extensive support to small schemes, commitment from farmers is needed to ensure that developments are sustained. It is the responsibility of government to ensure that farmers are given a realistic understanding of the potential difficulties and drawbacks, as well as the benefits, to be derived from a proposed development. Farmers must produce proposals for the operation and maintenance of a scheme. Figure 2.3 illustrates how schemes can decline in a 'downward spiral' if continuing effort is not devoted to management and maintenance.

The preferred development process follows a proposal by farmers to the government irrigation agency for assistance in developing, or improving, a scheme. The government functions in the role of a technical enabling agency, providing the necessary skills and know-how to ensure that feasible proposals become well-functioning schemes. Farmers are expected to take out credit under easy repayment terms and contribute to the work in kind during implementation.

In reality, it will take time for such a way of working to become established. Inexperienced farmers, or those who are not native to the area, may not have the necessary knowledge or understanding to formulate workable proposals. Government staff, under heavy pressure to resettle large numbers of persons, will probably have to adopt a promoting role in the initial stages of a programme, with the intention of later reducing their commitment. The basic principles outlined in the Guidelines should, nonetheless, be followed.

2.2 Procedural Tools

The necessary investigations, project review and selection processes can be formalized and simplified by adopting standardized methods and procedures such as:

- A checklist to structure field investigations, such as that prepared for ICID (section 2.2.1).
- A system of priority ranking, such as that used under the Smallholder Irrigation Development Project (SIDP) in Kenya (section 2.2.2), which can help select the order of project development from a number of possible alternatives.
- Design reviews. Designs produced in a number of provincial or regional offices in a single country will need to be standardized. The present document, supplemented by detailed design manuals, should help to produce designs of consistent quality. The need for a centralized design review panel, such as that established in Kenya, to review and approve designs (section 2.2.3), should be investigated.

2.2.1 Checklist to assist preparation of small-scale Irrigation projects in Africa

The ICID Checklist is intended to provide a rapid assessment of proposals to confirm (or otherwise) that there are no major constraints to development, and where necessary, allow alternatives to be formulated. It allows a structured investigation of schemes which are too small to justify full feasibility studies.

The checklist consists of four modules:

1. Project proposals. Checklist to define the principal features of a scheme as proposed.
2. Preparatory data collection sheets.
3. Field data collection sheets.
4. Summary, based on field data sheets, identifying possible constraints to the development, characterizing items in one of the following categories: 'major constraint'; 'marginal'; 'not a constraint' or 'not known'.

The items covered by the checklist include:

- Topographic data
- Previous investigations
- Other local irrigation schemes
- Environmental aspects
- Socio-economic aspects at village and community level
- Soils
- Climate
- Agriculture
- Water demands
- Hydrology
- Irrigation infrastructure
- Economic indicators
- Development, operation and maintenance aspects

The preparatory data sheets are intended to provide data for a field visit. By providing a logical framework for data analysis, it may become apparent that there are major constraints for the proposed development which accordingly should be halted at this point. Similar conclusions may be reached at the field data stage. The objective of the Checklist is to improve the likelihood of achieving sustainable development rather than to optimise development. Tried and tested rules of thumb have been used where appropriate instead of rigorous analysis, in order to make the document as simple as possible.

The general form of the Checklist may be adapted as an input to scored methods of ranking projects such as that used by the Kenyan Government (Section 2.2.2).

2.2.2 Ranking of proposed developments

Farmers will submit their outline proposals for projects to staff of regional or district offices. As the decision-makers may not be irrigation specialists, they may need assistance in judging whether to investigate further.

A formal "profile" of the proposal is likely to improve the process of project review. Proposals given the highest ranking receive priority. Under the system adopted in Kenya, which may serve as an example of good working practice, potential projects are assessed on the basis of twelve factors set out below. The factors are weighted according to their likely impact on project performance and sustainability. Guided subjective judgements still have to be made, but the potential for variability between individuals is reduced. Decisions either in favour of, or rejecting, a given development can be justified on a rational basis.

Factors marked in a range 0-12

- Strength of farmers' organization
- Land tenure
- Farmers' initiative
- Access to market

Factors marked in a range 0-9

- Potential for increasing gross margins
- Cost
- Chances of equitable water distribution

Factors marked in a range 0-6

- Availability of inputs
- Farmers' technical knowledge
- Cost of maintenance

Factors marked in a range 0-3

- Benefit to regional/national development

- Additional benefits, for example, agro-forestry

Each of the factors listed may depend on a number of variables. For example, access to market will depend both on the distance involved and the condition of the roads.

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

Category A	Water shortage expected once in five years only, or less frequently
Category B	Serious water shortage expected more frequently than once in five years
Category C	Reliability of supply not known. Further investigation required.

2.2.3 Panel assessment of developed proposals

Many smallholder schemes have failed because of technical and/or organizational shortcomings. All proposals developed by designers at provincial level are now reviewed before implementation by a panel of experienced engineers in Nairobi. The members of the panel are drawn from the irrigation agency and from academia.

The panel is charged with standardizing practice, reviewing the appropriateness of designs, determining and establishing technical quality. Schemes acceptable to the panel are cleared for construction.

The procedure helps to improve designs which may be produced by relatively inexperienced designers, and may constitute an appropriate model for other developing nations concerned to improve design standards.

2.3 Identifying Stakeholders

Stakeholders are defined as individuals, groups or organizations who have a vested interest in the project. They may be divided into groups as:

- **Key stakeholders** - those who significantly affect the outcome of a project. Women, who provide a large proportion of the agricultural work force, may be considered key stakeholders. Well-disposed landowners are also a key to success.

- **Primary stakeholders -** those who will be affected either positively or negatively by the project. Will include people displaced, or otherwise adversely affected, by the scheme.

- **Secondary stakeholders -** those who will have some involvement or impact on the project, such as marketing middlemen or extension service staff.

Stakeholders in a proposed project must be identified at the pre-feasibility stage. More details should be obtained during feasibility studies. The purpose is to provide a realistic assessment of all those involved in a project; their commitment, financial and otherwise to it; and the readiness of those directly concerned to accept responsibility for the continuing operation and maintenance of the scheme.

A preliminary list should be drawn up with assistance from farmers, administrators, and potential beneficiaries. During feasibility studies, stakeholders should be divided into sub-groups. For example, farmers might be categorized according to landholding size, family labour force, as landholders/tenants or by gender. The investigator will have to make a judgement as to the primary factor(s) which will affect stakeholders' response to the scheme.

The concerns and objectives of stakeholders need to be determined by meetings with sub-groups at feasibility stage. Discussion helps communities understand the implications of a development and indicates how participation will work at a later stage. The practical purposes of the meetings need to be clearly explained to participants. Interviewers should adopt an open-minded approach, avoiding value judgements insofar as possible. Groups may be encouraged to work round the objectives of other groups if they should conflict, rather than to change their own objectives. Aims may change during the course of discussions as a group's understanding of the issues develops.

Potential conflicts can be identified and addressed at an early stage, rather than when projects are underway or actually completed. Benefits will inevitably be unequally spread. Given general good will, relatively disadvantaged groups can be compensated. It is usually understood and accepted that responsibilities and contributions should be related to expected benefits.

Individual's influence on, and importance to, a project should be distinguished. For example, both farmers and agricultural suppliers may be considered stakeholders in a project. However, farmers are of basic importance to the project, whilst suppliers may have an influence on it. Cooperative action by farmers in purchasing fertilizer could make their business an attractive prospect to suppliers, who might not otherwise be interested.

The assumptions and risks for all stakeholding groups connected with a development must be systematically assessed. Strategies for dealing with the problems of individual groups need to be formulated. The results of the investigation should be analyzed to show the expected influence or importance of different stakeholders, and the outcome for them of different development strategies.

2.4 Participation of Farmers

It is frequently recommended that farmers' representatives be closely involved in the process of scheme development, but the mechanisms by which they are to be involved are rarely defined. The procedures introduced in Kenya, which are judged fairly successful, are summarized in the following section.

2.4.1 Responsibilities of agency and farmers

The responsibilities of agency and farmers need to be clearly defined. For example, the following list might summarise each party's responsibilities :

IRRIGATION DEPARTMENT	FARMERS
Field surveys and analyses	Organise loan
Design system	Donate land for canals and drains
Check and approve systems	Excavation work for canals and drains
Supervise of construction	Contribution to cost of structures and intakes
Extension	Operation and maintenance costs
Assistance to farmers' organisation	

A similar approach can be taken in defining steps in technical, economic and organisational matters. The procedure will help to ensure that both designers and farmers are aware of the progress of development, that opportunities for adapting design are recognised, and that a standard process can be adopted for all regions within a nation.

2.4.2 Development process: the irrigation agency

The following sequence lists in detail the process that has been developed in Kenya. Opportunities for *socio-political assessment at district level* are indicated *in italics* and those for professional assessment at national level are shown underlined.

Field visit
Field visit report
FARMERS REQUEST MEETING
Priority order in district profile
Proposal to investigate
Irrigation Department approves investigation
Technical and socio-economic investigations
Cost-benefit analysis
Farmers water permit request
Approval of water permit

Draft design and approval
Initial consultations
Priority order in district profile
Workshop consultations
Detailed design
Regional irrigation office approval
National Panel approval of proposal
Irrigation Department technical approval of design
Preliminary allocation of funding
Series of farmer meetings
AGREEMENT MEETING

Farmers contribution of money (deposit)
Tendering for construction
Evaluation of tenders
Selection of contractor
Excavation of canals and drains by farmers
Supervision of excavation
Supervision of contractor
HANDING OVER MEETING

Parallel to the above sequence, a series of steps to ensure that farmers are committed to achieving success through personal investment would include:

- Forming links with a loan agency
- Assessment of the proposed plans by the loan agency
- Establishment of groups to guarantee raising of deposits and subsequent loan repayment
- Signing a joint agreement to a clearly specified programme
- Group leaders participating in a training process to assist them in dealing with their members in servicing the loan.

2.4.3 Development process: farmers

It is clear from the process set out above that farmers' participation is basic to the system. The procedure to be followed by farmers is described below:

Three 'milestones' are defined:

- A written **REQUEST** by farmers for assistance
- An **AGREEMENT** signed by farmers and irrigation agency agreeing on the alignment of canals and drains and specifying the tasks of both parties
- **HANDOVER** of the scheme after construction

The operational steps below are the means to achieving the milestones:

Farmers’ enquiries
Leaders’ meeting
Farmers’ meeting
REQUEST MEETING

Meetings to discuss:
Design
Operation and maintenance
Effective water use
Cost-sharing
AGREEMENT MEETING

Progress meeting 1
Progress meeting 2
HANDING OVER MEETING

To ensure that meetings reflect the views of the whole community, some 70% of farmers must attend, half of them women.

The purposes of the meetings held prior to AGREEMENT are as follows:

- Design: approval of, or necessary changes to, canal and drain alignments pegged out in the field
- O &M: discussions on farmers’ roles in managing the scheme
- Water use: discussions to understand water sharing and allocation within groups
- Cost-sharing : organization and administration of farmers’ contributions (cash or kind)

It is recommended in Kenya that the Scheme Committee limit its role to the distribution of water, rather than include other issues such as cropping and farming activities generally. Individual farmers will make their choices on crops, land preparation, planting, harvesting and marketing. However, the Committee may need to intervene to enforce discipline. Farmers should be free to organize themselves on such other issues as they wish.

The intention is that, by committing labour, cash and land to the project, farmers will feel a vested interest in the success of the project. By participating, they should have an adequate understanding of the way the scheme should function and what is needed for successful operation and maintenance.

The introduction of participative procedures in Kenya initially caused a slow-down in small holder irrigation development, but in the long-term developments should be better- sustained and the rate of repayment of loans should be more satisfactory.

3 Identifying Resources

It is assumed in the following section that a potential scheme has been proposed and that stakeholders have been initially identified, on lines similar to those set out in Section 2.

Once there is a basis for believing that a development is possible, it is necessary to make a systematic assessment of available resources to establish that the most basic elements for success are in place. Initial assessments will need to be confirmed by more detailed analyses in the later stages of project identification and development. The following sections deal with the resources which are necessary for sustained output and the methods available for acquiring the necessary background information. Both farmers and professionals can contribute to the assessment process.

The extent of investigations at any stage of the development process must be planned and the activities balanced, see Table 2.1, to avoid a situation where detailed attention is given to one aspect, for example water supply, before it has been established that other aspects are favourable.

Water is fundamental to the success of any irrigated development. It is given particular weight in the scheme assessment and ranking processes used in the Kenyan smallholder irrigation programme. Nonetheless, it is just one of a number of factors affecting the performance of a scheme. Other physical, social and economic issues identified in Sections 3.2-3.5 can have a determining influence on the sustainability of a development. The following sections consider in turn :

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

Emphasis needs to be placed on each aspect before deciding whether the proposal warrants further investigation (Section 4).

3.1 Water

An adequate and reliable supply of water is fundamental to success. The diagram below, which is extracted from Figure 2.2, shows how all design/development decisions are affected by the water supply. The following sections refer to schemes supplied by natural rivers.

● Strong influence
O Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Water source		●							
Water availability	●		O	O	●				
Water quality	●								
Sediment		●	O			O	●		O
Climate	●		O	O					

The resources which can be assigned to investigations of the water supply will necessarily be limited by the scale of the development. Extensive analyses, conventionally used during studies for feasibility of large schemes, will not be possible owing to constraints imposed by a likely shortage of resources, and of basic hydrological data. The designer needs to make the best use of available information backed up by practical methodologies and sound judgement. For example, if small quantities of water are to be abstracted from a large river, only approximate calculations may be required. However, for small streams, greater precision is needed, especially where demand is high in relation to the mean flow rate. The following sections provide guidance on relevant techniques. Detailed information on the application of analytical methods should be obtained from relevant hydrological references (see bibliography).

3.1.1 Supply

River flows-General

The designer needs to determine whether a given supply is adequate by establishing the quantity of water which is reliably available (supply), and that which is required (demand). On run-of-river schemes, peak irrigation requirements, which can determine the scale of a development, commonly coincide with periods of low flow. Schemes will normally be designed to provide full crop water requirements each month in 4 years out of 5.

Estimates of flood flows are also required for the design of water-capture structures.

Information required for design:

- Magnitude and probability of low flows
- Magnitude and probability of flood flows

In most countries, the government ministry responsible for water resources will hold flow records at sites on larger rivers. Data may be in the form of daily readings and/or monthly averages with annual maxima and minima. Information on minor rivers is commonly not available. In such cases, other methods of acquiring the information must be adopted.

Many procedures are available to extend limited data sets. A summary is included below to help the design engineer commission appropriate hydrological studies at the feasibility stage.

For gauged sites:

Short period flow records (less than 10 years) and records of local rainfall. Flow records may be extended using a rainfall-runoff relationship for the site, or by a correlation with longer-term flow records for a catchment with broadly similar climate, topography, vegetation and soil cover, preferably one located elsewhere on the same river system.

For ungauged sites:

Preferably 15 years of local rainfall data available:

Annual rainfall may be correlated with rain on a broadly similar catchment for which a rainfall-runoff relationship has been established. Annual yields for the ungauged stream are generated, and distributed between months according to the profile on the neighbouring catchment.

It may be possible to derive estimates of discharge at the site from regional data. Various empirical relationships linking yield with catchment area have been developed in particular parts of the world. However, they tend to be region-specific and of uncertain accuracy.

Regional relationships, linking average annual rainfall and annual yield from measurements on gauged catchments, have been established in some parts of the world.

Under FRIEND, a current United Nations (UNESCO) project, including sub-Saharan Africa, regional time series hydrological data bases are being developed, so that information on rainfall and streamflow can be used within a group of adjacent countries. The work is divided into three groupings:

- Southern Africa, including 11 members of SADC, coordinated from Dar es Salaam.
- West and Central Africa, coordinated from Abidjan.
- Nile basin. Programme in the formative stages.

Results from the first two groupings are expected in late 1997, and for the Nile in 1999.

Other sources of information:

For initial investigations, a broad understanding of the river regime can be obtained by observing flows at various times of year. Deposited debris on the river margins and in adjacent vegetation can help to establish the height of possible flooding. Qualitative information can be gained by questioning local inhabitants who have been resident in the area for many years:

- Does the river flow all year round?
- How often, if ever, has the river dried up in the last ten years?
- In what months do peak and flood flows normally occur?
- What is the water level at times of high and low flows?
- How frequently does the river overtop the bank, if ever?

Further information on river flows may be available with upstream water users. Farmers who have been resident in the area for a long period should gave an indication of how frequently their crops are affected by low flows. Other water users, such as small industries or estates, may have further information. If there is an upstream irrigation scheme served by a weir, a programme of gaugings could be established. The information will inevitably relate to a short period and will not allow confident predictions for the long-term. At feasibility stage an engineering judgement will have to be made, based on assessments from a number of sources.

Design for Low Flows

At times of low flow, day-to-day variations are unlikely to be very great. Half-monthly or monthly average flows may be used in an analysis of probable flows at selected return periods. Preferably 15-20 years of data are needed for reasonably accurate predictions but the designer may have to settle for less. For most small scale developments, the flow at 20% probability of non-exceedance should be used, implying that in one year out of five the flow will be less than the amount required.

There may be order-of-magnitude variations in river flow at times of year when sudden storms can arise. During these periods, the monthly flow may derive largely from one or two short duration floods. The designer should be aware that at such times the water available for diversion may be substantially less than the monthly figures would indicate.
Probabilities of non-exceedance can be obtained by a simple ranking of historic flows, by graphical methods using log-normal probability paper, and by computational methods such as the Pearson Type 3 analysis. Table 3.1 summarizes the analytical methods.

Design for Floods

Floods are characterized by extreme and rapid variations in flow. Records of historic daily flows can provide an indication of intensity, but on small catchment areas the time of concentration may be much shorter than a day. It may therefore be necessary to factor the measured flows to allow for the fact that the peak discharge probably went unrecorded. Since flood magnitudes are so variable, a longer record of some 20-25 years is needed for meaningful analysis. Where extensive damage is likely to result from a failure, a design return period of 1 in 100 years may be considered warranted. Otherwise, a return period of 1 in 20 years is more appropriate.

Table 3.1 Required information on flows

	Low flows	High flows
Flow data	Monthly or half-monthly averages of low flows during irrigation period	Daily flows throughout year
Length of record	15-20 years minimum	20-25 years minimum
Acceptable probability of non-exceedance	10% to 20%	95% to 99%
Recurrence interval	1 in 5 /10 year event	1 in 20 /100 year event
Methods/estimates	Ranking order Graphical solution Pearson Type 3	Log – normal Pearson Type 3

Source: Irrigation and Drainage Board (IDB), Kenya, 1986

Where data are not sufficient, hydrological methods to estimate floods should be carried out by specialists. The methods are approximate and the designer should treat them with caution, comparing the results obtained by different methods.

Other Water Users
Discharges based on measurements at the proposed abstraction site will be net of upstream use. Demand is very likely to have increased over time. In creating a time series, the discharges corresponding to earlier years of record may therefore need to be adjusted.

A minimum discharge will probably need to be maintained in the river below the project as compensation for other users, and for environmental reasons.

Streamflows downstream of the development will be augmented by irrigation return flows, and drainage. The residual flow in the river may therefore need to be checked at a point downstream where the net effect of the project is felt.

Water Rights
In many regions, available water resources are rapidly becoming depleted. Proposals for new or upgraded developments should be cleared with the Ministry responsible for water resources, in order to comply with national policies for water development and allocation.

As an example of procedures, new water rights in Zimbabwe must be obtained by a lengthy process with Government to modify existing water right allocations. The Water Act is about to undergo revision and it is intended to introduce integrated water planning practices throughout the country.

The following information must currently support an application under the Zimbabwe Water Act:

- Delineation of land to be irrigated by available water
- Land classification showing the area suitable for irrigation
- Details of intended irrigation method

Volumetric seasonal irrigation rights are based on a continuous supply equivalent to 1 litre per second per hectare at the night storage dam at time of peak demand. The total quantity which may be abstracted varies with the season.

3.1.2 Demand

Total in-field Requirements
The Penman method for determining crop evapotranspiration, based on half-monthly or ten-daily - averaged climatic data and factors specific to the crop and its stage of growth, is widely used throughout the world. Regional values for reference evapotranspiration are available in

a number of countries in Africa. Otherwise, information on sunshine hours, windspeed, humidity, and temperature, obtained from the nearest reliable meteorological station, is needed to generate values for reference evapotranspiration. In the absence of processed data, the CROPWAT program developed by FAO may be used with climatic data from the CLIMWAT database.

The Penman method is particularly appropriate where a single crop predominates in each season, for example rice, as in some western parts of Kenya. Apparently accurate predictions of crop demand need to be considered in the light of possible major changes to cropped area, cropping calendar and climate.

Example: Case Study, Gem Rae, Kenya

One annual crop of rice is grown at Gem Rae. It was assumed in design that the crop would be planted in July/August and harvested in December. However, over the course of seven years, the planting date had slipped to November/December, owing to poor organization and maintenance by farmers. Yields were reduced to an average of 1.3 tonnes/ha. The calculated winter water requirements were no longer valid.

Simpler methods of estimating crop demand may be appropriate for small schemes, and sufficiently accurate in particular circumstances.

In Kenya and Zimbabwe, design has sometimes been based on a maximum averaged daily demand in the hottest period, uniformly applied across the scheme. This should represent the critical design condition if the supply is likely to be at an annual low at the time of maximum demand. It will be hard to anticipate operating practice at other times of year without more detailed information.

The maximum daily design demand may also be based on records of pan evaporation with appropriate crop coefficients. The rates of evaporation from pans vary somewhat from estimates of open water evaporation and from reference crop evapotranspiration, as deduced from the Penman method. In Zimbabwe it was found that the pan method tended to underestimate crop water demand at peak times and the method is now mainly used as a practical method of scheduling water to crops.

Where schemes are designed for year-round horticultural crops, or where a mixture of subsistence crops is grown, the simple method using maximum averaged rates may be appropriate. In addition to making the calculations simpler, greater flexibility in the farmers' choice of crops can be accommodated. Field investigations in Kenya showed that on average five different crops were grown on each horticultural scheme. In total, over twenty crops were grown, some schemes specializing in particular crops. To determine crop demand, a procedure similar to that shown diagrammatically below is recommended:

Step 1: Obtain monthly average reference evapotranspiration (E_{T0}) data. Use evaporation pan data or meteorological data with Penman equation, etc.

Step 2: Calculate crop water requirements (E_{Tc}) using a crop factor (k_c) of 0.9. (Varied crop choice, intercropping and varying planting dates will ensure that a k_c value of 0.9 is accurate enough.)

Step 3: Calculate monthly values for effective rainfall (see below) and subtract from the monthly E_{Tc}) values.

Step 4: Take the maximum monthly (E_{Tc} – effective rainfall) value as the design crop water requirement. (NB. Often, in peak periods, there will not be any effective rainfall at the 1 in 5 year dry probability level.

Effective Rainfall
Rainfall may vary greatly from year to year. In any given month, the contribution of rainfall to crop needs may be minimal, but the seasonal contribution may be important in reducing the net volume of water required from an external source. If rain can contribute significantly to crop needs, a probability analysis will give the expected depth of rainfall at the selected return period the most relevant being :

- The seasonal rainfall corresponding to the one in five dry year i.e. 20% probability of non-exceedance

If irrigation takes place throughout the year, peak demand will often occur when there is little or no rain. Therefore, effective rain determined on the basis of the 1 in 5 dry year will probably make little contribution to the design scheme water requirement. As an example, during the field studies in Kenya, rainfall contributed between 22% and 70% of crop requirements over the year as a whole, but most fell within distinct "wet" periods.

The effectiveness of any rainfall is dependent on a number of factors: total rainfall, crop consumptive use, irrigation application depth, antecedent soil moisture, and soil moisture holding capacity.

- Higher total rainfall during a given period will yield a lower proportion of effective rainfall, since runoff and percolation losses are likely to be greater.
- Under high consumptive use, the effectiveness of rainfall will increase since the available storage within the root zone of a given type of soil is likely to be higher.
- Where all of the available storage within the soil profile is not filled by an irrigation application, ie the soil is not brought to full capacity each time, the effectiveness of rainfall will be greater. Field measurements in Kenya confirm this to be the case much of the time.

In soils of low total moisture holding capacity such as those in the Egyptian delta, even light surface irrigations rapidly fill the entire available soil storage. However, the issue is not important in that region since rainfall is negligible.

Various methods are used to estimate effective rainfall. They include those due to the USBR and to the USDA SCS, which are described in detail in FAO Irrigation and Drainage Paper No 25.

Broad estimates, which assume that monthly rainfall is some 70% effective, are sometimes applied. Country-specific methods are also used. As an example, the values shown in Table 3.2, which correspond fairly closely to the USDA figures, are used in Kenya. A net irrigation gift of 75mm is assumed at each irrigation.

Table 3.2 Effective rainfall -Kenya

Average monthly rainfall (mm)	Average monthly consumptive use (mm)		
	125	175	225
	Effective rainfall (mm)		
50	35	40	45
75	55	60	70
100	70	80	90
125	85	95	105
150	100	110	120
200	105	115	125

Note: Rainfall above 200mm depth is assumed ineffective

System Efficiency
The crop water requirement at field level needs to be increased, allowing for losses between the crop root zone and the point of supply, to obtain the total scheme water requirement. The overall efficiency of a system is conventionally assumed to be built up from component

efficiencies, representing the efficiency of field application, distribution, and conveyance in the main system. The overall efficiency of small surface irrigated schemes was found to be 40%-50%, as compared with figures of 25%-40% commonly quoted for typical large schemes.

Irrigation design manuals usually provide standardized values for efficiencies. However, variations in topography, soil, and poor maintenance can mean that the values are inappropriate, most commonly over-optimistic. It is preferable to adopt a somewhat conservative value, because systems on the whole perform worse than assumed. However, if too conservative a value is adopted, farmers may be able to draw more water than strictly necessary and the system will be unnecessarily costly. Best efficiency is normally achieved when water is somewhat short, but not greatly so. In these circumstances, farmers are more disposed to cooperate with each other. It is also important to vary the design efficiencies where there are marked changes between parts of a system, for example when a canal passes through an area of sandy soil having a much higher permeability than soil elsewhere on the scheme.

Losses in conveyance include seepage and so-called "management losses", so measurements of seepage loss tend to underestimate total conveyance loss. Management losses include water leaking through offtaking structures and through tail escapes. As a result, water may be lost to the system as a whole, or may be unequally distributed within it.

It is common to adopt values for conveyance efficiency which are unrelated to the length of the channel, thus it is assumed that a given percentage of headworks flow will be lost at primary, secondary and tertiary canals levels, regardless of the scheme size. It is more realistic to assume a rate of loss per kilometre. Thus, if the average distribution canal on a scheme is 1 km long, and 80% is taken as an appropriate value for conveyance efficiency, the efficiency can be expressed as 80% per kilometre. A 2km canal would then have a design efficiency of 64%

Poor maintenance may not only reduce the capacity of a canal by increasing roughness and reducing waterway area, it can also lead to greater seepage losses. The effects could be readily demonstrated in the field to farmers in order to encourage them in better maintenance practices.

Application losses are also extremely variable, particularly at different times in the growing season. Efficiency is likely to be low when seedlings are being irrigated since the water holding capacity of the root zone is small. Water retained deeper in the soil may in fact be exploitable later in the season. Thus, efficiency should increase as plants develop.

Investigations on 10 schemes in Kenya gave an average application efficiency of nearly 58% for surface irrigation (ridged basin and basin irrigation), a result which was fairly consistent from scheme to scheme. For locally-manufactured sprinklers, efficiency was about 75%.

3.1.3 Matching supply and demand

It was assumed above that scheme water requirements can be exactly matched to the local supply. It was shown that there are many factors which make it difficult, if not impossible, to arrive at values which are 100% correct. If, in consequence, demand is over-estimated, the scheme should be well-supplied, possibly to the disadvantage of developments elsewhere if water management practice is poor.

What are the implications of under-estimating demand or over-estimating the available supply?

Of ten schemes investigated in Kenya, only one enjoyed a water supply which was always adequate (supply equal to, or in excess of, demand) but on eight schemes, the supply averaged at least 80% of crop needs on the irrigated area over the course of the season. It should be noted that on three schemes, farmers had considerably reduced the area irrigated below the design area, in line with the supply.

All schemes showed a positive net income to farmers from irrigation, although quite small in some cases. There was no correlation between average income and overall adequacy of supply at the scheme level. The reason seems to be that, by suitably reducing the cropped area, farmers succeeded in maintaining the supply above 70% of crop needs – below 75% crop yields fall off sharply. In the circumstances, choice of crop, use of inputs, market price, and marketing strategy had a much greater impact than variations in water supply.

However, there were marked difference of supply within individual schemes, see Table 3.3. The Supply parameter in the table is a measure of the extent of over- or under-supply, where a value of 1.0 indicates that supply exactly satisfied crop needs. The Adequacy parameter, a modified version of supply, is a measure of the extent to which immediate crop needs were met; it has a maximum value of 1.0, at which level the supply exactly satisfies crop needs. It is assumed that the soil is fully saturated by an irrigation and that any water applied in excess of crop use is lost. Values in the range 0.80 - 0.90 are taken to represent "fair" adequacy. An adequacy of 0.90 is "good", whereas values below 0.80 indicate "poor" supply. Further explanation of the parameters is given in Volume 2 (Case Studies).

Table 3.3 In-scheme water supply and irrigation incomes compared (selected Kenyan schemes)

Scheme name		**Supply**	**Adequacy**	**Irrigated income per ha (% of maximum)**
Mathina	Head	1.98	0.94	100%
	Middle	1.38	0.47	67%
	Tail	0.54	0.37	0%
Kangocho	Head	2.04	1.00	100%
	Middle	1.16	0.85	39%
	Tail	0.00	0.00	0%
Kwa Kyai	Head	1.37	0.89	100%
	Tail	0.45	0.43	33%
Kamleza	Head	1.98	0.91	32%
	Middle	1.38	0.96	100%
	Tail	0.54	0.50	66%

There is some variability within the table, but in general the figures show that when external factors are constant, as on a given scheme, the adequacy of water supply has a major impact on irrigated income. For example, at Kwa Kyai scheme, the adequacy at the tail end was only half that at the head; farmers in the tail earned on average only one third as much as those at the head. Section 5 discusses design and management of a scheme to reduce problems of water supply inadequacy and inequity

Supply must not only be sufficient, but also reliable, so that farmers can plan and invest. In conditions of uncertain water supply, they may opt to cultivate a higher proportion of subsistence crops, and their incomes will be reduced.

An example of the effects of problems in water distribution is included below:

Example: Case Study, Kamleza scheme, Kenya

Overall, the supply is excellent, water being readily available at all times. The supply is divided to various parts of the scheme by structures equipped with adjustable gates. It was found that water was shared very inequitably. Farmers at the head of the scheme took twice as much as required, whilst those at the tail received only half of what they needed. Yields at both head and tail end were poorer than in the middle part of the scheme. At the head there were problems of waterlogging, exacerbated by poor natural drainage, whilst the tail suffered from water shortage.

3.1.4 Water Quality and Sediment

Water Quality

All irrigation water contains dissolved or suspended particles, some of which can adversely influence the soil structure. For large scale developments, water should be analyzed for its suitability against criteria for total concentrations of soluble salts, (salinity hazard);

concentration of sodium relative to calcium and magnesium (sodium or alkali hazard); and concentration of boron, chloride and other ions (toxic or harmful). Good water management will be needed to alleviate the effects of a poor quality supply.

Water management techniques on small schemes are unlikely to be of a high standard. The supply should therefore be rejected if it contains significant concentrations of soluble salts and exchangeable sodium, boron etc. Water of a quality suitable for drinking will automatically be suited for use in irrigation.

If there are other successful irrigation developments nearby which draw from the same source without evidence of ill-effects, extensive investigations should not be necessary. In the absence of such background knowledge, **salinity** can be determined in-situ by an electroconductivity meter. The following approximate criteria may be adopted:

Table 3.4 Effect of salinity on crops

Conductivity (mS/cm)	Effects
< 1	Suitable for most plants under most conditions
1 – 3	Harmful to more-sensitive crops
> 3	Harmful to most crops

Laboratory analysis is needed to determine exchangeable **sodium** content. Values of less than 8.0 for the sodium adsorption ratio (SAR), the conventional measure of sodium, cause no problem. Increasing problems occur with higher SARs and increasing salinity.

Approximate standards for **other** ions are:

Table 3.5 Effect of other ions on crops

Boron (mg/l)	Chloride (meq/l)	Effects
<0.5	<4.0	Suitable .
0.7-3.0	4-10	Harmful to more sensitive crops
>4.0	>10	Harmful for most crops

Surface or groundwater supplies near large communities may be contaminated by pathogens. Unless the water is effectively raw effluent it is not likely to represent a significant hazard for the irrigation of field crops. However, there may be a serious risk to health if fruit and vegetable produce is washed or freshened up for market using a contaminated source.

Sediment
Any upstream development of formerly vegetated catchment areas is likely to lead to increases in the volume of sediment brought down by rivers. A major part of the annual load is brought down at flood times. Unless headworks are shut down during floods, excess sediment will be drawn in and deposited within the scheme, because the sediment-transporting power of the canals is normally less than the parent river.

The physical features of the catchment, such as soil type, slope and vegetation will affect not only the hydraulic yield and magnitude of floods but also the sediment yields. For example, bare soil can produce erosion products in excess of two orders of magnitude greater than forest, savannah or pasturelands where vegetation covers more than 80% of the soil surface.

Deposited sediment can represent a heavy and continuing maintenance burden for farmers' organizations. The output of the scheme may be affected, and in serious cases its continued operation may be at risk. An example of the effects of sediment on the operation of a scheme in Kenya is given below:

Example: Case study, Gem Rae, Kenya

Water is taken from the River Awach, which is seasonal in nature and carries a high sediment load during the rainy season. There is no means of either excluding or extracting sediment at the intake. As a result, large volumes of sediment enter the scheme. Farmers do not cooperate well together so that the task of clearing the canal is badly organized. The operation of the system is adversely affected, and the growing season has been progressively delayed over the years to the point where the overall output has been affected.

A number of possible design options are available for dealing with sediment problems on large schemes, including excluders, ejectors and extractors. However, they are unlikely to be economical for small schemes. The scope for introducing practical operational procedures to exclude sediment is also limited by the fact that small scheme headworks are often unmanned for much of the time. Manual clearance of channels on a frequent, even daily basis, may be the only viable solution. The designer must anticipate likely maintenance requirements by quantifying the scale of the problem and then define the implications to the proposers of the scheme.

Techniques for sediment measurement and analysis are not complex, but require expertise which may not be available within the design team. Government hydrological departments should possess the necessary equipment, skills and resources. Failing that, the likely scale of the problem may be anticipated by investigating adjacent schemes. In general, the size of the coarsest material deposited in upstream schemes will be greater than in schemes downstream on a given river. There will be quantitative differences in the sediment load in different rivers in a region but the overall nature of the problem is likely to be similar. For example, small schemes drawing their supply from the middle reaches of the Sabi River in Zimbabwe all suffer substantial problems caused by sand settling out in the head reaches.

In the absence of evidence from other schemes, the designer can gain an impression of the river regime by inspecting the course at times of low discharge. Meandering rivers with silty beds are likely to deposit silt unless the designer can ensure that the velocity of flow everywhere within the system exceeds 0.4m/s throughout the year, so that material is transported through to the fields. Braided rivers with sandy beds are likely to give particular maintenance problems, aggravated by a tendency for the main channel of the river to move unpredictably. In the flood season, fast-flowing torrents are likely to move sand, gravel, pebbles and boulders which can obstruct or block irrigation intakes.

3.1.5 Water - key considerations

1. Carry out a careful determination of water availability. Daily and monthly flow data are basic to analysis but may not be available. The scope of analysis will depend not only upon the type and extent of available data but also upon the stage of the investigation. If schemes continue to appear feasible after outline investigation, more detailed assessments by hydrological specialists, to determine dependable low flows and flood flows, may be justified.

2. Identify present and future development plans of all Ministries concerned with water use and abstraction. Interview other water users about the incidence and magnitude of low flows and flood flows. Women may have better information than men, as they tend to visit water sources more frequently.

3. Determine half-monthly /ten daily rainfalls at different levels of probability and estimate the proportion which will provide a reliable contribution to crop needs. At a five year design return period, rainfall may make virtually no contribution to crop needs at the time of peak demand though it can reduce seasonal water need.

4. Calculate water requirements for cropping patterns which have been discussed and agreed with farmers. Provide some flexibility in the design to allow for possible changes in cropping.

5. Determine conveyance and application efficiencies, selecting conservative values to allow for poor maintenance and management. Attainable overall efficiencies for small surface

schemes can be taken to be 45% - 50%. Too low a value will lead to wastage of water. Too high a value can cause water shortage and conflict. A limited degree of water stress can help promote good water use practices.

6. Match supply to demand to confirm the size of the irrigated area.

7. An adequate water supply is basic to the proper functioning of a scheme, but other social and economic aspects must be satisfactory to achieve sustained success. If 70% - 80% of theoretical crop needs are reliably available, the financial returns to farmers depend on other factors such as the choice of crop, market prices and opportunities, appropriate agricultural practices and the use of inputs.

8. Designers must anticipate how a scheme is to be operated and maintained. The tasks and the labour involved in operation and maintenance must be clearly identified for farmers so that they can make an informed commitment. Otherwise schemes may fail.

3.2 Land and soil

New irrigation developments will generally involve the acquisition of land. Both individuals and communities may be affected because issues of land use and society are inextricably linked. If schemes are to be sustained, potential conflicts must be identified at the outset by defining rights, present and former owners of land, proposed allocations and their effect on present users.

● Strong influence
O Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Topography	O	O	O	●	●	●			
Soil type	●		O	●		O			
Soil depth	●			●					
Land tenure			O		●	O	O		

Changes to traditional patterns of land use frequently accompany the introduction of irrigation, and they may well affect the impact of a project. As an example, land formerly used for feeding animals may be turned over to irrigation with the result that surrounding areas are degraded by overgrazing. It is important to anticipate changes to group schemes and communally-owned land by structured enquiries because it is unlikely that full sociological investigations can be justified.

In the following sections the characteristics of private and communally-held land which can affect scheme design and management are identified, so that irrigation may be developed appropriately.

3.2.1 Land tenure

Many disputes arise over land, particularly irrigated land. It is desirable that farmers get legally-binding agreements on ownership or tenancy.

Private Land
Ownership provides strong incentives to invest in, and improve land. It encourages the use of agricultural inputs and growth of long-term crops, such as trees, which can draw moisture from depths not accessible by more shallow-rooted crops.

Where group schemes are developed around existing small-holdings, there will be pressure for canal or pipe layouts to follow land boundaries to avoid loss of land and fragmentation of holdings. There are advantages to farmers in that their work can be concentrated in one area. However, indirect alignments are likely to cost more, both initially and during subsequent maintenance. Water must be conveyed through other private holdings, providing potential for conflict over access to, or misappropriation of, water. Appropriate regulations and sanctions are needed to deal with such conflicts.

Example; Case study, Mutunyi, Kenya

The total area of the Mutunyi scheme is 420 ha, of which less than half is irrigated, the remainder being rainfed. Irrigated lands are scattered across the scheme. In consequence, the distribution canals are roughly twice as long as needed if the irrigated land were consolidated towards the head of the scheme. The canal network is indirect and very informal. Many small offtaking canals feed individual plots. As a result, there are high losses in conveyance, of the order of 28%. Farmers at the tail of the scheme have to spend a lot of time and effort in 'husbanding' water along the canals to their farms. Maintenance workers each have a long stretch of the system to maintain. A compact layout would have greatly reduced water losses and maintenance.

If farmers' irrigated holdings are scattered across an area, water management efficiency may be low and could be improved by consolidating holdings. However, successful consolidation can only be achieved by consensus rather than coercion.

Communal Land
Development of land for irrigation can disrupt traditional patterns of use. Those who lose by conversion of communal lands may not benefit from irrigation. However, the losers are also stakeholders and must be identified at the outset. Formal and informal meetings may help to reach necessary compromises or compensating arrangements. Agreements need to be reached on priority use of water at times of shortage, unhindered access to the irrigation system, rights of way and access to traditionally important sites.

3.2.2 Land – physical characteristics

Location
The project needs to be sited within a practical distance of the water source, the irrigating community and local roads.

Not only is the cost of the system increased by long intake canals, but conveyance losses will reduce the benefiting area. Lining the system can reduce losses, but it adds considerably to the initial costs. The potential savings of water may not be realized over the long term unless the lining is properly constructed and maintained.

Good access must be possible if strategic points on the system, such as the headworks, are to be manually controlled. Remote intakes on farmer-managed schemes will probably not be operated and maintained.

Slope
The slope of the land may limit the potential for irrigation or determine the method of water application. Cultivation of over-steep slopes will promote erosion if natural year-round vegetative cover is replaced by intermittent cropping. It may not be practical to irrigate properly by surface methods if the land is too flat. To avoid costly land grading and possible reduction in fertility by loss of topsoil, longitudinal and cross-slopes should be adapted to the natural topography.

Slopes can be simply determined from maps at a scale of 1:10,000 or greater, if available, or from rapid field measurements.

The range of land slopes suited to surface irrigation is highly dependent on the type of soil. As an example, for furrow irrigation, a slope of around 0.25% may be used on very sandy soils (although other methods of irrigation are to be preferred), whereas slopes of 2.5% on clays and up to 5.0% on heavy loams are possible. Similar ranges apply to border strip irrigation.

Small ridged basins, such as those used in Kenya, are possible on slopes up to 5.0% on the heaviest soils.

Pressurized irrigation methods may be used on slopes up to 15% on heavier soils, but problems of erosion, aggravated by rainfall, may occur with light soils on slopes steeper than 5%.

Land use
The present use of the land needs to be established and confirmed in discussion with farmers, local residents and Government departments.

The future irrigators may also wish to keep cattle and maintain subsidiary rainfed agricultural farming. Governments such as that of Zimbabwe may encourage smallholder irrigation as an important activity complementing other forms of agriculture.

It may be feasible to devote part of the identified area to non-irrigated enterprises, whilst still developing the available water resource effectively. Such alternative uses need to be identified in the early stages of investigation.

3.2.3 Soil

Texture and moisture-holding capacity
For crops other than rice, soils need to be free-draining. Excessively sandy soils have a low intrinsic moisture-holding capacity and so demand frequent irrigations. They are less suited to surface irrigation because excess water must be applied to achieve a practical irrigation stream size.

The soil moisture available to the plant is taken as the difference between the water held in the crop root zone at field capacity (FC), when the soil is saturated and excess water has drained off, and that remaining when the crop experiences permanent wilting (PWP).

Table 3.6 sets out average values of the parameters for different types of soil, expressed as a percentage of soil dry density, and also, for available moisture, in terms of a water depth (mm) per unit depth of soil.

Table 3.6 Soil moisture parameters

Soil type	Field capacity (% by weight)	Permanent wilting point (% by weight)	Available water	
			% by weight	mm/m
Fine sand	3 – 6%	1 - 3%	2 – 3%	30 – 50
Sandy loam	6 –14%	3 – 8%	3 – 6%	40 –100
Silt loam	12 – 18%	6 – 10%	6 – 8%	60 – 120
Clay loam	15 – 30%	7 – 16%	8 –14%	90 – 210
Clay	25 – 45%	12 – 20%	13 – 25%	190 - 300

Soil Depth
Crop yield can be adversely affected if the depth of fertile soil is insufficient to allow full root zone development. Waterlogging and salinity problems can also occur if there is a shallow, poorly-permeable layer underlying the top soil.

The soil profile can be established by drilling auger holes or digging trial pits. Investigations should be carried to a minimum depth of 1.5m. The intensity of investigation will depend on the topography and the uniformity or otherwise of the soil, but should be about one hole per 6-8 ha for small scheme developments.

The logs should identify:

- mechanical barriers such as rock or hardpans
- chemical problems such as saline or sodic soils
- the depth to groundwater

The depth to groundwater will probably vary with the time of year, being highest at the end of the wet season, so the date of measurement must be known. The water table will rise further with the introduction of irrigation.

The required soil depth for a given crop is related to the soil texture and moisture-holding capacity.

Table 3.7 Soil depth: suitability for irrigation

Soil depth	USDA description*	Suitable for
>0.90	Moderately deep-deep	All crops, except on sandy soils
0.60-0.90	Moderately shallow	Less suitable for deeper-rooting crops such as cotton, maize and sorghum
0.45-0.60	Moderately shallow	Only suitable for shallow-rooting crops, but not in sand or sandy loam soils
<0.45	Shallow-very shallow	Only suitable for very shallow-rooting crops such as onions on clay, clay loams and silty loams

The minimum depth to the water table required by different crops is shown in Table 3.8. A system of drainage will be needed if the existing water table at its shallowest is within two metres of the surface, allowing for a rise accompanying irrigation.

Table 3.8 Drainage depth: suitability for irrigation

Drainage depth in metres	Suitability for irrigation
≥ 1.6	Suitable for all crops except rice.
1.2 – 1.6	Less suitable for deep rooting crops such as cotton, maize and sorghum. Unsuitable for rice.
1.0 – 1.2	Less suitable for shallow rooting dry crops and rice. Unsuitable for deep rooting crops.
< 1.0	Suitable for rice. Unsuitable for all other crops.

Design criteria for surface flooding are referred to in Section 5.1.5.

Example: Case Study, Kamleza

Soils at Kamleza are predominantly silty loams and clay loams well-suited for irrigation. However, a hard layer of soil at a depth of approximately 1 m underlies much of the scheme area. Poor drainage has led to salinity in areas at the tail of the scheme whilst at the head, excessive water application has led to waterlogging and reduced yields.

3.2.4 Land and soil - key considerations

1. Disputes over land are common. Legal definition of tenure helps to commit groups to the disciplines of communal irrigation.

2. Sustained development requires that stakeholders, the status and use of land at present and in future, are clearly identified so that early efforts can be made to resolve conflict and identify acceptable compromises. Irrigation, by changing responsibilities and practices, can produce conflict even within households.

3. There are both advantages and disadvantages to consolidating holdings. Farmers should be advised of the implications of consolidation for development cost, water deliveries and operation and maintenance.

4. Soil testing should be undertaken on new developments to avoid problems with shallow soils of low fertility, progressive waterlogging, and salinity.

3.3 Labour and Skills

Smallholder agriculture in sub-Saharan Africa is commonly constrained by shortage of labour. The reasons include the use of labour- intensive technologies and outmigration of male labour to urban and other areas providing employment. Women make up a high proportion, in some cases the majority, of the agricultural work force.

Irrigated agriculture is particularly constrained by labour shortage. Planting and system maintenance are commonly affected. Subsistence or low value crops may be grown because they need minimum labour. Over half the Kenyan farmers interviewed in the field experienced difficulties in obtaining sufficient labour at peak periods.

In Zimbabwe, farmers organized themselves into groups to undertake tasks jointly for individual members. In Kenya, it was more common to hire occasional labourers for specific tasks. Horticulture demanded more labour than subsistence cropping, but within those broad categories the labour assigned did not vary significantly with the crop. On some schemes, women were responsible for the production of food crops, on others they concentrated on cash cropping. Whatever strategy was in use, there was difficulty in securing sufficient labour.

The importance of identifying how much labour will be required for proposed cropping patterns, and matching with what is in practice available, is illustrated by an example from Gambia. (Day 1990, Carney 1988). Under the prevailing division of responsibilities between men and women, the introduction of irrigated rice as a formal crop at Jahaly Pacharr meant that women were over-worked. They demanded compensation. The scheme was riven by conflicts, achieving poor yields and financial returns.

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

3.3.1 Assessing labour requirements

Crop budgets may be available in government agricultural departments, academic institutions and consultants' feasibility studies. They should include the number of standard man-days required to grow a particular crop. In some budgets, tasks are detailed, showing who does what. Such a level of detail helps in identifying periods of the year when demand for labour will be greatest.

If local information is not available, international organizations such as IFAD and FAO may hold relevant facts. International data will need to be checked for basic assumptions about, for example, the number of daily working hours and whether mechanized methods were used.

Information required:

- Cropping patterns
- Family size
- Population figures
- Labour costs
- Peak labour demand

Experience from similar local developments may be taken as a guide.

Labour requirements for a proposed development can be arrived at from information on cropping patterns, farm sizes and crop budgets. However, the process is time-consuming and may be biased by the available information towards rain-fed, rather than irrigated, farming. Allowance for tasks such as water application, operation, and maintenance may not be included.

On successful farmer-managed schemes in Kenya, farmers estimated they spent between 5 and 10 days per year on maintenance tasks. Water application and land preparation on holdings averaging 1 ha required one man-day per week.

System maintenance requirements appeared to increase with the age of the scheme as components and materials progressively deteriorated. Other factors affecting farmers' commitments for maintenance were :

- design/layout
- the water-borne sediment concentration
- the total number of farmers on the scheme
- the functioning of the farmers' committee

The overall labour requirement may vary somewhat from season to season as farmers vary their cropping pattern in response to opportunities. Justification for using approximate estimates of labour need is provided by the results of the field investigations. Despite differences in farm size and cropping pattern, the information was remarkably consistent between schemes, see Table 3.9.

Table 3.9 Labour requirements

Scheme type	Mean no. of full-time workers per irrigated hectare	Standard deviation
All schemes	4.1	0.8
Sprinkler	3.5	0.2
Rice schemes	5.1	0.8
Surface, mixed cereal/horticultural	4.0	0.5

The figures include time spent on irrigating the crop, but not time spent on maintenance. Time spent on system operation by individuals would need to be estimated separately. Horticultural schemes need more labour than those growing single crops and subsistence crops generally. The schemes operating sprinklers appeared to receive less labour than surface schemes, however the available data on the former method were limited.

The figures were obtained on smallholdings in Kenya and Zimbabwe sized between 0.2 ha and 1.0 ha. There is minimal mechanization. Cropping patterns vary, but irrigation is commonly combined with rain-fed and livestock farming. On rice schemes, the workforce was employed on irrigated rice production during one season and rain-fed farming for the remainder of the year.

Example: Predicting Labour Needs

One acre (0.4 ha) irrigated holding growing subsistence crops and vegetable cash crops on an annually cropped area as follows:

- maize - 0.2 ha
- tomatoes - 0.2 ha
- French beans - 0.2 ha

	HR Method	**GOK Method**	
Based on:-		Based on:-	
Farm size	0.4 ha	Labour rates:	
Crop type	Horticulture/cereal	Maize:	230 man-days/ha
Average no workers/ha	4/5	Tomato:	625 man-days/ha
		French beans:	1310 man-days/ha
		Working days/annum:	240

Workers required:

Workers required:

$$\frac{(0.2 \times 230 + 0.2 \times 1310)}{240}$$

1.6 – 2.0 workers/farm

= 1.8 workers/farm

The example illustrates that the approximate calculation on the left, based on field survey, falls within the range indicated by the more exact calculation on the right. Therefore, little is to be gained by detailed calculations for individual schemes. Farmers will also need to allocate labour between irrigation and other activities at peak periods. Planners should identify such possible conflicts at an early stage and discuss the problem with farmers if it appears not to have been anticipated.

Timing of Agricultural Activities
The correct timing of agricultural tasks is important. With the assistance of farmers, planners should identify key tasks and timings for farm and household activities like water-carrying and fuel gathering. An example is shown in Table 3.10. The table shows mainly household activities with which agricultural activities must be coordinated. The information should be obtained from representative cultivators.

Table 3.10 Timing of household activities

Essential daily activity	Timing	Time required	Female workers	Male workers
Water carrying	pm	1hr	2	-
Cattle feeding	am/pm	45mns	-	1
Milking	am/pm	45mns	1	-
Cattle herding	am/pm	10hrs	-	2 boys
Fuel gathering	pm	2hrs	3 girls	-
Cooking	am/pm	2hrs	1 + 1 girl	-
Egg gathering	pm	30mins	1	-

Weekly and monthly tasks could be summarized in a similar format to Table 3.10.

Example: Case Study, Gem Rae, Kenya

Farmers at Gem Rae cultivate a single irrigated crop of rice annually, growing rain-fed maize during the second season. Sediment deposited in the system must be cleaned out before the start of the irrigation season. In 1992 the maize harvest coincided with the normal start to the rice season. Labour was diverted to bring in the maize so the start of the rice season was put back, a pattern which had caused progressive delay over a number of years. The 1992/93 rice yield was substantially below national norms, in part because of the delay.

Availability of Labour
The formerly labour pool available for agriculture in Kenya is initially a constraint. However, when irrigation becomes a profitable enterprise, farmers will be able to hire additional workers. Within a given type of scheme, for example horticultural, available labour is unlikely to affect choices between, say, french beans and tomatoes. However, it may affect a move from subsistence to horticultural farming.

The potential supply of labour and the costs involved (or benefits foregone) in releasing labour from existing activities need to be identified. The size of family or households can provide an indication of available labour. On the smallholder schemes investigated, less than 40% of family work time was devoted to irrigated agriculture. In some cases, only 10% of time was devoted to irrigation. The proportion of total income derived from irrigation and the time devoted by the family to irrigation positively related (Summary matrix 2, volume 2). Less profitable activities may be undertaken for social reasons. If estimates of labour demand predict a short-fall between available family labour and requirements, the costs of hiring at local rates must be estimated so that realistic margins can be determined. To help farmers decide on cultivation patterns, it is also necessary to assess the availability of labour to ensure that plans fit with existing commitments. Table 3.11 is an estimate based on the key tasks in Table 3.10. Farmers should benefit from the exercise by identifying inefficiencies in the way labour is allocated.

Table 3.11 Example of projected labour needs

Month	Total family labour		Labour used in existing tasks		Available for irrigation		Required for irrigation		Shortfall	
	M	F	M	F	M	F	M	F	M	F
Jan	4.5	5	3	3.5	1.5	1.5	2	1	0.5	-
Feb	4.5	5	3	3	1.5	1.5	1.5	2	-	0.5
March	2.5	3.5	3	3	-0.5	0.5	1	2.5	1.5	2
Apr	2.5	3.5	3	2	-0.5	1.5	3	3	3.5	1.5
May	2.5	3.5	2.5	2	0	1.5	1	1	1	-
Jun	2.5	3.5	2.5	2	0	1.5	1	2	1	0.5
July	2	3.5	1.5	2	0.5	1.5	1	1.5	0.5	-
Aug	2	3.5	1.5	2	0.5	1.5	0	2	-	0.5
Sept	2	2.5	2	2	0	0.5	0	2	0	1.5
Oct	2	3	2	2	0	1	2	5	2	4
Nov	4.5	4.5	3	2	1.5	2.5	0	2.5	-	-
Dec	4.5	5	3	2	1.5	3	1	2	-	-

The above example shows serious labour shortage in March, April and October, and less serious shortages in other months. Some adjustment to the labour allocation is therefore needed. A number of questions need to be asked at this stage:

- Will the expected profit allow labour to be hired?
- If so, will labour be available for hire in that month?
- Can labour be freed from an existing task?
- Can the timing of irrigated crops be changed without affecting yield?

The times when labour is available must be linked insofar as possible with the time when water is available.

Alleviating Constraints
Parallel developments may help to ensure that sufficient labour is available for irrigation. For example, developments might include:

- Water and/or sanitation at household level
- Specialised agricultural activity, for example, nurseries
- Cattle watering points
- Fuel from communal wood lots.

It might be possible to develop the scheme to alleviate labour constraints. The size of plot and operational tasks on the system have a major effect on demand for labour. The method of water application, and maintenance requirements are also determined by design. If it appears necessary to alleviate a constraint imposed by shortage of labour all involved need to be consulted. The views of sub-groups may need to be obtained separately.

As an example of the consequences of design, maintenance tasks are affected by:

- Headworks design
- Layout and channel design
- Block, and therefore cooperating group, size

Designers must therefore balance the development as far as possible to take account of available labour.

Gender
Effective participation requires the involvement of a broad cross-section of the agricultural labour force. Both men and women need to define the needs and tasks with which they will be concerned.

In particular, it is important to identify who will be principally concerned with irrigation, what their obligations will be and how they will interact with other participants. Designers should be able to visualize the end-user, so that operational and maintenance requirements can be met.

In some communities, social roles and agricultural choice may be strongly linked.

Example: Case Study, Jahaly Pacharr, Gambia

The Jahaly Pacharr irrigation project in the Gambia was intended to increase rice production. It was assumed that the cultivators would be male. However, rice is traditionally produced by women, who must also cultivate other crops on land owned by men. Land rights and benefits were severely affected by the irrigation project and women withheld their labour in an attempt to rectify the situation. The yield of rice fell from some 7 tonnes/ha to barely half of that figure. Apart from reducing output, the dispute increased conflict generally and threatened to make the project unsustainable. A more sustainable and cost effective system might have developed if planners had consulted both male and female farmers about traditional land ownership, land use systems and labour obligations. (Carney, Dey, van Hooff, 1988)

To ensure balance in tasks and returns, the views of women are needed, but it may be very difficult to obtain them. There has been a general tendency to exclude or discourage women from participation in project formulation. Even in Kenya, where women are required to make up 50% of participation at the initial project meetings, they may still play a passive role.

Men play a dominant role in ministries and consultancies. They contact male members of the community. Women within a community are often reticent about speaking to male strangers. Women may also feel constrained about expressing their problems and aspirations in the presence of local men. As an example, at Nyanza scheme in Kenya, it was necessary to redesign a proposed scheme once the women had been consulted. It was also found necessary to employ women to solicit women's views. (Ubels and Horst, 1994.)

Education and Skills

It was found in field investigations that well-managed schemes often included well-educated officers on the management committees. However, some schemes would definitely benefit from better management. In Kenya, there are good numbers of individuals with developed agricultural and managerial skills who have experience from working in commercial farming. There is a need for transfer of experience and skills.

In rural areas educational levels are often low. However, in Kenya, education is a high priority for farming families. Between 65%-80% of workers interviewed in the field studies were literate and could obviously manage the instructions on agricultural inputs.

Short, on-site training courses can be effective in improving farmers' skills. In South Africa, low-cost, mobile displays linked to demonstrations of irrigation techniques have been found effective. Publications, videos and radio programmes are all in use in different parts of the world to put over messages to farmers. There is also potentially a role for the private sector.

3.3.2 Labour and skills - key considerations

1. Designers need a good understanding of the way the existing farming system functions. "Who does what, when, and what do they get out of it?". Traditional responsibilities in agriculture, and in the community generally, can strongly affect the outcome of new developments.

2. It may be necessary to interview men and women separately. Combined meetings, including representatives of all participants and sub-groups, will be needed to obtain binding agreements on developments.

3. Irrigation application method, layout and channel design will all affect the labour required to irrigate effectively. In particular, plot size should be determined after considering the availability of labour. Farmers need to be involved in the decision process. It will take more time than customarily allowed in design for farmers to respond meaningfully to proposals.

4. Designers need to clearly identify for farmers the labour requirements for operation and maintenance associated with possible designs. It will help not only in design but in subsequent operations.

5. The effects of parallel developments on the functioning of irrigated agriculture need to be identified. For example, the installation of domestic water supply can have a positive impact on agriculture by reducing the time women spend in drawing water.

3.4 Capital and Equipment

3.4.1 Need for funding

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

It is difficult for smallholder farmers, largely dependent on rain-fed agriculture, to accumulate capital. Uncertain climatic conditions can cause unpredictable crop losses. Investigations at Nyanyadzi in Zimbabwe, which was badly affected by droughts in successive years, showed that capital accumulated by communities over a decade was completely lost. The risks of farming are compounded if farmers also depend on cattle, as entire herds can be lost in drought conditions. There are a few rain-fed cash crops, such as tea, coffee, or cocoa which allow farmers to accumulate capital.

With experience, irrigation should reduce the risk of crop failures and increase returns. It is therefore attractive to farmers. However, inexperienced farmers may find it difficult to balance the risks involved with investing in irrigation against the returns from other agricultural enterprises. In Kenya, it is policy to encourage farmers to invest their own capital in irrigation so they have a strong incentive to succeed. Funding for the agricultural sector from government and donors is being progressively reduced. It is therefore likely that future development costs will be increasingly met from funds raised by farmers through credit organizations. Though funds and advice may be available, they may be conditional on the farmers' willingness to contribute to the total cost of a project.

In the past, token deposits and long repayment periods were commonly chosen to give irrigators the best possible chance to establish a new farming system. External funds are increasingly scarce and so revolving funding, commonly involving relatively short payback periods, is more common. The loan must therefore be used to cultivate high-earning crops. Once a scheme is developed, farmers will also need funds to cover seasonal production costs. Without recurrent credit, they are likely to restrict the use of inputs, so the returns will be less than optimal, possibly insufficient to cover family needs and to repay loans. Planners/designers will need to make sure at scheme feasibility stage that affordable sources of credit will be available to the farmer.

3.4.2 Credit

Development

Funders will impose minimum conditions for a loan, but there may be some scope for negotiation, or alternative sources may be available. If the rate appears excessive, borrowers are likely to default on the loans.

In Zimbabwe, the cost of scheme development is shared by Government and farmers, the latter contributing unskilled labour for construction. At Exchange scheme they were paid in kind for their contribution and appeared to possess a strong sense of ownership for the scheme. They do not own the land, though possessing some assurances about continuing tenure, and they can in fact be excluded from a scheme by AGRITEX if they do not make active efforts to use the land productively. Unlike large farmers, they lack the collateral needed to obtain credit through normal commercial channels and at the time of the investigations in the early 1990s, development loans were not readily available. Irrigation development is now increasingly restricted, particularly in the drier parts of the region, with the removal of Government subsidies on the costs of scheme implementation.

In Kenya, NGOs such as the Smallholder Irrigation Support and Development Organisation (SISDO) specialize in unsecured loans to groups for irrigated horticulture production. SISDO has developed a detailed specification for the procedure to be followed by a group in order to secure a loan. Financial packages are available to help farmers, who remain financially accountable and in control of policy and planning for their system. Members of the group guarantee repayment. Minimum conditions imposed for the management of the scheme, to ensure financial accountability and repayments include: a requirement to ensure minimum participation at group meetings; loans to be secured by the group; and responsibility of the entire scheme for the performance of sub groups. The intake works are mortgaged to the lending body so SISDO can impose sanctions if payments are not made. Conditions for loans are summarised in SISDO's Fact Sheet No 1.

Credit organizations may make special provisions for new schemes, particularly where applications are made by farmers' groups and where the project aims to improve the status of women.

Example: Case studies Mathina and Kibirigwi, Kenya.

Over the last decade, women in Kenya have been encouraged to take out credit in response to the realisation that loans channelled through women are effective in combating poverty. Women and women's groups have good records of repayment. On some schemes, notably at Kibirigwi, where zero-grazing units have been established, women use credit to start up complementary enterprises. The repayment on irrigation production loans has also improved.

Recurrent credit

Credit will be needed in the production stage to cover the costs of seasonal inputs, small equipment, repairs and replacement. Government credit institutions, parastatal bodies, agricultural banks, NGOs or local moneylenders will provide production loans.

Traditionally, farmers borrow from village lenders and relatives. In practice, less than 20% of Kenyan smallholders appeared to be taking formal production loans and some were actively opposed to credit. The reasons are likely to be connected with the economics of horticultural schemes. In the first place, the prompt returns to short duration crops reduce cashflow problems. Secondly, some of the horticultural schemes were producing to contacts under which inputs were provided.

Service Fees

Example: Case Study, Arombo, Kenya

The scheme benefits from a nearby development at SouthWest Kano. Formerly, farmers had irrigated using drainwater, without charge. The introduction of fees for irrigation water met resistance, and repayments were poor. There were continual disagreements about the areas irrigated, water releases and services. In particular, farmers considered that the water supply was not sufficiently improved to justify the charges. It is possible that a modified system of charging, linked to performance, would have been more successful (see below).

Farmers will have difficulty in meeting loan repayments if the water supply falls below a specified agreed minimum. A cut-off point on repayment should therefore be agreed, possibly on the lines of a system which has been in use for a number of years in the Philippines, where irrigation staff are judged by the level of repayments they obtain. Agreements on repayment should contain a clause dealing with unforeseen problems.

SISDO Fact Sheet No. 1

IRRIGATION INFRASTRUCTURE OF GRAVITY-FED SCHEMES

In an area where gravity-fed irrigation is possible and farmers preferably have started some form of irrigation, a group-based scheme can be started. Identification of the scheme and applying for technical assistance by the farmers will go through the Ministry of Agriculture at District level. At present, most Districts have District Profiles, which have been prepared with assistance of the Dutch-funded SIDP Project. These profiles consist of farmers' requests for assistance in:

- rehabilitation and improvement of existing schemes;
- new schemes and extension of existing schemes.

All of these are ranked in order of priority for assistance, and are assessed for environmental impact. The District Profiles also contain 3-year plans covering District irrigation staff activities.

STEPS IN SISDO'S INVOLVEMENT

SISDO's involvement in scheme development generally takes the following course:

1. SISDO is ***introduced*** by District irrigation staff to members of the scheme.
2. An assessment is done by SISDO to clarify the scope of the scheme (***membership list*** and area occupied by its members).
3. ***Groups are established*** who guarantee each other payment of a monthly deposit for the security fund and later for the loan instalment payment.
4. A Memorandum of Intention of Cooperation is signed by elected representatives of the scheme and SISDO. The Scheme and its Groups commit themselves to a programme of depositing money in a joint SISDO-Scheme account.
5. Group and Scheme leaders participate in a ***training workshop on SISDO loan procedures*** and conditions, and are trained in dealing with their members in security deposits and loan instalments.

Figure 3.1a SISDO Fact Sheet No. 1:Irrigation Infrastructure

6. In *monthly meetings* Groups and the Scheme monitor the deposits of their members. Failure to pay the agreed deposits will result in rejection of the loan request, unless penalties are paid and sufficient assurances are given to prevent reoccurrence of default.

7. A Topo-survey Agreement in which SISDO and the Scheme agree to each meet half the costs of the survey is prepared and signed by both parties. (SISDO's input to the topo-survey will later constitute part of the loan).

8. With full participation of the farmers, investigations are carried out and a scheme design is prepared by the MoA staff or SISDO.

   - A series of *design meetings* are held to elaborate on groupings, alternative designs and their maintenance, operation and loan consequences.

   - A series of *SISDO meetings* are held to explain the details of the loan agreements and to elect leaders at group and scheme level.

PRE-CONDITIONS FOR LOAN APPLICATION

Prior to SISDO entering into a loan agreement with the scheme, the following pre-loan conditions must be observed:

1. There must be a clearly defined system of water distribution among the members, in general equity of water distribution sufficient to irrigate 1/2 - 1 acre per farmer is aimed for.

2. The groups of farmers (made up of 10-30 members who will have their own independent water supply) must agree to individually and collectively secure the groups' share of the security fund and loan repayment of the scheme.

3. A security fund of 6 monthly loan instalments (roughly 15% of the total loan) has to be paid by all members into a group bank account. This account is a trustee account with SISDO as the trustee. (Signatures of SISDO as well as scheme and group committees are required for withdrawal of funds.)

4. A series of group meetings led by SISDO must be held, with an attendance of at least 70% of all household members involved (man and wife/wives) and with an attendance of at least 50% women.

5. Group committees must be chosen in the presence of a SISDO facilitator and should consist of at least 50% women.

6. Representatives of the groups to the scheme committee must be chosen in the presence of a SISDO facilitator and should also consist of 50% women.

Figure 3.1b SISDO Fact Sheet No. 1:Irrigation Infrastructure

AGREEMENTS AT HOUSEHOLD, GROUP AND SCHEME LEVEL

In every *Household* the head and his wife(s) are required to sign an agreement with the Group committee agreeing that:

- any default by a member gives the group the right to lease that member's water allocation, and if need be his/her irrigated plot for half a year to other group members or an outsider to offset the debts;
- monthly group meetings will be held at scheduled places and times with the SISDO loans officer to follow up loan repayments. Penalties for absence and default are also agreed to.

Every *Group* is required to sign an agreement with the scheme committee where it is stipulated that:

- the group is responsible for the loan repayments of its members
- defaulting by a group will give the scheme committee the right to lease the group's water allocation, and if need be their irrigated plots for half a year to other groups or outsiders to offset its debts.

The *Scheme* signs the loan agreement with SISDO to be read together with the above-mentioned agreements. The agreement between SISDO and the scheme stipulates that:

- the scheme is responsible for repayments of its groups;
- defaulting by the scheme gives SISDO the right to cut off the water supply at the intake, for which the intake works are mortgaged to SISDO;
- Monthly scheme committee meetings will take place at scheduled times and venues with the SISDO loans officer to follow up loan repayments with penalties for absence and default.

LOAN CONDITIONS

1. Loan repayments start after a maximum grace period of an estimated 9 months. (Construction takes approximately 3 months and 6 months is allowed for harvesting of the first crop).
2. Following the grace period, principal and interest payments are made in 48 monthly instalments. Interest during the grace period is calculated into the total loan to be paid back.
3. The loan includes costs of technical assistance including investigations, design, and supervision of contractors as well as construction costs.

Figure 3.1c SISDO Fact Sheet No. 1:Irrigation Infrastructure

4. The loan is secured as follows:

- Farmers in the scheme have to show interest and commitment on household level as well as on group and scheme management level.
  - commitment by all farmers through 70% presence in meetings;
  - full commitment by women farmers has to be ensured through 50% presence in meetings and 50% representation in Committees;
  - strict adherence to a mutually agreed modality of deposit payments for the security fund;
  - provision of rooms for SISDO and MoA staff involved in scheme development;
  - down payment of half of the topo-survey costs.
- The scheme must pay a deposit of 6 monthly loan instalments.
- Each group guarantees repayment of its members' loans.
- The scheme guarantees repayment of its groups' loans.
- A chattels mortgage of intake works is raised.

Figure 3.1d SISDO Fact Sheet No. 1:Irrigation Infrastructure

3.4.3 Capital Equipment

The equipment required by farmers will to some extent affect, or be determined by, the design and the method of irrigation. For example, the field size on many smallholder schemes in Zimbabwe is limited by the need to get reasonable irrigation efficiency from furrows graded by animal-drawn ploughs. If the scale of work is too large for the farmers to manage themselves, the cost of contracting out work, possibly to an agency, will reduce the advantage to be gained from irrigation. Designers need to consider whether farmers will be able to buy or hire the necessary equipment, and the effects on the farm budget and scheme output.

At Nyanyadzi and Exchange schemes in Zimbabwe, farmers ploughed using animals. However, the returns from the schemes were insufficient to allow individuals to purchase cattle. Delays in planting sometimes occurred because farmers could not hire draft power on reasonable terms at the right time. Crop yields were affected.

In Kenya, ridged basins could be prepared with hand tools and serviced with back-pack sprayers at relatively low cost. The returns from small horticultural plots were sufficient to cover the costs of the equipment.

> **Example: Case study, Kibirigwi, Kenya**
>
> Farmers at Kibirigwi irrigate from a pressurized system using locally-made sprinklers. Although the scheme is potentially profitable, farmers have to invest substantial labour in maintaining the system, thus reducing the returns.

3.4.4 Capital and equipment - key considerations

1 Those benefiting from a scheme should invest their own capital or labour.

2 Scheme developers should be in a position to advise farmers on taking out loans. In the absence of collateral, credit organizations need assurance that the proposed developments have a good chance of success and that loans will be repaid. Formally constituted groups and clear agreements need to be established.

3 Farmers will need to take out recurrent credit to cover the costs associated with high value crops which can provide the necessary returns to pay off development loans and to accumulate reserves.

3.5 Infrastructure

The economic performance of a scheme can be strongly influenced by the standard of the local communications and infrastructure.

● Strong influence
O Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Communication infrastructure	O							●	
Agricultural suppliers	O								
Markets	●							●	
Extension	O		O	O				O	
Farmers' capital		●	●	●				O	
Credit availability	O	O	O	O				O	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					

3.5.1 Communications

The cost of inputs and the returns on harvest are obviously affected by the distance from local markets. Farmers must either transport fertilisers and pesticides to site from market or purchase them locally from an intermediary at a premium. In Kenya, crops may be sold on-site to buyers at agreed prices or transported to a market by growers. Middle men and merchants bear the cost of transport and the buying price is accordingly reduced. Merchants are therefore reluctant to purchase from remote schemes or where infrastructure is poor unless the quality of the produce can be assured or there are marked shortages in the market. For most smallholder schemes investigated, good road access was an essential element in the development.

Poor communications limit farmers' income by:

- Increasing transport time and risks, and thus the costs of inputs and outputs (though cooperation amongst farmers can reduce cost to individuals)
- Restricting crop choice owing to scarcity and cost of inputs
- Reducing the value of sensitive crops by damage in transit
- Limiting contacts with extension service workers

Good communications can improve incomes and sustain developments by:

- Simplifying the transport of heavy and bulky items, such as fertiliser and crops
- Allowing farmers to market an increased range of fresh produce
- Improving the transfer of experience and knowledge from extension specialists, and between irrigators from different irrigation schemes

Example: Case Study, Exchange, Zimbabwe

At Exchange scheme, which is sited a long way from the nearest town, farmers' income was restricted by difficulties in marketing green maize. There was insufficient local demand for the product. Transport was costly and sometimes unreliable. Inputs were scarce and could only be acquired against advance payments.

3.5.2 Social infrastructure

Irrigators need facilities such as schools, hospitals, and policing. Most smallholder developments are not directly linked to rural development programmes. However, the designer should be aware that:

- Siting an irrigation development close to good facilities will encourage farming families to remain in the area and to buy services locally.
- Siting a development where essential facilities are poor costs the farmer money, reducing the amount available for investment on the farm, for maintenance, and for development generally.
- Schools and hospitals are considered essential. Farmers at Exchange in Zimbabwe invested time, effort and resources in constructing a local school.

A site may appear unsuitable for lack of infrastructure despite the fact that land and water are available. In such cases, consideration should be given to including the scheme in an integrated rural development project.

Public Health

Clinics and hospitals play a particularly important role in developing regions. Irrigation may introduce water-borne diseases or aggravate existing health problems. Disease reduces the number of available working days, limits the output of labour and reduces the return to irrigated development.

Malaria is endemic in Kenya. However, local health workers considered that irrigation was not a primary cause of the disease, and that the general rise in living standards and nutrition resulting from irrigation outweighed any increase incidence of the disease.

In Egypt, virtually all surface water resources are infested by snails, the intermediate host for schistosomiasis. The disease has a debilitating affect on sufferers. Major national efforts are needed to reduce the incidence of schistosomiasis.

In lowland areas of Zimbabwe, schistosomiasis was found to be the major health problem amongst smallholder farmers. Irrigation is an important factor contributing to the spread of the disease. Recommendations from earlier HR Wallingford work at Mushandike to reduce the prominence of disease at source included:

- Engineering measures to reduce disease transmission as part of an integrated programme including education and treatment
- Well-constructed and maintained concrete linings help to reduce snail populations
- Free-draining hydraulic structures eliminate snail breeding sites
- Night storage and other reservoirs should be sited away from settlements
- Formal arrangements for water supply and sanitation are essential

There was significant reduction in the incidence of the disease in response to such measures.

A supply of good quality drinking water is of prime importance to health. A domestic water supply not only improves health, but also reduces the work in carrying water, traditionally undertaken by women. Wherever possible, water supply should be considered as a parallel development to irrigation. In Kenya, sanitation and water supply are not provided as part of development. Some 25% of the homes investigated had provided their own domestic water and nearly all had installed latrines. In Zimbabwe, where farmers worked at a considerable distance from their homes, sanitation was provided on the scheme. It is less essential when farmers work nearer home.

Schools
Schools are of major importance to local communities. Farmers in Kenya spend large amounts of money on transport and boarding costs for children at secondary level. Since education is considered essential, remote communities have difficulty in accumulating capital to finance maintenance or rehabilitation of the irrigation infrastructure and they give priority to building schools whilst the condition of the irrigation scheme deteriorates. Schools not only provided education but also a source of employment. In turn, local professionals from Kenya work for their own communities. In several of the schemes, local teachers are office bearers on irrigation committees.

3.5.3 Infrastructure - key considerations

1. Problems of transporting inputs and harvests at schemes remote from population centres must be identified at the feasibility stage. Realistic costs for transport and inputs must be included in financial and economic analyses. Designers and farmers must discuss the effects on farm budgets and consider whether a scheme can remain viable. In lieu of more detailed information, it is suggested that incomes might be reduced by around 20% when communications are poor.

2. Access is needed throughout the year.

3. The availability of social infrastructure, i.e. schools and health centres, must be considered during pre-feasibility studies.

4 Confirming Development Potential

The objective of the following section is to investigate in more detail the constraints and likely economic and financial returns to irrigated farming under differing inputs. It is expected that it will be necessary to supplement the initial investigations (Section 3) to ensure that a proposed scheme will remain attractive to farmers over the long-term. The focus is on the activities and support services associated with irrigated farming. It is aimed to summarize for planners the processes farmers must successfully master, so that they are in a position to make informed judgements about whether cultivators are ready and able to take up irrigated farming, and to identify where support should be given.

Sustained development requires that farmers achieve a satisfactory net income for their efforts. Conventional economic analyses (Section 4.3) are not good indicators of success. The planner should anticipate individual returns to a development by preparing typical farm budgets using costs and returns relevant to the area.

Potential sources of information are:

- District administration offices
- District agricultural services
- Published district "Profiles" (Kenya) and reports
- Local academic and research institutes
- Land registration offices
- Local elders and groups

● Strong influence
○ Influence

	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
RESOURCES									
Water source		●							
Water availability	●	○			●				
Water quality	●								
Sediment		●	○			○			○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

Farmers must make the best of the new opportunities offered by irrigation if they are to repay loans and increase living standards. They will benefit from the experience of existing smallholder irrigators. Most will have no alternative but to fund their investment through loans. They face the challenge not only of learning how to irrigate successfully but of covering production costs substantially greater than those associated with rainfed farming, of repaying loans, and of funding increased family expectations.

This section indicates the impacts of crop, land and water, other agricultural inputs, specialization in production and marketing skills on profits. Issues which must be addressed by designers, working together with farmers to ensure adequate supports for new developments, are identified.

4.1 Crop Choice and Farm Budgets

Crop choice may be affected by many of the factors shown in the matrix on the previous page.

Farmers must be in a position to make informed decisions to manage new enterprises. They must make good estimates of potential profit from the production processes available to them, (Upton, 1996). Judgements about the availability or otherwise of water, labour, input costs and marketing opportunities, require detailed knowledge about particular crops. The investigations in Kenya showed that fewer than 15% of farmers kept records, although most were literate. The preparation of a farm budget is a useful aid to decision-making (Dillon and Hardaker, 1980).

Prior to implementation, extension trainers need to focus their work on the special skills required by irrigated farming. Real farm budgets can be used as examples to encourage farmers.

In the following sections, the ways in which farmers match resources to opportunities are compared with outcomes in terms of yield and revenue.

4.1.1 Farmers' skills, knowledge, and the extension services

Extension advice is often generalized and directed towards problems in rainfed farming. What are the benefits of expert advice on irrigated farming?

The small schemes investigated in Zimbabwe were run by a specialist extension agency (AGRITEX). Contact with farmers was made about once every two months but the scope of information transferred was limited. However, where changes to the cropping pattern had been introduced, it was usually through the combined efforts of the farmers' committee and the extension service. The impact of extension on individual's decisions could not easily be judged.

On the farmer-managed schemes in Kenya, farmers were contacted by the extension service about once every four months, except on two schemes where there was greater support. In most cases, decisions on cropping were made by individuals. On the better-supported schemes, average yields and financial results were above average for all the schemes. (Summary Matrix 2, Volume 2). More generally, farmers considered that the available advice was poor because officers concentrated on problems of rainfed agriculture. Where extension staff concentrated on irrigated farming, farmers considered the service to be adequate. It was clear that even experienced farmers derived benefit from specialized extension advice.

Farmers prefer to spread risk and maximize the use of available resources by growing a number of different crops. Over the years, crops achieving a good yield and good returns gradually become specialities of the scheme.

The more successful irrigators characteristically benefited when several of the following circumstances were present:

- produce was graded and marketed on site
- scheme located near commercial centres

- extension provided good support

Farmers naturally tended to choose crops achieving better yields and financial returns. Good extension advice is clearly important to success.

Designers/developers should contact local extension agencies to investigate what services can be offered. If the service appears inadequate, farmers should be actively encouraged to seek advice, to contact other irrigators and possibly to share the services of a specialist from the private sector.

4.1.2 Agricultural suppliers, contractors or merchants.

Farmers must locate reliable commercial services to obtain a sustained income from irrigation. Evidence from Kenya shows that enterprising merchants may be willing to service relatively small schemes.

Local sources of supply help to keep down factor prices, for irrigators will have a range of products and prices from which to choose, and access to commercial information. On remote schemes, the costs of transport become onerous. Supplies and deliveries become unreliable. (Section 3.5.1)

In such cases, the designer/developer may need to assist in advising on, or initiating, links between farmers and firms who would be interested in arrangements for bulk supply or other strategies. Farmers will need credit facilities to make such solutions viable.

● Strong influence
○ Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Water source		●							
Water availability	●		○	○	●				
Water quality	●								
Sediment		●	○			○	●		○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

In some circumstances, it may be appropriate for farmers to contract out certain services. The use of agricultural contractors may be necessary when farmers are short of labour at crucial periods when the success of a crop is dependent on the timeliness of operations. Delay in land levelling or ploughing, can significantly reduce yield. At Arombo in Kenya, conflict arose over the managing agency's inability to provide essential services on time.

Farmers on the small communal schemes in Zimbabwe contracted out their ploughing. Contracts allow farmers to employ their available resources efficiently and remain productive despite labour shortages.

The expected margins to irrigation development need to be adjusted downwards if contractors will be used.

It is unlikely that contractors will have a role to play on small horticultural schemes.

4.1.3 Market opportunities

Farmers' decisions on irrigated cropping will be strongly influenced by market prices which may fluctuate widely, depending on climate, variations in supply and demand, and government policy.

Farmers will depend on information from outside sources concerning the demand and price of commercial crops. Group committees should give particular attention to acquiring good market information, as the successful development of outlets involves continuing effort in the face of changing circumstances. The extension services, the media, entrepreneurs and farmers' organizations will all have a role in helping farmers to select cropping patterns best-suited to the conditions of the market.

Circumstances favouring profitable sale are:

- Location. Schemes such as Kangocho and Kibirigwi (Kenya) and Nyanyadzi (Zimbabwe) are sited on main roads. Produce is readily sold by the farmers at little extra cost.

- Extension advice. Schemes at Kiguru, Kibirigwi and New Mataro in Kenya all benefited from effective extension support.

- Group marketing arrangements. Farmers' committees at Kiguru, Kwa Kyai (Kenya) and Exchange (Zimbabwe) had successfully developed their own grading and packing facilities.

Agencies and marketing boards had a poor reputation amongst farmers. Group marketing arrangements were found beneficial in increasing negotiating power and in improving quality control of produce. Groups specializing in the quality production of particular crops succeeded in attracting regular buyers.

4.1.4 Crop choice and farm budgets - key considerations

Unless progress milestones are agreed and the concerned irrigation authority monitors performance with the aim of providing assistance in the early years, there is a danger that farmers do not achieve the required returns from irrigation, and the scheme may fail.

Assistance may be needed in the following aspects:

- Extension advice. New techniques will be needed to obtain the production increases necessary to offset the higher costs of irrigated farming. Specialist advisers will be required. Government agencies may be short of appropriate personnel. Additional staff may need to be posted.

- Crop choices. Schemes specializing in crops directed at a niche in the market tended to be successful. However, the strategy may be risky unless farmers are well-informed about market prices and conditions. Farm records and budgets can help to plan and control expenditures but farmers in Kenya were not trained in the practice.

- Group marketing and quality control. Better prices can be obtained for prime produce marketed collectively. Existing, well-functioning schemes can provide models of cooperative working. The cost of transport from remote schemes may be such that farmers need to join together to hire a vehicle, if entrepreneurial buyers cannot be attracted to the site.

- Inputs. At remote schemes, it may be necessary for farmers to seek out potential suppliers located at some distance and promote agreements on the supply of inputs under suitable credit arrangements.

4.2 Costs, Yields and Returns

4.2.1 Expenditure on Inputs

Smallholder farmers will be strictly limited in the amount they can spend on inputs.

Provided the water supply is sufficient to meet at least 70% of assessed crop needs ("70% Adequate"), when required, yield and output will be greatly affected by the extent to which other agricultural inputs are used. Where the water supply is not reliable, farmers may initially try to improve yields by increasing the use of inputs, particularly fertilizer, but will rapidly conclude that the investment is not worthwhile and will revert to low input agriculture.

Farmers' spending on inputs for irrigated agriculture was generally found to be high relative to that on their dryland plots, indicating their broad understanding of the returns to be gained. Even so, the average use of fertilizer was below generally-recommended rates. Site-specific advice from a well-trained extension officer (Section 4.1.1) would help to improve outputs and income.

The need for a reliable source of inputs, at reasonable cost, regardless of where the scheme is located, was discussed in the previous section. In Kenya and Zimbabwe, farmers on schemes where communications were difficult succeeded in obtaining inputs by working together, and obtained good yields.

Example: Case studies, Zimbabwe

Two schemes in Zimbabwe were compared: Nyanyadzi, where inputs were readily available but the water supply was unreliable, and Exchange, where it was difficult to get inputs, but the water supply was reliable. At Exchange, a strong farmers' organization took responsibility for arranging the supply of inputs. Farmers there gained little from their rainfed plots and invested proportionately more on inputs for their irrigated plots than their fellow farmers at Nyanyadzi , obtaining yields some 45 % higher on average for the same crops (beans).

The example confirms that farmers must have confidence in the water supply before making substantial commitment to irrigation by organizing and investing in the inputs necessary to achieve good yields. It was found that expenditure on inputs was reasonably maintained on certain schemes where there was some shortage in overall supply, the effects of which could be reduced by introducing rotational operations between different parts of the scheme.

Table 4.1 shows that there is a difference in the pattern of spending on inputs between small scale farmers with relatively higher incomes, and those less well off. As might be expected, richer farmers allocate a high proportion of their spending on inputs to fertilizer, whereas poorer ones spend proportionately more of a smaller amount on labour. The results should be of assistance to planners in drawing up farm budgets. Brief notes on the individual components of the spending are included below.

Table 4.1 Distribution of input expenditure for irrigated crops

Input	% of total expenditure		
	Overall	**High income farmers**	**Low income farmers**
Seed	25	21	19
Fertilizers	24	45	12
Manure	4	4	5
Sprays	30	23	37
Labour	17	7	26

Seed
Spending on seed averaged some 25% of total input expenditure on horticultural schemes. Seed retained from previous crops is sometimes used to grow subsistence crops and also cash crops where the water supply is unreliable, but the results are poor. The extension services recommend the use of quality seed, and their advice is normally followed.

Chemical fertilizer
The high cost of chemical fertilizer means that all farmers use it sparingly, despite the obvious fact that greater use, up to a limit, will normally produce better results.

Manure
Manure is a cheap alternative to manufactured fertilizer, accounting for no more than 4% of total input costs (Table 4.1), but it involves a heavy labour cost. It is widely bought and sold on the small schemes. Animals are sometimes grazed on crop residues, particularly on rice-growing schemes. Almost 75% of farmers use manure, recognizing that it will also contribute to improved soil moisture retention.

Example: Case studies, Zimbabwe, Kenya

At Nyanyadzi in Zimbabwe, manure from the night kraals is widely used, whereas in Kenya, zero-grazing systems provide manure which can be easily transported to the point of use.

Sprays
Small quantities of pesticides are purchased on the small horticultural schemes, so the unit cost is relatively high, representing the largest proportion of the input budget of vegetable growers. The highest costs are associated with the growth of tomatoes because they need frequent spraying. Farmers spending heavily on sprays tend to reduce expenditure on fertilizer, so they obtain sub-optimal yields.

Techniques to reduce the use of pesticides, such as intercropping, bio-control methods and revision of plot layouts, are not always practical or obvious to farmers. Good extension advice can improve farmers' net income but it will be realistic to adopt conservative figures in drawing up farm budgets.

4.2.2 Yields

On schemes where notably good incomes were achieved, it was found that farmers concentrate on one or two crops. They create a steady demand for inputs which may encourage suppliers to deliver to site. Farmers who specialize in this way, concentrate on producing good quality, reliable crops to maintain market share. The circumstances and the opportunities which may be exploited by farmers will vary between schemes, so that general observations only are made here.

Farmers will probably see their interests best served by cooperating as a group, but the choice of crops is better left to individuals, provided that their decision does not have adverse implications for the water management of the whole scheme.

Successful farmers will provide a model for others to follow. Extension officers can encourage enterprise by illustrations from successful schemes, and by arranging for farmers to visit to see for themselves. Such visits are arranged in both Zimbabwe and South Africa, and appear to stimulate innovations elsewhere.

> **Example: Case studies, Kiguru and Mathina, Kenya**
>
> Farmers at Kiguru achieve a high yield from cabbages (32 T/ha) and potatoes (9 T/ha) and have developed a 'niche' market in mangetout and carrots. They manage well and make high incomes.
>
> Although farmers at Mathina achieve a good yield from maize (3.6 T/ha), the scheme is not well-managed, and incomes are relatively poor because the returns to maize are low. Farmers at the head of the scheme, where the supply is reasonably secure, are now turning to other crops (tomatoes, cabbages, kale).

4.2.3 Financial Returns

The uncertainties of agriculture tend to make farmers conservative. Faced with a new practice such as irrigation they will need help in making realistic judgements. They will have certainly estimated potential revenue when considering a scheme but they may not have realistically determined the net returns to irrigation. For example, it is difficult to anticipate the costs of necessary additional inputs and the possible loss of output/revenue from land already used for agriculture or other activities. Irrigation may also represent only part of all farm activities. The true effects of the new enterprise on existing activities may not be appreciated at the outset.
In the initial years the returns will be lower than would be expected from experienced farmers. At this time also, returns are particularly at risk from uncertainties in the market and fluctuations in the climate.

Anticipated revenue will not represent the true return to irrigation. It is important to remind farmers of the hidden costs of irrigation (such as loss of pasture or increased costs of labour).

Income will be revenue net of costs and the income derived from the land under previous use, if any. In discussion of farm-level financial returns, it should be brought to farmers' attention that household arrangements should motivate all individuals to support irrigation.

The development ministry or agency must be able and prepared to train farmers, and advise on these and other aspects.

4.2.4 Economic Evaluation

Governments and funding agencies may require formal, though brief, economic analyses to justify assistance and investments.

Costs and benefits from the present use of the land need to be established so as to derive the net costs and benefits arising from irrigated development. At this stage it will be possible to consider the returns to other possible uses of the land such as for rainfed agriculture, fuelwood production or small scale industry.

The capital and running costs of the development will be compared to the net returns from the intended cropping patterns after all input costs have been included. Estimates based on previous developments in the region need to confirmed by information derived from the field.

A project benefit : cost analysis which yields apparently satisfactory economic returns is not a good indicator for the sustained success of a project. Individual farmers must achieve a satisfactory financial return for their efforts. (Cavey 1988, Dey 1990).

4.2.5 Costs, yields and returns - key considerations

Planners need to anticipate problems and identify where farmers will need assistance to overcome possible constraints:

1. Farmers need to invest in inputs to make irrigated farming financially viable, but they will not do so unless the water supply is reliable. Shortage or excess of water reduces returns to inputs.

2. Small farmers typically lack cash-in-hand. The use of inputs can be improved if:
   - a farmers' group arranges bulk purchase
   - reasonable credit facilities are available
   - specialist advice on selecting the most productive inputs is sought

3. The techniques needed to make irrigated farming viable are different from the rainfed agricultural practices with which farmers and extension workers may be familiar. Planners need to identify possible skill weaknesses so that suitable support can be arranged, or advise farmers to employ services from the private sector.

4. Farm budgets may be drawn up on the basis of regional experience, but the effects of local conditions, particularly the location of a scheme relative to the intended market, need to be quantified.

5. Chemical sprays are particularly expensive. Alternative methods of control may help to reduce costs without leaving the crops vulnerable to pests and diseases. The potential for replacing manufactured fertilizer by manure should be investigated.

6. Farmers need to balance the risks and returns of specializing in production of one or two profitable crops. Whilst demand is good, farmers should be able to make a reasonable living. If the market changes, alternative strategies must be adopted.

4.3 Integration of Irrigation into Existing Farming Systems

4.3.1 Farm Level

Different elements of the smallholder farming system may complement each other or conflict.

Example: Case study, Kibirigwi, Kenya

At Kibirigwi, women are encouraged by SISDO, a Kenyan NGO, to undertake zero-grazing cattle rearing. A cow is provided on credit and advice provided on stall design, management and commercial practices. Fodder, grown as a boundary crop under irrigation, is brought daily from the fields.

The cow provides milk, manure and a calf annually, leading to a good profit whilst paying off the loan. Irrigated crops are not affected by the extra enterprise. By comparison, cattle reared elsewhere on the scheme under traditional management are less profitable. The advantages of the zero-grazing enterprise are fourfold: cash income, improvement in the situation of women, improved nutrition and

Irrigated cultivation and livestock enterprises often complement each other. Crop residues can be used for fodder, and manure for crop production. In Zimbabwe, draught animals assist in irrigated farming, although they are primarily kept for ploughing and haulage. Hand tools used in traditional Kenyan agriculture are also employed in irrigated farming. On rice – growing schemes near Lake Victoria in Kenya, a single crop is irrigated each year, employing labour which would otherwise be under-employed when there is no rain-fed agriculture. On the other hand, in some farming systems the available family labour force may not be sufficient to satisfactorily manage both traditional and irrigated tasks.

Example: Case study, Gem Rae, Kenya and Nyanyadzi, Zimbabwe

At Gem Rae, previously referred to, conflicting demands for labour to harvest maize and maintain the canal system led to delay in the rice season and poor returns.

At Nyanyadzi, the water supply in the lower part of the system was unreliable. Poor cereal harvests led to a shortage of fodder; reduction in the number of cattle held; shortage of draught power for ploughing; delays in land preparation and further reduction in yield, a downward spiral. The subsequent construction of a new pumping station was aimed at remedying many of these problems.

Planners should possess a working understanding of the interactions between irrigation and existing farming systems so as to be in a position to discuss with farmers the implications of potential conflicts in allocating available resources. Individuals will obviously vary in how they allocate resources, but they are unlikely to concentrate solely on a single irrigated crop. In evaluating the contribution irrigation can make, it is simplistic to consider irrigated gross margin simply as an additional income, for some existing enterprises are likely to suffer, whilst others may benefit. The overall effect on farm income needs to be established.

4.3.2 Scheme level

The Kenyan Ministry of Agriculture describes smallholder irrigation as "a bottom-up process which is demand-driven, community-managed and self-sustaining." To be self-sustaining, the community must be able to manage and maintain the system to provide a reliable supply. If the supply is not reliable, the irrigated enterprise and the farming system as a whole will suffer, as farmers concentrate effort on saving their irrigated crops.

Irrigation provides cash which may be used to buy food, probably from rainfed lands. However, in particularly dry areas, or where the water source is unreliable, farmers tend to irrigate some subsistence crops. Designers need to consult farmers' groups about how such needs can best be accommodated with available land and water. If farmers are willing to consider land consolidation, such that their irrigated holdings are contiguous, strategies for allocating limited water to all holdings at times of shortage may be possible.
The field studies showed that the rise in living standards due to irrigation leads to the establishment of businesses linked to agriculture and food.

Example: Case studies, New Mataro, Kiguru, Mutunyi, Kenya

New businesses have been established at, or near, the schemes at New Mataro, Kiguru and Mutunyi. Shops and eating places quickly developed. Without irrigation, local incomes would have been too small to support such enterprises. In less isolated schemes, existing commercial activity is boosted by irrigation.

With increasing pressure on available resources, it is essential to plan a scheme within the context of surrounding developments. In Kenya, the Ministry of Agriculture coordinates developments using District Profiles, which detail irrigation potential, existing schemes and proposals within an area, drawn-up on the basis of information from other government departments and NGOs. In the absence of such material, contacts need to be made with central and local government departments, local social and cultural groups. Tribal courts may also provide information on land rights.

Rights to water may be unclear or limited in definition. The water permit in Kenya sets a maximum abstraction but does not guarantee a minimum. Once realistic assessments of the probable monthly minima of the resource have been made, it may be necessary to draw up binding agreements with other water users both upstream and downstream, because schemes which have been designed on the basis of proportional water distribution may cease to function effectively if the incoming discharge is too small.

Example: Case study, Mathina, Kenya

At Mathina, the fixed flow distribution structures (division boxes) were damaged by farmers when the supply was short. The system should be designed for rotation during periods of low flow. In this case, the flexibility of operation might have been improved by making provision for stoplogs on the weir crests of the boxes.

Further issues which may require consideration during the detailing of a project:

- Access: existing tracks for people and cattle may need to be preserved.

- Cattle watering points : it may be feasible to provide watering points to compensate for loss of traditional open access to water

- Fish ponds: might compensate for restrictions on traditional fishing rights

Issues which cannot be resolved by discussion with the various involved parties may need to be resolved by the local administration.

4.3.3 Integration into existing farming systems - key considerations

1. The financial and economic effects of irrigation on other existing enterprises need to be quantified in drawing up typical farm budgets. The expected irrigated gross margin cannot merely be added to farmers' existing margins, for some existing activities will suffer, whilst others may benefit.

2. Failure in the irrigated component of the farming system may be aggravated by impacts on other dependent enterprises. Risks should be identified and discussed with farmers.

3. Existing stakeholders' rights to water and communal lands need to be clearly identified to reduce the scope for subsequent conflict. It will be necessary to contact local government and communities. Public meetings may be required.

4.4 Environmental Impact

Full environmental impact assessments are inappropriate for small scheme developments. Nonetheless, structured investigation should be made of aspects which could adversely affect a development.

In particular, the potential occurrence of waterlogging and salinity with surface irrigation schemes must be anticipated. If a real problem is expected, necessary remedial measures could be included in the design.

Irrigation can also aggravate water-borne health problems such as schistosomiasis and malaria. Integrated development plans will be needed if health risks are identified.

Irrigation can also reduce biodiversity and affect existing riparian interests.

Positive environmental benefits can result from a changeover from low-input rainfed agriculture, which often promotes erosion, to more formal agriculture. Basin irrigation can also help to improve soil moisture retention, reducing sheet flow which can occur under rainfall on cleared slopes.

The International Commission on Irrigation and Drainage has prepared an Environmental Checklist (ICID, 1993). The scope of the publication probably goes beyond the needs of small – scale development but many of the issues may be relevant.

5 Achieving Sustainability

The following sections are concerned with physical and institutional practices that contribute to, or endanger, the sustainability of developments.

For the purpose of the field investigations, those schemes where the area irrigated remained at least 90% of the design area were considered sustainable. Sustainability requires that farmers have an appropriate incentive, normally financial, for continuing to irrigate.

Of the schemes investigated, over 75% were sustainable according to the above definition, whilst irrigation continued on a reduced area on the remaining schemes. However, it should be pointed out that four schemes were directly supported by Government, so that the farmers were not meeting the full economic costs. It was also found, however, that on a few of the poorer schemes where the financial returns did not cover the farmers' true costs, they continued to farm, presumably because agriculture provided their traditional livelihood and opportunities for alternative employment were limited. Sustained schemes were normally well-maintained and farmers organisations were active.

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

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

5.1 Design, Intake, Layout and Delivery System

The designer is faced with a large number of choices concerning aspects of scheme design, construction, operation and maintenance. Necessary decisions extend from harder engineering concerns such as the type of intake, to softer choices about the type of distribution best suited to the potential irrigators.

The individual components of the system and the way in which they are combined must reflect the way in which the system will be operated and maintained, from field level up to headworks. Decisions on holding and block sizes, the irrigation stream, canal discharges and lengths, the types and sizes of control structures must accommodate amongst other issues:

- the method of irrigation
- traditional practices
- available operating hours
- the need for cooperative actions
- the relative locations of the scheme and homesteads

5.1.1 Intake structure

General

Many smallholder gravity schemes extract water from a river at a diversion weir. It was found in two investigations in Kenya that there was a wide range of quality in design and construction at such structures. Performance, in terms of providing adequate and consistent volumes of water to the schemes, was also highly variable.

On a scheme in Zimbabwe which was partially dependent on a pumped supply from a sand bed river, there were frequent problems with pump breakdowns. Spare parts were often unavailable. In this case the electricity supply was fairly reliable. Most of the scheme was served by a long, earthen canal from an intake on a tributary river. The headworks gate and flushing gate were not operated and had become unusable. Large volumes of sediment were consequently drawn into the system.

AGRITEX replaced both systems of supply by a single new pumphouse equipped with large capacity pumps, spreading the costs over the existing project and a new area of development.

In Egypt, on a scheme supplied by low pressure pipeline from the Mansouriya canal near Cairo, pumping capacity was severely constrained by the power supply network and by limits on the operational funds available to pay pump operators. Under the prevailing system of canal operation, the pumps could also only function on some eight days out of each twelve day period.

Pumped supply may be satisfactory if:

- the electricity supply is reliable
- adequate funds for operation and maintenance are available
- a stock of spare parts is kept at site
- the pump design is suited to the quality of the water (particularly transported sand)

The figure below shows how various factors can affect the choice of intake and how the intake in turn affects other design decisions.

● Strong influence
○ Influence

	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
RESOURCES / ISSUES									
Water source		●							
Water availability	●		○	○	●				
Water quality	●								
Sediment		●	○			○	●		○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

Small scheme developments are constrained by:

- Available construction skills and materials
- Economics. Costs must be spread over a relatively small area, and returns will be limited
- Available O&M manpower and skills

> The design must be functionally correct, whatever the size of the scheme. However, the scope of small irrigation developments may rule out solutions that may be considered for large schemes, because they are either not practical or not economically viable.

Some aspects of design are discussed below:

Location
The approximate location for the intake will usually be determined by the water levels required within the scheme. By suitably selecting the canal bed slope, a longer canal will correspond with a lower weir height. The relative costs must be set against the commanded area, which might be greater with a longer canal. The intake should be located wherever possible on the outside of a river bend to reduce the volume of sediment drawn in, and never on the inside. The channel reach should be stable and well incised, otherwise extensive training work will be required.

Foundations
The foundation material strongly affects the detailed design of the intake. Firm materials, ideally rock, will greatly simplify the design. More usually, gravels, sand or silty/clay material will be encountered.

The small scale of the work means that the designer cannot afford to include more than a small number of exploratory holes and a few soil classifications in the site investigation.

Trial pits and hand-operated augers can provide information on conditions in situ and samples for further testing. Soil classification and grain size distribution will allow the designer to estimate the engineering properties of the soil, such as its permeability, and to select a safe hydraulic gradient.

Small hydraulic structures usually do not fail because the foundation pressure exceeds the bearing capacity of the soil, but due to scour of the foundation, differential settlement, seepage or outflanking. Small weirs built on rigid foundations impose a very small pressure compared with the soil bearing capacity. However, the contact pressure must be low enough to avoid large settlements of the structure. In the case of flexible gabion weirs, settlement of the foundation is unlikely to create a problem. Table 5.1 gives the allowable bearing pressure on different types of soil corresponding to a maximum settlement of no more than 25-50 mm (Terzaghi, 1967). The stress under the foundation on different soil strata should not exceed the value given in the table, after allowing for dispersal of load with depth. In the case of small weirs on a rigid raft foundation, a 50 mm settlement should not significantly affect the water level to be maintained upstream of the weir.

Table 5.1 Allowable bearing pressures (spread footings and rafts) (t/m^2)

Type of soil	Max Settlement of 25mm	Max settlement of 50mm
Sand		
Loose	-	-
Medium	7 – 25	14 – 50
Dense	25 – 45	50 – 90
Very dense	> 45	> 90

The above information should be adequate for design. If more detailed data are required for any reason, the methods of soil testing and investigation established by the USBR (1965), may be followed.

Standard designs may be prepared following procedures included in texts such as Baban (1995). For the special design, the structure needs to be checked against seepage and uplift pressures, for which assumed parameters, based on the general soil type, should be adequate.

Flood Flows

Diversion weirs for small schemes will be designed to pass flood flows with a minimum return period of 25 years, and 50 years or above where hazard to life would result from failure. Small weirs on smallholder developments will normally have small impact downstream in the event of failure. However, the effect on the scheme itself may be catastrophic.

> **Example: Case studies, Kenya**
>
> Water for Kangocho scheme is abstracted at a weir across the Ragati River. The weir collapsed during seasonal floods in 1990. Farmers complain of a poor supply. Only 60% of the command area is now irrigated.

Short-term problems may include total loss of crops for that season. The acquisition of additional funds for repair or reconstruction of the weir may take considerable time and may seriously affect the ability of farmers to continue repayments on loans.

Backwater effects

The weir will be designed to raise water levels at medium-to-low flows and to minimize the backwater (afflux) under flood conditions. Once the crest level has been set according to the required command level, the principal variable will be the width of the weir.

In some circumstances it may be unacceptable to allow any significant afflux. If the water level under design conditions were to be raised by a metre on a river falling at 1 in 2000, the effect would be felt well over two kilometres upstream. Protection would need to be provided for existing infrastructure such as bridges, roads and buildings if the bank heights upstream were not sufficient.

It is common to set the weir width similar to the existing channel width. If an ungated structure is adopted and very little afflux is acceptable, a wide and costly structure may be needed to pass the design flood.

Controlled structures allow flood flows to be passed without afflux, and can reduce problems of sediment accumulation, but the gates may become worn, rusty or generally inoperable for lack of regular maintenance. Farmers are generally unwilling to post an operator full-time to the site which is often remote from the scheme. Stoplogs are a relatively low-cost method of controlling water level, but it may be hard to anticipate flooding. During floods it can be difficult, arduous and sometimes dangerous to remove logs which have been sealed against leakage during the dry period.

Changes to river bed levels

The construction of large weirs can lead to erosion of the river bed for considerable distances downstream and to accumulation of sediment upstream. The problem is less severe with small structures.

Excess energy of flow must be dissipated in a stilling basin or pool immediately downstream. Additional local bank protection in the form of rip-rap or gabions is normally provided. Rigid forms of protective pitching should not be used. A cut-off wall can help to resist seepage and also protect against back-erosion.

Example: Case study, Kiguru, Kenya

The intake for Kiguru scheme is located in a natural pool just downstream of a waterfall. The unprotected main pipe serving the scheme follows the bank of the river for some 0.5 km. The pipeline was damaged by boulders and floating debris brought down by a flash flood. Although farmers are well-organized and carried out necessary repairs, the extra cost of protecting the pipe from the outset would have been well-justified.

On rivers carrying high sediment loads, the river upstream can sometimes silt up to the level of the weir crest, causing major problems in the offtaking canal system.

Sediment exclusion/extraction

Where schemes derive their supply from springs, sediment is unlikely to be a problem. More generally, schemes sited downstream of eroding catchments may suffer to a greater or lesser degree from water-borne sediment.

Few of the intake structures on the schemes investigated were provided with means to exclude or extract sediment from the system. Sluiceways or flushing gates were generally not constructed. Removal of sediment deposited upstream of the weir became a difficult and time-consuming task which was rarely, if ever, undertaken.

Example: Case study, Gem Rae, Kenya.

Large quantities of sediment, mostly sands and gravel, are deposited annually in the main canal at Gem Rae. The farmers are poorly organized, failing to clear the sediment until long after the desirable start to the season. The season was prolonged, extra sediment was drawn in at the end of the season as a result of the delay, and yields were poor.

Generally, there are a number of possible solutions to problems of water-borne sediment, but they are not all equally effective nor are they all suited to small schemes, particularly the technical options.

- construct sediment excluders and extractors, such as settling basins, vortex tubes and vanes
- closing the intake gates when the river carries high sediment loads, particularly on flood recession
- clear sediment from the system either manually, or where possible and suitable, by machine. Farmers need to organize effectively and set aside funds for the purpose.

The first option requires specialist investigations, design, supervision and training in operation and maintenance. It is expensive and will only be suitable where a large command area can provide returns to justify the initial expense, and significant savings in the expenditures on channel clearance. The bibliography provides a number of references on such devices.

The second option requires farmers to change their operating practices and possibly to employ a gate keeper, at least during part of the year. The impact of the change would depend on the site. A good part of the annual sediment load might be excluded in some situations. In other circumstances, the load drawn in during normal flows might still create a substantial maintenance problem. Local investigations would be needed to guide an engineer.

The third option may be the only practical solution for small schemes, but it requires cooperative working to be successful.

Water control

The intake needs to be provided with means for “On-Off “ control as a minimum requirement. Regulation could also be achieved with a standard lift gate. Field investigations showed that head gates were rarely, if ever, operated. Nonetheless, the system may need to be shut down in an emergency, so a control must be provided.

Farmers need to be made aware of the consequences for downstream users, and also possibly for the local water table, of taking too much water from the river. It may be necessary to initiate a joint meeting of water users.

Extension workers can help farmers to assess how much water should be applied throughout the growing season and how to recognize when too much is being applied. Advice on suitable irrigation intervals and application times for stream sizes typical of the development will be needed. They could train farmers to focus on the use of water by using irrigation “spikes” to check the depth of soil wetting after irrigation. However, it must be recognized that if the supply and/or the climate are uncertain, farmers will adopt conservative practices in anticipation of dry periods.

Construction quality
Most intakes in Kenya were constructed of blockwork with a cement screed. Some cracking had occurred in the weirs and wingwalls, but the stability and operation of the structure were not affected. Where failures had occurred, the cause was usually settlement owing to inadequate foundations.

Overall the quality of construction was found to be satisfactory, with a few poor exceptions. This type of construction appears generally suited to the conditions, skills, and materials available on small schemes in rural areas.

Reservoir storage
The inclusion of a reservoir at the intake adds flexibility to operations but will usually only be practical on larger schemes where the cost can be set against greater returns.

Canals typical of small schemes provide negligible storage. Separate storage structures within, or adjacent to, the irrigated area have the following advantages:

- irrigation can usually be carried out during daylight hours
- the capacity of the main canal or pumps may be reduced for irrigation during only part of the 24 hour period
- pump operating costs may be reduced if they are operated at night when electricity tariffs are usually lower
- variations in demand, particularly following rainfall, can be evened out
- unplanned disruption to the main supply can be tolerated for a limited period

Disadvantages of storage structures are:

- cost; the initial investment needs to be set against the reduced costs of supply canals
- loss of potentially productive land
- progressive siltation and weed growth within the structure. Clearance is a heavy, time-consuming and therefore expensive task, most effectively carried out using machinery
- water-borne diseases, such as schistosomiasis, may be encouraged

The decision as to whether to provide storage depends on the relative availability of water, farmers’ irrigation practices, the availability and cost of land and the potential for reusing runoff from the scheme at sites elsewhere.

For schemes with an assured and adequate gravity supply where runoff can be reused downstream it is unlikely that storage will be justified. Where water is scarce, storage can help reduce waste and simplify management.

Storage will be required to balance out mismatches between supply and demand on pumped schemes where changes to the delivery can only be achieved by switching in or out modular pump units.

In most small schemes in Africa, farmers cultivating upland crops irrigate principally during daylight hours, occasionally extending operations at peak times or when the supply is scarce. In Zimbabwe, night storage reservoirs are almost invariably provided within gravity irrigation schemes. The practice has been carried over to the development of smallholder schemes. In

Kenya, the practice is rare. In new developments the designer is urged to consider the merits of providing storage in each individual scheme.

> **Example. Case studies, Kenya**
>
> The reservoir and dam at Kwa Kyai were built to serve the scheme and a local processing factory. The high costs of construction were therefore shared.
>
> The reservoir at Kiguru is filled with sediment, so that all storage capacity has been lost. There is no indication that allowance was made for transported sediment. It is unlikely that a practical and economic solution to the problem could be devised.

5.1.2 Scheme layout

Many factors influence the layout of a scheme, which in turn affects many other design parameters.

● Strong influence
○ Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Water source		●							
Water availability	●		○	○	●				
Water quality	●								
Sediment		●	○			○	●		○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

Assuming that the designer has correctly located ridges and gullies from the topographic survey so as to make a preliminary alignment of canals and drains respectively, and that soils, existing features and non-cultivable land have been mapped, attention can be turned to lower levels of the scheme.

Field layout/Application method

Small, ridged basins are commonly used in Kenya and Egypt to grow many types of crops. Intercropping is often practised. Basins commonly range in size from 3m by 3m to 10m by 10m, depending partly on the topography. They are simple to prepare, well-suited to smaller flows and do not require levelling to a high degree of accuracy. However, irrigation is a labour-intensive activity involving preparation and constant supervision during watering. In Kenyan practice, each farmer takes the entire flow from a tertiary canal. A discharge in the range 10 - 20l/sec can be managed by individual farmers. Farmers experienced in irrigation can organize the layout of their farms without affecting the overall scheme design, because the basins are so small. Typically, a small basin takes a few minutes for water to pond to the required depth. Skilled farmers are able to control quite accurately the amount of water applied, but investigations showed that there was considerable variation between plots. Efficiency of application was low when the plants were young and shallow rooted.

> Ridged basins allow farmers to vary crops and set the layout of their plots

● Strong influence
○ Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Water source		●							
Water availability	●		○	○	●				
Water quality	●								
Sediment		●	○			○	●		○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

Furrows are used in Kenya in locations where water is more plentiful. They are perceived to require less labour than basin irrigation, but they need good preparation and water management. In practice, low efficiencies are achieved, and problems of waterlogging sometimes occur. In Zimbabwe, furrows typically 70 metres long are graded by animal-drawn plough. Individual farmers are able to irrigate medium-light soils on flat lands sloping at less than 1 in 300 with a discharge of up to 30 l/sec, watering a dozen furrows simultaneously with a set of siphons. They typically achieve an application efficiency of some 50% by cutting off the flow at 70% of the furrow length.

Border strips, 3- 6 metres wide by 70 metres long are also commonly used in Zimbabwe. A discharge of 30 l/sec can be handled reasonably well on the wider basins in conditions similar to those described above.

Both furrows and border strips strongly determine the scheme layout at tertiary level. For good water application efficiency, the field dimensions and unit discharge need to be closely matched to soil and land slope.

Overhead methods of irrigation can be used over a wider range of topography than surface methods and therefore do not affect the system layout so directly. They are briefly discussed in Section 5.1.3, under Pipe networks.

Field water management
Rotations at field level should be as simple as possible. Complications are introduced if it is necessary to divide the flow between farmers. A "one-by-one" rotation, under which each farmer receives the water in turn, is therefore best.

Scheme layout is strongly affected by the scheduling of water at field level, as shown in the example below:

Example

Soils of medium moisture-holding capacity; furrow irrigation; a basic working week of, say, 60 hours; a peak crop demand of some 7mm/ day and typical irrigation application efficiency. What block size could be irrigated on a weekly interval?

Assuming a stream size of 30 l/sec, a weekly in-field irrigation of 50 mm could be delivered to a block of 8 hectares (net of unproductive land).

Tertiary unit layout
It is easiest to arrange an equitable supply to compact blocks of land. Long, extended blocks involve long channels and correspondingly larger losses for farmers situated at the tail. If the tertiary canal is limited to a length of some 800 meters, a rectilinear 8 net hectare block (perhaps 9 hectares gross), would be some 100 metres wide. It would be better, if the topography allows, to design blocks some 500 metres long, with the canal irrigating to both sides.

Example: Case study: New Mataro, Kenya

At New Mataro, farmers at the tail of tertiary canals became dissatisfied with the formal distribution system, since they received impractically small flows owing to the length of the canals. Some resorted to siphoning water directly from the main canal using flexible plastic pipes.

Communal schemes require cooperation between members. As the number of farmers required to work directly together increases, cooperation tends to break down. Small groups of cooperating farmers need to be formed. A group is considered to be a number of farmers served by a common water supply, such as an offtake from a secondary canal. The main tasks of the group are to organize water management amongst members, drawing up rotation schedules and maintaining local parts of the system.

The size of the group should be limited by the needs of good water management, considering:

- the area which can be effectively irrigated by a manageable stream size and canal discharge within the critical rotation period
- the number of farmers who will have to cooperate

Design practice in Kenya limits the number of farmers in a group to an absolute maximum of 30. In practice, it is better to work with smaller numbers, 15-20 is recommended.

Experience from Egypt showed that individual farmers, served by direct outlets from the system, were at a distinct advantage compared with groups when it came to obtaining water. A minimum size of group is therefore desirable, set at 10 farmers in Kenyan practice.

For land holdings averaging 1 hectare gross, the minimum number of 10 farmers would occupy a block sized at 10 hectares gross, similar to the figure in the example above. For holdings of 0.5 hectare, a block would include some 18 farmers, a number close to the desirable upper limit.

Example: Case study, El Hammami, Egypt

Each outlet from the low pressure pipeline installed at El Hammami served a number of farmers on an existing mesqua, or open watercourse. Some served fewer than five farmers, whereas others had to supply more than twenty. In an extreme case at the tail of the system, 78 farmers were included within the command area of the outlet. In practice only 27 received water. The system of water distribution was highly complex, requiring rotation between outlets and between farmers below the outlets.

Outlet no.	No. of farmers in the command	No. of farmers actually served
4	31	21
5	11	10
7	29	22
10	22	12
19	47	27
20	21	21
22	17	17
26	78	27
27	12	7

5.1.3 Delivery System

The functioning of the distribution system affects the overall performance of a scheme. Should a canal system or pipe network be used? Should canals be lined? What are the relative efficiencies of different designs? What are the implications for operation and maintenance?

The selection will be influenced by factors shown in the matrix on the next page.

Design for operations

The intended operational pattern of the system also strongly affects the design capacities of individual components. Soil, crop, climate and farming practice will influence the operating hours in any given period. Water at any level of the system might be supplied continuously, or according to many possible patterns of rotation.

A system of continuous flow at all levels of the scheme is usually adopted on rice-growing projects. At the lowest level of distribution water is continuously provided to all groups simultaneously. Within the group, supply may be continuous, passed from field to field in the case of rice schemes, or rotated between group members (upland crops) for a period related to their holding. Each group becomes effectively self-managing, so less formal organization is needed at scheme level. The procedure is easily understood by farmers. An assured supply is required so that canals can operate at their designed discharges and levels.

Designers must be realistic about the number of hours for which farmers will normally irrigate. In many parts of the world, farmers will be unwilling to irrigate at night. If the system is based on 24 hour irrigation, the canals will be undersized. Yields and planted area will be lower than expected. Farmers are unlikely to shut off supply at the head of the system at the end of the working day, so provision should be made for storing excess water (section 5.1.1) or for passing it back to the river.

● Strong influence
○ Influence

RESOURCES / ISSUES	Crop choice	Intake design	Distribution method	Application method	Scheme layout	Labour requirements - operation	Labour requirements - maintenance	Marketing strategy	Recurrent costs
Water source		●							
Water availability	●		○	○	●				
Water quality	●								
Sediment		●	○			○	●		○
Climate	●		○	○					
Topography	○	○	○	●	●	●			
Soil type	●		○	●		○			
Soil depth	●			●					
Land tenure			○		●	○	○		
Labour availability	●			●	○				
Communication infrastructure	○							●	
Agricultural suppliers	○								
Markets	●							●	
Extension	○		○	○				○	
Farmers' capital		●	●	●				○	
Credit availability	○	○	○	○				○	
Farmer knowledge/skills	●		●	●				●	
Local artisans			●	●					
CROSS-LINKAGES									
Crop choice				○		●		●	
Intake design							○		●
Distribution method				○	●	●	●		●
Application method					●	●	●		●
Scheme layout						●	●		●
Labour requirements - operation									○
Labour requirements - maintenance									○
Marketing strategy									
Recurrent costs									

Example: Case study, Mathina, Kenya

Owing to developments upstream, the water supply at Mathina has decreased markedly within recent years. Farmers have constructed their own on-farm reservoirs to store water that would otherwise be wasted. The structures are either well-constructed of masonry, supplying low pressure sprinklers, or hand-dug pits from which water is lifted manually or by diesel pump.

The pattern of operation of small schemes is strongly affected by the operational capability of the available personnel, leading to practices which differ from those on large agency-managed schemes. On the latter, upland crops may be irrigated under a rotational supply at the lowest levels of the system during times of normal water availability. In the face of increasing water scarcity, rotational supply is often introduced at progressively higher levels of the system. On small schemes, the response to scarcity is commonly to reduce the area being irrigated, by excluding areas at the tail of the system.

Example: Case study, New Mataro, Kenya

The original rotation schedule at New Mataro was based on each farmer having rights to the water for one day in each rotation. This encourages equity since the landholdings were all approximately the same size. Since then some of the plots have been divided but the farmers have not accepted that their entitlement to water should also be reduced. Thus the irrigation interval is now longer than before and disputes often arise between farmers who need to water their crops more often. The farmers' committee should devise a new schedule under which the time of supply is related to the landholding size.

Canal Design

Earth canals can be relatively cheap to construct, using farmers' labour under overall technical control to ensure quality of workmanship. They do not require specialist skills for operation and maintenance. Poor design, construction or maintenance can seriously affect the proper functioning of the scheme.

At Mutunyi scheme in Kenya, up to one third of the supply is lost in the intake canal alone. Poor scheme performance can be attributed particularly to inadequate desilting of canals. Division structures easily become drowned and ineffective if the downstream water levels are raised by siltation. Farmers are likely to respond by tampering with the structures to the disadvantage of the scheme as a whole.

Many standard texts deal with the detailed design of canals (see bibliography). In Kenya, the Irrigation and Drainage Branch of the Ministry of Agriculture possesses design manuals which include tables for canal design. An extract from a table is included below:

Table 5.2 Extract from "Tables of dimensions of small canals", IDB, Kenya

Q_{design} (l/s)	Strickler k_m	slope (%)	Bed width (m)	flow depth (m)	vel at Q_{des} (m/s)	free-board (m)	Canal depth (m)	Q_{max} (l/s)	k_m at Q_{max}	vel at Q_{max} (m/s)
20	15	0.20	0.40	0.20	0.17	0.10	0.30	57	2.0	0.27
		0.50	0.30	0.18	0.24	0.12	0.30	74	2.0	0.41

Small canals will usually have steeper bed slopes than larger ones. The bed slope of tertiaries should normally be taken approximately the same as the land slope if the network has been orientated correctly. The alignment must take account of existing field layouts, if any.
The average velocity of flow at design discharge should be within an upper limit, to avoid erosion, and a lower limit to avoid sediment settling out. The bed slope should not decrease down the network so as to maintain the transporting power of the flow.

Realistic assumptions must be made about the effective roughness of the channel after time has elapsed. Poor maintenance commonly makes channels rougher than assumed at the design stage. Conservative assumptions can lead to a channel somewhat over-designed. However, small channels are commonly designed to minimum dimensions imposed by prevailing methods of construction, so the implications for cost are unlikely to be significant.

Tertiary channels tend to lose proportionately more water than larger channels because of their large surface area relative to small rates of flow and the fact that they receive heavy usage at the hands of farmers. As a result farmers at the tail of tertiaries often receive little or no water. The channel length should be strictly limited to reduce losses and to keep the block size, and the number of farmers who must cooperate in water use, to a workable number. In more permeable soils, a maximum channel length of 1 kilometre may be too great. Farm channel lengths should not be extended to compensate for short tertiary canals, otherwise overall losses will be greater still. The canal layout needs to be designed with sufficient density of canals to adequately serve the blocks (Section 5.1.2).

Section 3.1.2 dealt with losses in conveyance.

Conveyance efficiency should be referred to unit length of canal , alternatively loss should be calculated per unit area of wetted cross section. Otherwise, inequity of supply is almost guaranteed from the outset.

Where the irrigated land is scattered and not contiguous, the total length of canals will be greater than otherwise need be. If water is short and distribution losses are likely to be high, the possibility of consolidating the land in one area should be considered. Otherwise, the alternatives are to limit the total area to be irrigated, line the system or introduce a piped supply.

Lining

A decision to adopt lined channels over parts, or the whole of, a system should be based on realistic assumptions about the amount of water which can be saved, its real value in terms of increased production, the cost of lining, and possible operational improvement.

There are circumstances where advantages to be gained from well-constructed lining outweigh the cost. For example, lining could be suited to long intake channels through permeable soils, where it is difficult to gain access for channel clearance.

Lining is normally considered to reduce problems of seepage. The rates of loss given in references such as Irrigation Canal Lining (FAO, 1977) apparently provide clear justification for lining in many circumstances. However, experience from around the world shows that poorly constructed and maintained lining can rapidly become functionally ineffective, although still apparently quite sound structurally. Since a defect in a solid lining is generally much more permeable than the underlying soil, a relatively few cracks and leaks can destroy the resistance of a lining to seepage. In more severe cases, the rate of leakage may rapidly revert to a value determined by the permeability of the base soil. Linings should have an effective life of some 25 years.

Decisions about lining should start from a realistic understanding of the likely future condition of the system once the first years of operation have elapsed.

The functioning of existing systems using lining methods proposed for the new development can be rapidly checked by simple field measurements to determine losses within, say, a kilometre length of channel.

Example: Case study, Kwa Kyai, Kenya

The main canal is lined for the first two thirds of its length. Thereafter, between 33-50% of the flow is lost in sandy soil. The overall water supply to the scheme is inadequate, but farmers at the tail suffer particularly from shortage.

Pipe Networks

Pipe networks for smallholder developments are increasingly being considered in Kenya and elsewhere. Farmers observing commercial operations using sprinkler and drip technologies are motivated to follow suit, without necessarily understanding all the implications. As water becomes increasingly scarce, the advantages of reduced seepage loss, and better control become more attractive.

Sprinkler systems also offer the farmer the potential for on-demand irrigation, greatly increasing the flexibility of operations.

There are many examples where the attempted introduction of new irrigation technologies into existing farming system has failed. Farmers must have the means, the skills, the incentives and the support to successfully manage new technology. Only high value crops produced by improved agricultural practices can provide returns to offset investment in pressurized systems.

The following questions need to be asked:

- Have the farmers the necessary skills and knowledge to operate and maintain of the equipment?
- Is their organization competent to hold stocks of spare parts, or to purchase them at short notice?
- Are they proposing to grow high value crops for market?
- Have they a realistic understanding of the true returns, net of additional inputs, and the true costs of the initial purchase of the system, its assembly/construction, and continuing maintenance?
- Are local extension workers able to provide support for irrigated agriculture based on piped/sprinkler systems?
- Are local suppliers and skilled technicians available to provide support both initially and subsequently?
- If it appears feasible to introduce improved technology what type of system is most likely to be successful in the given circumstances?

The issues are discussed in detail by Cornish (1997).

Pipe designs may be considered in two broad categories, high pressure systems operating at heads of 2-4 bar (200-400kPa), and low pressure systems operating under a few metres head of water. For the present purposes, in the latter category are included pipe networks linked to both pressurized application methods (sprinkler and drip) and to surface application by existing methods.

High pressure systems were originally developed for use with fixed or moveable rigid pipelines, but are now also associated with draghose irrigation, widely adopted on government-sponsored smallholder schemes in Zimbabwe.
Low pressure systems are taken to include more recent developments such as drip and bubbler systems, but also pipelines conveying water for surface irrigation - as introduced on a limited basis in both Zimbabwe and Egypt - and the type of gravity-fed sprinklers adopted by farmers at Kiguru scheme in Kenya.

Example: Case study, Mansouriya, Egypt

The low pressure pipelines at Mansouriya replaced an existing minor canal serving some 500 farmers. Originally designed with 4 combined outlets on each mainline, the system had to be modified after protests from farmers that an outlet was needed at every existing field channel location. In consequence, it was not possible to operate the system on demand, as the pressure fluctuated widely. A system of rotation controlled by the Ministry of Water had to be used. The experience emphasises the need for farmers to be involved in design from the earliest stages, and for functional water user groups to be formed in advance of construction.

Example: Case study, Kiguru, Kenya

The scheme is successful owing to a combination of good water supply, user-friendly design, equitable water distribution, good choice of crops , effective marketing and a good committee. The main pipeline consists of PVC pipe, operating under a maximum of 5 meters of gravity head, constructed by the Ministry of Water of the time. Farmers advised by the Ministry of Agriculture make their own connections, cementing in 25mm PVC pipes to which they attach locally-made ('jua-kali) sprinklers on 12mm rubber hose. Each farmer has two sprinklers. There appears to be little seepage from the main line, but water is lost on farm at valves and poor joints. Overall scheme efficiency is 60%.

Low pressure systems involving simple, branched networks which are easily operated by farmers appear well-suited to selected smallholder schemes, particularly where the sprinklers are manufactured locally. The equipment is cheap, robust and can be repaired and maintained using locally-available technologies.

Farmers appeared fully conversant with the system in Kenya. Scheme performance was significantly better than for the surface schemes, although less good than commercial schemes. Application efficiency was typically 75% as compared with 55% by surface methods.

At Kiguru, the sprinklers were operated off a line from an existing canal system. The wetted diameter was up to 5 metres. There were some defects in the network design. A number of farmers at the head of the system received less water than others, owing to low operating pressure.

Less labour was required for operation in comparison with surface irrigation and with rigid pipe systems which need to be moved frequently. Labour thus freed was diverted to other agricultural activities, such as weeding, which can improve the quality of produce. The system allowed farmers to work elsewhere as the sprinklers were left unattended for an hour or two before the next move.

It is unlikely that the systems require less maintenance than surface irrigation schemes, although the nature of the tasks is different. Designers asked to advise farmers who wish to introduce similar systems should prompt them to obtain first-hand knowledge from farmers elsewhere.

High pressure systems are less likely to be sustainable on smallholdings unless there is already a strong tradition of use on local commercial schemes and farmers have gained first-hand operational experience, perhaps as employees. A strong local industry and dealer network is also essential to provide support. Difficulties can arise with imported equipment if spare parts are not readily available.

5.1.4 Water Division

Proportional division

Proportional division structures are the simplest and most robust way to divide water between irrigation blocks. Supply is split automatically between offtaking channels according to the length of the corresponding weir crest, which should be related to the size of the commanded area. Standard division box designs were used on many of the Kenyan schemes investigated. They were found to be successful in achieving equitable distribution of the available flow, as compared with systems where the flow had to be adjusted manually by farmers. The structures are easily understood by farmers so disputes over water can potentially be resolved on a rational basis.

Every time that flow is divided, there is potential for inequity and disputes. The Irrigation and Drainage Board, Kenya, works to two simple rules, illustrated in Fig. 5.1:

- water should pass through the minimum possible number of division boxes between the head of the scheme and the farmer.
- it is best to divide flow in a proportion close to 1: 1. Division ratios exceeding 1:5 should be avoided.

The structures are constructed of concrete blocks to a reasonable standard by local artisans. Careful supervision is required to ensure that the foundations are adequate and that the dimensions and levels of the weir crests are correct. If a fall in level is provided across the structure, the designer must be aware of the possibility of damaging seepage and should provide extra downstream protection to guard against erosion.

Under normal circumstances, division structures are designed so that the discharges are proportional to the downstream commanded areas. Field investigations showed that in practice, head end blocks received a supply which was on average 87% adequate, in other words, full crop needs were satisfied some 87% of the time. On the other hand, supply to tail end blocks was found to be just 48% adequate. The problem was exacerbated by the prevailing design practice of using a fixed value for the conveyance efficiency of a channel at a given level of the system, whatever its length. As discussed in section 5.1.3, conveyance efficiency should be referred to unit length of canal. The weir length serving longer channels would therefore be increased in length to provide a more equitable distribution.

It was difficult to introduce rotational operation at times of limited supply.

> Division structures should be designed to allow rotations by making provision for stop logs on the weir crest, or otherwise.

Poor maintenance of the downstream channels can cause some or all of the weirs on a structure to become drowned out, with the result that control of offtaking discharges is lost. Farmers need to be trained to recognize drowned structures - perhaps marks can be made on the structure to show design water levels - so that the issue can be raised with the committee and appropriate maintenance actions initiated. If there is sufficient head available on the scheme, it would be possible to design for a drop in bed level in the offtaking channels immediately downstream of the structure. The structures would become less sensitive to the condition of the channels, but the need for maintenance would merely be delayed, not eliminated.

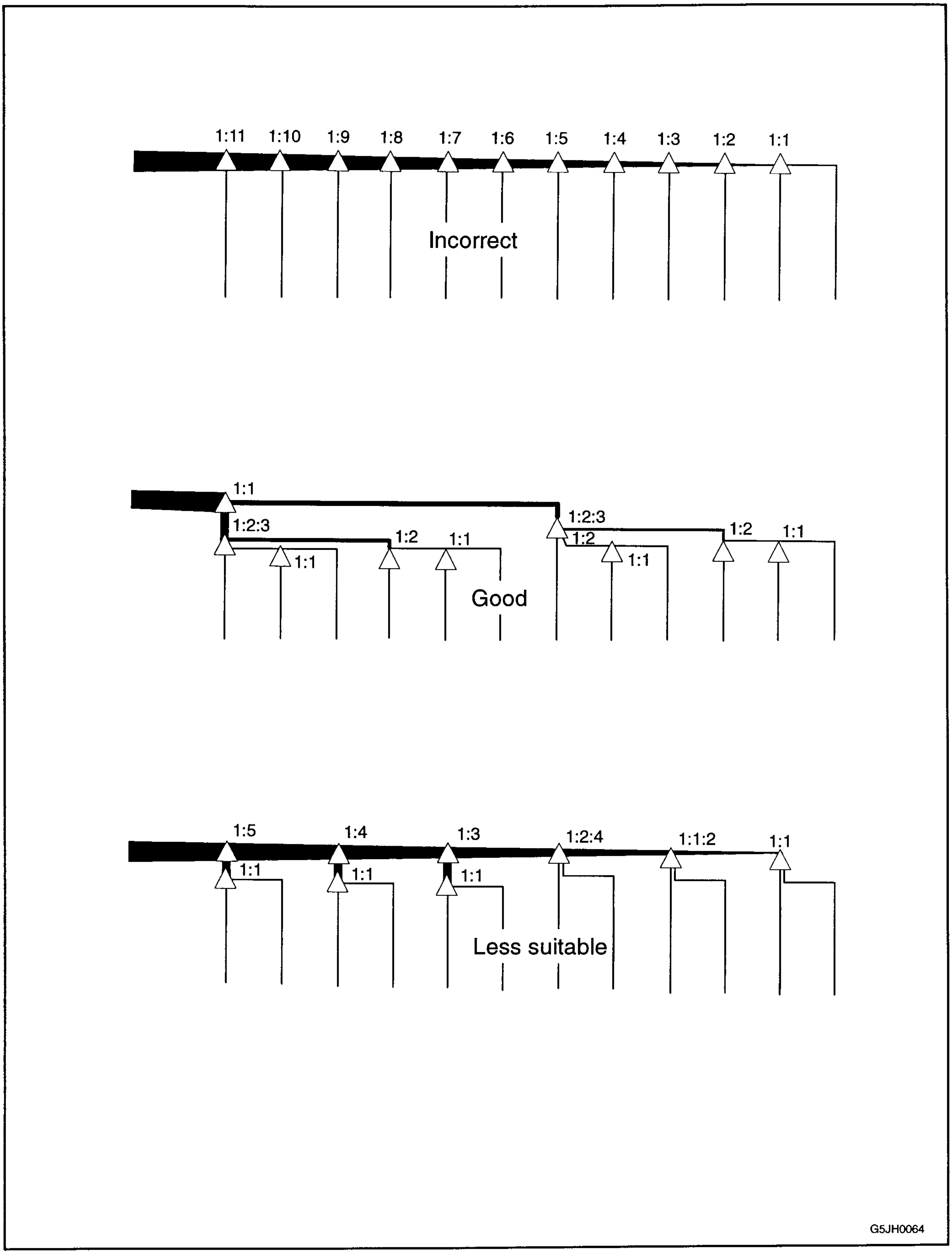

Figure 5.1 Water Division Ratios (After IDB, Kenya)

Orifice structures
Orifices, gated and ungated, are widely used instead of weir structures. Orifices include pipes and traditional gated check structures as well as more modern water control structures depending for their operation on the local water levels. Gated structures apparently offer more precise control over discharges, however they are particularly prone to unauthorized operation or damage by farmers. Experienced operators are required if the gate is to be used to regulate discharges and not merely to work open or closed. In the former case it is hard for farmers to detect improper operations, even when the structure always operates fully undrowned, a situation quite rarely encountered. Orifices will also be more immediately affected than weirs by the condition of the downstream channel.

Gated offtakes, intended to allow variable discharge, were used on two schemes investigated in Kenya. At Kamleza, undisciplined operation of the structures contributed greatly to the poor performance of the scheme. At SW Kano, the ability to provide variable flows allowed flexibility of operations. However, the scheme is managed by the irrigation agency, and not by farmers.

Choice of structures
Designers should be aware that weirs are more effective than gates in maintaining a fairly constant water level under a range of flows. However, gates will maintain a required discharge better than weirs if the water levels fluctuate. It is therefore not advisable to use gated checks in a canal with weir offtakes because changes in supply will cause unequal changes to the discharges in offtaking canals upstream and downstream of the structure. It may be that a gated check structure is required, for example to pass sediment or control rotational supplies at times of shortage. In such cases, a gated check equipped with side weirs to pass excess flows will help to reduce imbalances in distribution. Generally, similar types of structure should be used both on the parent and minor channels.

Inequity of supply leads to unwillingness on the part of unfavoured farmers to contribute equally in group responsibilities.

Example: Case study, Nyanyadzi, Zimbabwe

Farmers cultivated four separate blocks, one of which was particularly favourably sited relative to the main water supply, and two of which were poorly served at the tail of the system. Water was regulated by gated orifices under the control of the managing agency. Farmers' groups were too large for efficient functioning. Members lost faith in the ability of the committee to solve problems of inequity of supply so there was little cooperative working.

On the basis of field investigations, fixed weirs appear better suited to small schemes than orifice structures.

5.1.5 Drainage
The initial investigations should have eliminated from consideration sites which are prone to damaging flooding and waterlogging, since the cost of the necessary remedial measures to make a site suitable for irrigated production is unlikely to be viable for small schemes.

It is obviously desirable to select schemes which, by suitable design, will not require extensive drainage works. In particular, subsurface drainage is unlikely to be economic for small schemes. However, increasing pressure to develop available land and water resources may mean that surface drainage, is required. Sites which are potentially at risk from progressive drainage problems, will be characterized by some of the following:

- poorly draining soils
- low surface gradients
- a water table already close to the surface
- an underlying impermeable layer

Failure to consider drainage needs during design can have serious consequences and make the scheme unsustainable. In the short-term, crop yields may be reduced by waterlogging. In the long-term, severe damage can be caused to the soil and the environment through raised water tables and soil salinity.

The strategy to be adopted will depend on the origin of the problem, its likely severity, and the rate at which it may develop. There are major differences between systems designed to clear surface runoff, and those to remove excess irrigation water in arid/semi arid areas. Drainage design in the wetter parts of Kenya will be determined principally by rainfall, whereas in Egypt problems are directly linked to irrigation and the ground water table.

In cases where it is expected that problems will develop relatively slowly, it is sometimes possible to delay the construction of drains until shortly before they start to become necessary. However, this practice depends on funds becoming available at a later stage for the drainage works. Experience has shown that even on large, government-run schemes, implementation of staged drainage works is often delayed until major problems have arisen. It is therefore not recommended for small scheme developments.

Rainfall: in wetter climates it is impractical to attempt to provide drainage for the maximum rainfall which is likely to occur within the lifetime of the scheme. Firstly, schemes are designed on the basis that reliable outputs can be achieved in four years out of five. Secondly, it is not necessary to clear instantaneously the peak runoff from a selected rainfall event because all plants can tolerate some degree of flooding. Drains must remove the total runoff from the event, which would commonly be either a two day or three day rainfall at 1 in 5 years return period. The shorter event would be suitable for upland crops, the longer for rice.

Crops, including rice, are sensitive in differing degrees to the timing, depth and duration of surface flooding, sensitivity varies also with the stage of growth. Information on the effect of flooding is very limited. For rice, it is commonly taken that there will be no yield reduction if water stands up to 150 mm above normal for a maximum of 3 days. Wheat, cotton, citrus and fruit trees show medium tolerance to flooding whilst maize, beans and tobacco are particularly sensitive.

Subsurface: design coefficients for subsurface drains are normally a depth or volume to be removed within 24 hours. The aim of design is to maintain the water table midway between drains at a depth which will be clear of the crop root zone and thus remove constraint on yield. The unit discharge or depth is usually smaller than for surface drainage. Design practice is set out by, for example, the International Institute for Land Reclamation and Improvement (ILRI, 1972) and the United States Department of Agriculture (USDA, 1971).

The design drainage requirement is commonly expressed as a drainage coefficient, which represents the average rate at which runoff must be removed within the selected period. The coefficient may vary with the size of the area to be drained, and is expressed either as a volume (litres/second/hectare), or as a depth (mm/day).

As an example, in Kenya a surface drainage coefficient of 15mm/day (1.75 l/sec/ha) is used in small scheme design. It should be adequate for locations in the higher rainfall areas around Mount Kenya.

In Zimbabwe, a general surface drainage coefficient for small schemes is 12 mm/day (1.4 l/sec/ha).

In the Nile Delta in Egypt, a design figure of 1mm/day (drain spacing) and 2-3mm/day (pipe design) is commonly used for subsurface drainage design.

5.1.6 Operations

Farmers often interfere with the proper functioning of division structures, particularly where water is scarce and the scheme committee is weak, for example, the practice of obtaining extra water by piping supply direct from the main canal was common in Kenya.

Before commissioning a scheme, designers should discuss with farmers the introduction of a rotational system of operation at times of water shortage. Under low flows, losses are proportionately much higher and it is harder to manage the available flow. Rotational operation might be triggered by an observation at the headworks that the water had fallen below an agreed level, corresponding to a supply say 70% of requirements. A simple but practical pattern of operations will need to be worked out jointly.

Proportional division structures could be designed to include provision for stoplogs, sliding in grooves or metal frames above the weir crest.(5.1.4)

Flow measurement
Unlike large schemes where operations personnel are required to set variable flows, there are unlikely to be trained individuals on small schemes designed for proportional division who will be able to make use of information on discharges.

It will be important to provide a measurement point just downstream of the intake so government personnel, or others, can check the quantities of water drawn in by the scheme. The weirs on division boxes will provide a good measure of flow at lower parts of the system, if required. Separate flow measurement structures should therefore not be necessary.

5.1.7 Key considerations

1) **Intake:** Establish the location for the intake. Assess suitability of foundation material. Design so that flood flows can be passed safely. Consider effects upstream and downstream. Assess whether provision is needed for sediment exclusion/extraction structures.

2) **Distribution:** Are canals or pipes to be used for distribution?
If canals, use recommended design methods or tables of standard values. Use appropriate roughness coefficients. Check that flow velocities are acceptable. Limit tertiary canal lengths. Check the economics of canal lining against a reduction of, say 50% in water savings assumed according to standard texts. If a marginal benefit can still be achieved, then lining is likely to be justified.
If pipes, can a low-pressure, gravity fed, system be installed? Keep the design and layout simple. Check that farmers and extension workers have the necessary skills and knowledge. Is there an adequate network of suppliers of equipment?

3) **Division:** Where possible use proportional division structures. Design for rotation during periods of low flow. Division ratios should be as close as possible to 1:1 and not exceed 1:5. Water should pass through as few division structures as possible.

4) **Application:** Small ridged basins are recommended and allow flexibility for farmers. Application efficiency will vary widely but can average between 50 and 60%. Substantial water savings can be made with sprinkler irrigation and locally manufactured equipment is recommended where available.

5) **Group Layout:** Divide schemes into tertiary groups and if necessary into larger secondary blocks. Groups should be limited to between 10 and 30 farmers, preferably less than 20. Limit flow rates to groups to between 10 and 30 l/s. Tertiary canals should be less than 1 km, long, preferably even shorter, but don’t make farm channel length excessive as a result!

6) **Drainage:** Check that drainage is adequate for the design runoff.

5.2 Scheme management: institutions, organizations and O&M

The two most common arrangements for managing smallholder irrigation schemes are:

- Farmer-managed schemes, with advice and assistance from a government irrigation department or agency
- Agency-managed schemes where a management fee is charged and a farmers’ committee assists

In the last two decades, both models have been promoted in different countries/regions.

The choice of system will probably be determined by financing. The water management performance of schemes under both types of management was found to be rather similar, some 45% overall. Provided farmer-managed schemes are properly established they have been found to be sustainable, even if the general level of maintenance is poorer than on agency-managed schemes. It is likely that it will be increasingly hard to justify the employment of government staff on schemes of this size.

5.2.1 Farmer-managed schemes

General

Farmer-managed schemes are models of self-determination and capacity building and are therefore attractive to governments trying to reduce spending. They must cover the recurrent costs of operation and maintenance. They are self-financed or financed through loans to the farmers' group. Farmers are supposed to participate at all levels of decision-making.

A strong management committee is essential for good performance. Schemes performing badly, with extreme inequity of supply, were characterized by:

- Inactive and poorly supported management.
- Conflict
- Poor maintenance

Where irrigation contributed only a small part of the total farm income, management was given a low priority. In general, committees were poor at solving the problems of minority groups, such as women and tailend farmers.

Example: Case studies, Kiguru and Mathina (Kenya) and Exchange (Zimbabwe)

Kiguru, Kenya, managed by farmers, and Exchange, Zimbabwe(agency) are both successful group ventures. At Kiguru, farmers cooperate to overcome a reduced water supply owing to developments upstream. Supply is assured at Exchange, but the scheme is remote. Farmers work together to obtain inputs, manage water and market produce.

There is extreme inequity of supply across the scheme area at Mathina, which is managed by farmers. Problems of supply at the head are aggravated by poor operation. Large areas do not receive water. Maintenance is poorly done. The scheme is now effectively reduced to the head reach only.

Organization

The aims and functions of the organization and committee should be set out in a constitution. Ministries and community organization departments can assist farmers to draw up bye laws based on a standard format. Committees must have legal standing to allow them to enforce decisions. Assistance from rural administrators and community developers will almost certainly be required to help farmers deal with the issues.

It was found in Kenya that farmers with professional qualifications, such as teachers and civil servants, were often chosen to act as chairperson and office bearers generally. The chairperson needs to demonstrate an appreciation of the problems of minorities, such as tail-enders and women. The constitution should allow for regular changes of office-bearers.

Ensure that farmers can obtain assistance in formulating a constitution and bye laws.

The elected committee is responsible for managing physical and financial affairs. In some cases, committees are successful in expanding their duties beyond water management to matters such as group marketing. However, the process should not be encouraged until the basic O&M management procedures are well-established and the committee has the confidence of the group.

Elected committees appear to function well when there are about 12 members re-elected at regular intervals. Large smallholder schemes could consider some kind of federal arrangement.

Voting rights are normally restricted to members owning or leasing irrigated land. The tasks involved in cultivation and irrigation may be carried out by others, commonly women. If women do not own land they may not have a voice on the committee and therefore be unable to communicate with visiting irrigation specialists and managers. Management is likely to be more effective when both genders are represented on the farmer committee. A restricted category of membership could improve the management of the schemes and motivate participating individuals. The issue of membership should be fully discussed when primary stakeholders are identified at the outset.

Elected members represent the interests of groups of farmers, organizing and overseeing activities such as water sharing and maintenance.

> Conflict between irrigators can be reduced if procedures are established to allow equal access to available water, even when the supply is limited.

Management, system O&M

It may be difficult for farmers to include management within their existing workload, and there may be tasks for which they do not have the necessary technical training or skills. Accordingly, engineers in Kenya have designed schemes with the aim of minimizing operational tasks. In broad terms, designs of this type seem to be successful but they involve a number of compromises.

Ease of operation usually involves a lack of control which restricts farmers in their choice of strategies to cope with unusual conditions. The requirements of operation should be dealt with in design meetings with farmers. The balance between simplicity and flexibility of management should be set by farmers, assuming that the resulting costs can be met within the budget. Sub-groups, particularly women, who will have to work the system need to be consulted.

Committees need advice and instruction from designers about the maintenance tasks likely to be involved. Important issues need to be clarified:

- What maintenance tasks are needed for each structure?
- How often has the task to be performed?
- What are the consequences of failing to do the task?
- What is the minimum man-power required?
- What materials are needed?
- Where can the materials be obtained?
- How much do they cost?

> Designers should help to draw up maintenance schedules for proposed designs. Farmers will need training in the correct ways to carry out common maintenance tasks.

Once a design is agreed, designers should assist farmers to draw up alternative strategies for dealing with problems such as water shortage and flood. Farmers should be trained to identify warning signs of poor maintenance, such as inequity of supply, waterlogging, deteriorating structures or a general decline in available water. The procedures to be followed for obtaining advice and support from irrigation departments or agencies should be clearly understood.

Other activities

Irrigation committees must consider the best way to delegate tasks amongst sub-groups so as to make the best use of members' skills. If the committee intends to extend its role beyond water management, sub-groups should be formed and extra members co-opted as necessary. Sub-groups must be answerable to the elected body. Opportunity for fraud exists as soon as accountability is lost and transactions are not transparent.

5.2.2 Agency-managed schemes

General

Agency-managed schemes are promoted by governments wishing to increase food production and to support farmers who may be judged unable to handle the necessary technical and organizational tasks. Agencies normally levy an irrigation service fee to cover part of the cost of operation and maintenance. They may also extend their activities from water delivery to other agriculture services, like land preparation or marketing.

Generally, farmers work the land as tenants, although in some cases they may own the land whilst the infrastructure is owned by the agency. Farmers are normally supposed to take responsibility for the tertiary system. Formal contractual arrangements between farmers and agencies are increasingly common. Farmers should be involved at an early stage of scheme development (Cernea, 1988).

Organization

A core of permanent salaried staff is normally assigned to the scheme to operate and maintain the intake and all, or part of, the distribution system. An elected committee with a limited mandate is supposed to act as the interface between the agency and farmers. The committee is often responsible for collecting fees, organizing maintenance and imposing discipline. Conflict is inherent in the system if the agency is not accountable to farmers for its performance.

Some irrigation agencies are now required to fulfill a contractual agreement with farmers with penalties attached for non-performance.

Management, System O&M

Water scheduling at system level is normally managed by agency staff. Farmers are sometimes permitted to operate the control structures at weekends or otherwise when agency staff are off duty.

> Although constrained by shortage of funds, agencies were found to manage maintenance better than farmers, although the quality of the work is often poor. Farmers may be required to undertake some of the maintenance tasks under agency supervision, but the response is often poor.

The cost to governments could be reduced if full responsibility for maintenance is devolved to farmers. However, unless the scheme is in very poor condition, and farmers believe that they can do a better job than government, they have little incentive to take increased responsibility for maintenance, particularly if the work is costly or time-consuming.

Other activities

Agencies sometimes take responsibility for supplying inputs and marketing produce, as formerly in the Republic of South Africa (Lange, 1995). Farmers resent agency involvement as an infringement of their right to undertake commercial operations.

5.2.3 Participation.

The effectiveness of participatory processes will be limited unless stakeholders are directly involved in decision-making.

Although the end ought to justify the means, participation has disadvantages. The process is :

- slow
- frustrating to individuals with vested interests
- involves extensive training
- needs to be continuously practiced

There have been notable failures.

Developments must demonstrate a better sustained performance than conventional projects in order to justify the additional time and effort involved. Expenditure will be higher owing to the extended project cycle and the costs of training.

Farmers should be helped to visit existing schemes so as to obtain a better understanding of the requirements and the possible difficulties involved.

> Success will depend on a commitment by government to continue low-level support in the form of training and advice. The only alternatives are to maintain a costly direct involvement with small schemes, or to accept that numbers of schemes may cease to operate without caretaker support.

6 Conclusions and Recommendations

1. **Governments aiming to reduce their financial involvement in the irrigated agriculture sector in response to budget shortfalls need to frame policies to encourage sustained smallholder development**.

A number of Governments, such as that of Kenya, are actively encouraging the development of schemes managed and funded by farmers. The irrigation authority has adapted its role, to act as an enabling agency, rather than an executive and managing organization, providing technical assistance and advice to projects of established feasibility.

- The basic objectives and responsibilities of government organizations in the irrigated agriculture sector may need to be redefined. If Government is providing a service, then agreed standards of performance should be established.

- Farmers are increasingly required to take a greater responsibility for sustaining irrigated developments. To do so, they must identify a positive return. The status, roles and responsibilities of farmers need to be formally defined at national level. Standardized agreements between Government and groups can be modified to suit individual developments, as necessary.

  Women often make up more than 50% of the agricultural workforce in Africa. It is therefore important that they are brought in, and can contribute to the development process.

- There is growing competition for water, both within agriculture, and with other sectors of the economy. Irrigation is perceived to be an inefficient user of water. Integrated planning is required to set realistic allocations, and rights to water should be established in law.

- Farmers need to continuously improve their practices. Programmes of regular, targeted training for development/extension staff and farmers need to be developed and introduced.

- Participatory development. Project cycles are likely to be extended by the introduction of processes aimed at improving the prospects for sustained development. Traditionally-formulated projects aimed at the rapid implementation of large numbers of schemes will need to be rescheduled to allow individual proposals to be properly assessed and provide time for collaborative development.

- Policies on prices and incentives for development. Service fees and water charges, input and output costs, short-term arrangements to encourage wide-spread uptake of new technologies (for example, overhead irrigation), will all affect the attitude of farmers to increased responsibilities.

- Projects outside the irrigated agriculture sector, such as rural road construction and water supply/sanitation, can improve the productivity of irrigated agriculture by allowing better use of available labour . The potential for coordinating developments by different Ministries should be investigated.

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

The limited size of small scale developments can work to advantage, potentially promoting a sense of community amongst farmers, which is essential for cooperative management, and also allowing designers to become personally familiar with the terrain, with farmers and with their proposals. If farmers have been resident in the area for some time they should make a substantial contribution to the design and development process, provided adequate time is set aside for working discussions on site. For their part, designers need to ensure that farmers fully understand their commitments, that they are prepared to seek out additional help as necessary, and will invest time and money to ensure success.

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

The stakeholders to a potential project must be identified during the earliest stages of investigation so that conflicts of interest can be brought out and resolved in discussion. Failure to do so can result in a failed development.

The processes of participatory development as summarized in this document involve a series of meetings between farmers and designers to discuss different topics.

Factors such as land tenure; farmers' expertise; the location of a scheme; market conditions; the cost and availability of inputs and labour; the functioning of the group and committee, social and cultural norms, amongst other issues, can all affect the way a scheme performs.

Farmers should be required to consider the effect of irrigation development on other activities and identify possible conflicts of interest. They will need :

- Advice and assistance in supplementing traditional rain-fed production systems with irrigated production. Investments must be paid for by adequate returns from cash cropping. Government agricultural services often do not include enough specialists in irrigated agriculture. Expertise from the private sector may be needed, particularly in the early years of a development when returns to investment are urgently needed.

- Advice on, and access to credit, both for scheme development and for subsequent production. Cooperative banks, NGOs or development agencies may have special lending facilities for formally-established farmers groups.

- Sufficient labour. Production on many smallholder schemes in Africa is constrained by shortage of labour as family members seek work elsewhere. Extra demands will fall on those individuals already involved with agriculture, a majority of whom may be women. If the necessary labour cannot be obtained at times of peak demand, yields will be limited, and the viability of the scheme may be jeopardized.

- Information on, and access to, markets. Farmers' groups, assisted by the agricultural extension services, will need to actively seek out markets or enter into bulk contracts with buyers, particularly on remote schemes where road connections are poor.

- A reliable source of agricultural inputs, which are basic to viable irrigated production.

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

Various aids and methods are available to help the engineer investigate the feasibility of proposals. Checklists for use in the field; district or regional "profiles" detailing existing developments in the area; and ranking systems for judging potential schemes against a set of technical and socio-economic criteria may be appropriate.

An assured water supply is essential to development. Crops can tolerate some degree of shortage, but if the supply falls below some 70% of estimated crop requirements, yield will be seriously affected and destructive disputes over water may break out.

It will not be practical to carry out full environmental impact assessments. Nonetheless, the designer must ensure that possible adverse effects such as waterlogging, salinity, soil erosion, water-borne disease and downstream pollution are minimized.

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

Traditional agricultural practices, and limitations on the available irrigating hours need to be accommodated in the design.

On the schemes investigated, it was found that maintenance was better carried out on those run by government, despite limited funding, than on those managed by farmers. Since continuing maintenance is required to sustain scheme performance, farmers must understand from the outset the nature, approximate magnitude and timing of necessary work on the system. Designers must detail the long-term implications for O&M of possible designs, in terms of yearly labour and time.

Deposited sediment is a major maintenance task on many schemes. Apart from reducing conveyance capacity it can interfere with the proper functioning of division and control structures. Technical solutions applicable to large schemes are probably not economically viable on small schemes. Unless farmers are prepared to assign personnel to shut down head gates prior to, and during floods, they will be need to clean out the system manually.

The Agreement should detail farmers' commitments in O&M. To carry them out effectively they must:

- set aside money and time for the tasks
- develop skills in organization and execution of the work

Government will need to assign staff and resources for initial support and training in the necessary tasks.

6. Appropriate designs

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

A number of examples are included below:

- Schemes should be laid out as compactly as possible to simplify cooperative working and avoid excessive water loss in conveyance. Farmers should be encouraged to consolidate irrigated lands. Canal lining may be justified in sandier soils, provided farmers are trained in necessary maintenance techniques.

- The size of tertiary, or lower order blocks, will be governed primarily by considerations of water management:- the time needed to complete an irrigation rotation within available operating hours, and the numbers of farmers who must operate.

- Every time it is necessary to divide flow there is scope for dispute and inequity of supply. Designers should aim to divide the flow as few times as possible between the field and the main supply canal.

- Proportional division structures, constructed of locally-available materials, are robust, and easily understood by farmers. They can distribute available water reasonably fairly except at times of extreme shortage, when it may be necessary to introduce rotations. Provision for stoplogs on the weir crests can improve the flexibility of operation at such times. Farmers will need training in operational strategies.

- Adjustable gated controls are likely to lead to inequity of supply because they require skilled, experienced and incorruptible operators to function correctly.

- Design should be sufficiently flexible to allow for reasonable changes in the cropping pattern. The farmer will need to make seasonal decisions based on the potential and pricing of the market.

  In some circumstances, farmers must agree to restrictions on what they can plant. For example, crops such as rice, bananas and sugarcane all demand large quantities of water, which may be in short supply. Rice production should be limited to soils of low permeability.

- Locally-made sprinklers linked by flexible hoses to plastic pipelines operating under gravity head, are easily understood, operated and maintained by farmers, and supported by local skills and enterprise. They offer potential for improving the productivity per unit of water.

- Storage. Small on-scheme reservoirs to store water overnight may be justified if land is cheap, farmers will irrigate only within daylight hours, and the size of a development will be constrained by the available water supply.

7 Bibliography

7.1 Irrigation design, hydraulics, hydrology

Bentum, Robert van and Smout, Ian K, 1994
Buried Pipelines for Surface Irrigation. Intermediate Technology Publications Limited, ISBN 1-85339-187-5, UK

Baban, R, 1995
Design of Diversion Weirs. John Wiley & Sons, UK

Booher, L J, 1974
Surface Irrigation. FAO Agricultural Development Paper No. 95, FAO Land and Water Development Series No. 3, FAO, Rome

Bos, M G and Nugteren J, 1982
On Irrigation Efficiencies. ILRI Publication 19, International Institute for Land Reclamation and Improvement, ISBN 90-70260-875, Wageningen

Cornish, G A, 1997
Modern Irrigation Technologies for Smallholders in developing Countries, Report OD/TN 87, HR Wallingford

Diemer, G and Huibers, F P, 1991
Farmer Managed Irrigation in the Senegal River Valley: Implications for the Current Design Method. WARDA Water Management Project, Wageningen Agricultural University, Department of Soil and Water Conservation.

Food and Agriculture Organization
1995 Irrigation and Drainage Paper 53, Environmental Impact Assessment of Irrigation and Drainage Projects
1989 Irrigation and Drainage Paper 45, Guidelines for Designing and Evaluating Surface Irrigation Systems
1977 Irrigation and Drainage Paper 24, Crop water Requirements
1974 Irrigation and Drainage Paper 25, Effective Rainfall
1977 Irrigation Canal Lining.
Published in Rome

Government of Kenya, 1986
Scheme Identification and Evaluation. Irrigation and Drainage Branch Ministry of Agriculture, Livestock Development and Marketing, Nairobi.

Hansen, V E, et al, 1979
Irrigation Principles and Practices. John Wiley and Sons, UK

HR Wallingford
1992 DASCE (Design Analysis for Canal Sediment Extractors). Software User Manual
1992 DORC (Design of Regime Canals). Software User Manual
1992 DOSSBAS (Design of Sluiced Settling Basins). Software User Manual
1993 The ICID Environmental Checklist, ISBN 1-898485-01-1
1993 Vortex Vane Sediment Excluder: Field Verification of Design Procedure. Report OD 126
1994 MIDAS (Modular Irrigation Design Aid Software) User Manual
1995 ENCHECK (Environmental Impact Assessment Software) User Manual

ICID, 1993
The ICID Environmental Checklist to Identify Environmental Effects of Irrigation Drainage and Flood Control Projects. Compiled by Mock and Bolton. HR Wallingford, UK.

ICID, 1996
Checklist to Assist Preparation of Small-Scale Irrigation in Sub-Saharan Africa. International Commission on Irrigation and Drainage, UK

ILRI, 1972
Drainage Principles and Applications. Publ 16, Wageningen, The Netherlands.

Ingle-Smith, David and Stopp, Peter, 1978
The River Basin: An Introduction to the Study of Hydrology, Cambridge University Press, ISBN 0-521-29307-3, UK.

Jensen, M E, 1983
Design and Operation of Farm Irrigation Systems. American Society of Agricultural Engineers

Kay, M, 1993
Surface Irrigation: Systems and Practice. Cranfield Press, UK

Kay, M, 1983
Sprinkler Irrigation: Equipment and Practice. Batsford Academic and Educational Ltd. ISBN 0 7134 1229 1, UK

Laar, A van de, 1994
Working Paper Series No. 169, Irrigation, Evaluation, Performance measurement and Trades-offs Between Production, Efficiency, and Equity in Irrigation Investment Strategies. Institute of Social Studies, Management of Common Pool Resources, Discussion Note 14, Netherlands

Mutrya, K N, 1986
Applied Hydrology, McGraw-Hill, New Delhi

SIDP
1986 Manual for Scheme Identification and Evaluation
1986 Manual for Scheme Design
1986 Manual for Design of Structures
1989 Smallholder Irrigation Manual Ministry of Agriculture, the Netherlands
1990 Evaluation of Small Scale Irrigation development Project
Publication available from the Irrigation and Drainage Branch of the Ministry of Agriculture, Livestock Development and Marketing, Nairobi, Kenya

Simon, A L, 1981
Practical Hydraulics. John Wiley and Sons. ISBN 0 471 05381 1, UK

Smedema, L K and Rycroft, D W, 1983
Land Drainage: Planning and Design of Agriculture Drainage Systems. Batsford Academic and Educational Ltd. ISBN 0 7134 3500 3, UK

Stern, Peter, 1990
Small Scale Irrigation. Intermediate Technology Publications Ltd, ISBN 0-903031-64-7, UK

Terzaghi, K and Peck, B R, 1967
Soil Mechanics in Engineering Practice, 2nd Ed. John Wiley & Sons

Ubels, J and Horst, L, 1994
Towards interactive Irrigation Design. Agricultural University of Wageningen, Nieuwe Kanal, Wageningen, Netherlands

USBR
1965 Earth Manual
1974 Design of Small Canal Structures
1974 Design of Small Dams
Published by United Sates Department of the Interior and Bureau of Reclamation, Denver, Colorado

USDA, 1971
Drainage of Agricultural Land. Soil Conservation Service, Washington, DC

Withers, Bruce and Vipond, Stanley, 1980
Irrigation Design and Practice. Batsford Academic and Educational Limited, UK

7.2 Case studies

Brown E P and Nooter, K R, 1982
Successful small-scale irrigation in the Sahal
World Bank Technical Paper No 171, New York

Carney, J A, et al,1988
Struggle over crop rights and labour within contract farming households in a Gambian irrigated rice project, Journal of Peasant studies, 15 (3)

FAO, Richard Carter (ed), 1989
NGO Casebook on Small Scale Irrigation In Africa, Food and Agriculture Organization, Rome

Lange, Marna de, 1984
Small Scale Irrigation in South Africa. Murray Biesenbach and Badenhorst Inc., South Africa Water Research Commission (WRC), Pretoria, South Africa

Moris, J and Thom, D J, 1985
An Overview of African Irrigation. USAID, Water Management Synthesis Project II, report 37, Utah State University, Logon, Utah

Rihal, S, 1994
Performance Evaluation in Small Scale Irrigation Schemes in Kenya.
ENGEES, Strasbourg, France

Rousseau, J G and Bembridge, T, 1993
Aspects of the Impact of Imposed Technology in the Neavee Irrigation scheme in Transkei. Development Southern Africa 10 (4): pp 535-547

Seckler, D (ed), 1983
Agricultural Transformation in Africa. Winrock International. ISBN 0-933595-77-8, USA

SIDP, Michele, W, 1994
A labour input study in a small scale rice scheme in Kenya
Publication available from the Irrigation and Drainage Branch of the Ministry of Agriculture, Livestock development and Marketing, Nairobi, Kenya

7.3 Socio-economics

Bembridge, T, 1991
Farmer Characteristics, Innovativeness and Cotton Production at Makatini Irrigation Scheme, Kwa Zulu. Development Southern Africa 8 (1):pp 61-77

Cernea (1988)
Putting People First. World Bank Washington.

Dey, J, 1990
Gender issues in irrigation project design in sub-Saharan Africa. Contribution to design for sustainable farmer managed irrigation schemes in sub-Saharan Africa, Wageningen Agricultural University.

Dillion, J L and Hardaker, J B, 1980
Farmer Management Research for Small Farmer Development. FAO Agricultural Services Bulletin 41. FAO Rome

Government of Kenya
1991 Loan scheme for group based Smallholder Irrigated Horticultural Production in Kenya
1989 Profitably of Smallholder Irrigation in Kenya (1 and 2)

Grimble, R and Chan, M, 1995
Stakeholder analysis for Natural Resource Management in Developing Countries. Natural Resources Forum 19 (2): pp 113-124

Hooff, I van, 1990
Irrigation planning for women: The planning process of Jahaly Parcharr in the Gambia in sub-Saharan Africa, Wageningen Agricultural University.

HR Wallingford
Socio-economic parameters in designing small irrigation schemes for small scale farmers: Case studies

1990	Nyanyadzi, Zimbabwe	Report no. OD/114-117
1991	Exchange, Zimbabwe	Report no. OD.121
1992	Kamlesa, Kenya	Report no. ITM/35
1992	KwaKyai, Kenya	Report no. ITM/36
1993	Gem Rae, Kenya	Report no. ITM/41
1993	El Hammami, Egypt	Report no. OD/TN 66
1994	Kangocho, Kenya	Report no. ITM/45
1995	Mathina, Kenya	Report no. ITM/47
1995	Mutunyi, Kenya	Report no. ITM, 50
1996	Kiguru, Kenya	Report no. ITM/51

Published in Wallingford

Rouxel, J M, 1995
Socio-economic Parameters in Assessing the Performance of Small Scale Irrigation Schemes, in Kenya,. ENGEES, Strasbourg, France.

SISDO, 1993
Financial Assistance to Farmers for Smallholder Irrigation Development. (Smallholder Irrigation Support and Development Organization), PO Box 76622, Nairobi, Kenya

Upton, M, 1996
Economics of Tropical Farming Systems. Cambridge Press, UK

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Appendices

Appendix 1

Cross-reference: Guidelines & ICID checklist

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Aspect	Chapter/Part/Section no.	
	HR Guidelines	ICID Checklist
Background and scope	Ch 1	Preamble
Project identification and development	Ch 2	Part 1
Collect existing physical and socio-economic data	2.1	Part 2
	3.1-3.5	P1-P11
Detailed physical data collection and field investigations:		
Water		
- Supply/demand/balance	3.1.1-3.1.3	F5-F8
- Quality and sediment	3.1.4	F6, F7
Land and soil	3.2	F1, F3
Labour/Skills	3.3	F1, F4, F11
Capital/Equipment	3.4	F11
Infrastructure		
- General	3.5	_
- Irrigation	5	F9
Crop Choices/Agriculture	4.1	F4
Financial/Economic	4.2	F10
Integrating Irrigation into Farm Systems	4.3	F4
Environment	4.4	F2
Design for Sustainability	5.1, 5.2	-
Scheme Management: Institution, Organizations & O&M	5.3	F11

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