Efficient Water Use for Agricultural Production (EWUAP) Project

Best Practices and Guidelines for Water Harvesting and Community Based (Small Scale) Irrigation in the Nile Basin

Part II – Guidelines for the Implementation of Best Practices in Community Based (Small Scale) Irrigation

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Indicative Exchange Rates (5 January 2009)

Country	Currency	Rate to US$
Burundi	Burundi Franc (FBu)	1215
DRC	Congo Franc	557
Egypt	Egypt £	5.52
Ethiopia	Ethiopian Birr	9.96
Kenya	Kenya Shilling	78
Rwanda	Rwanda Franc	560
Sudan	Sudan Pound	2.19
Tanzania	Tanzania Shilling	1,330
Uganda	New Uganda Shilling	1,975

Acronyms and Abbreviations

ADB	African Development Bank
AEZ	Agro-Ecological Zones
BCM	Billion Cubic Meters
BP	Best Practice
BoQ	Bill of Quantities
CMI	Community Managed Irrigation
CMIWG	Community-Managed Irrigation Working Group
ASALs	Arid and Semi-Arid Lands
CGIAR	Consultative Group on International Agricultural Research
CIDA	Canadian International Development Agency
CRS	Catholic Relief Service
DRC	Democratic Republic of Congo
DRWH	Domestic Roof Water Harvesting
DSS	Decision Support System
EIRR	Economic Internal Rate of Return
ENSAP	Eastern Nile Subsidiary Action Project
ENTRO	Eastern Nile Technical Regional Office
EWUAP	Efficient Water Use in Agriculture Project
ET_o	Reference Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organisation
FCT	Ferro Cement Tank
FFS	Farmer Field School
GAA	German agro-action
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographic Information system
GTZ	Germany Agency for Technical Cooperation
ICARDA	International Center for Agricultural Research in the Dry Areas
ICB	International Competitive Bidding
ICCON	International Consortium for Cooperation on the Nile
ICR	Implementation Completion Report
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
I & D	Irrigation and Drainage
IFAD	International Fund for Agricultural Development
ILRI	International Livestock Research Institute
IO	Irrigation Organisation
IPM	Integrated Pest Management
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management.
JICA	Japan International Cooperation Agency
KBO	Kagera Basin Organization
MCM	Million Cubic Meters (Mm^3)
M&E	Monitoring and Evaluation
NBI	Nile Basin Initiative
NBTF	Nile Basin Trust Fund
NCB	National Competitive Bidding
NELSAP	Nile Equatorial Lakes Subsidiary Action Project
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organization
Nile-COM	Council of Ministers of Water Affairs of the Nile Basin States
Nile -SEC	Nile Basin Initiative Secretariat
Nile-TAC	Nile Basin Initiative Technical Advisory Committee
NPC	National Project Coordinator
NTEAP	Nile Transboundary Environmental Action Project

O&M	Operation and Maintenance
PAD	Project Appraisal Document
PMU	Project Management Unit
PIP	Project implementation plan
PPMI	Public/Private Managed irrigation
PMIWG	Public and Private Managed Irrigation Working Group
PRC	People's Republic of China
PSA	Project Services Agency
PSC	Project steering committee
PUWR	Potentially Utilizable Water Resources
PWS	Primary Water Supply
QCBS	Quality and Cost-Based Selection
RBA	Rapid Baseline Assessment
RWH	Rainwater harvesting
SAP	Subsidiary Action Program
SC	Steering Committee
SSI	Small Scale Irrigation
SIDA	Swedish international Development Agency
SLM	Sustainable Land Management
SVP	Shared Vision Program
SWC	Soil and Water Conservation
TAC	Technical Advisory committee
TOR	Terms of Reference
UNDP	United Nations Program for the Development
UNOPS	United Nations Office for Project Services
USAID	United States Agency for International Development
WB	World Bank
WFP	World Food Programme
WH	Water Harvesting
WHWG	Water Harvesting Working Group
WUAs	Water Users Associations (also see IO)

Note: For Acronyms by Country, see Annex J. Agricultural Water in the Nile Basin – An Overview, Final Report, Ian McAllister Anderson, April 2008.

Glossary

General	
Hectare (ha)	10,000 m^2 = 2.471 acres
Blue water:	Equivalent to the natural water resources (surface water and groundwater runoff)
Green water:	Rainwater directly used and evaporated/transpired by non-irrigated agriculture, pastures & forests.
Agro-ecological zones	Agro-ecological zones defined by FAO on the basis of average annual length of growing period for crops, which depends inter alia on precipitation and temperature. The lengths are: humid > 270 days; moist sub-humid 180-269 days; dry sub-humid 120-179 days; semi-arid 60-119 days & arid 0-59 days.
Deficit irrigation	Deficit irrigation is the application of less irrigation water than that required for maximum plant growth, to optimize yield per unit of water rather than land – in other words, to optimize water productivity
Farmers' Field Schools	Farmer Field Schools are a way of testing and adapting new technologies. They consist of a community-based, practically oriented, field study programme, involving a group of farmers, facilitated by extension staff (public or private) or, increasingly, by other farmers, in which farmers learn together and test/adapt practices, using practical, 'hands-on' methods of discovery learning that emphasize observation, discussion and analysis to combine local indigenous knowledge with new concepts.
Food security	Food security is the condition of being able supply one's food needs either from one's own production or by buying in from other sources, whichever is more economically advantageous. Food security may be expressed in terms of the household, the nation or the region.
Irrigation and drainage system	The network of irrigation and drainage channels, including structures.
Irrigation and drainage scheme	The total irrigation and drainage complex, the I & D system, the irrigated land, villages, roads, etc.
Irrigation	Comprises operations to supply additional water to agricultural land to augment rainwater (if any) for the purpose of crop growth. Irrigation water may be supplied from groundwater, surface water, agricultural drainage wastewater or other wastewater (including from domestic or industrial use). For the purpose of this report, reference to irrigation includes drainage where appropriate.
Supplemental irrigation	'Supplemental' (or supplementary) irrigation involves providing water to augment rainfall for crop growth. Most irrigation is supplementary, except where it is provided entirely within a dry season.
Egypt	
Feddan	0.42 ha [2.375 Feddan = 1 ha]
Ardab	Wheat ~ 150 kg
	Maize ~ 140 kg
	Rice ~ 120 kg
	Bean ~ 155 kg
Cutl	Barseem ~ 150 kg
Kantar	Cotton ~ 157 kg
Ethiopia	
Bereha	Hot and hyper-arid): General term that refers to the extreme form of Kola, where annual rainfall is less than 200-mm.
Dega	Cool, humid, highlands): Areas from 2500-3000 meters where annual rainfall ranges from 1200 to 2200-mm
E.C.	Ethiopian Calendar (Add 8 to convert to Gregorian calendar)
Kebele	Lowest administrative unit below a district
Kola	(Warm, semi-arid lowlands): Areas below 1500 m with annual rainfall ranges from 200-800 mm.
(Weina Dega	(Temperate, cool sub-humid, highlands): Areas from 1500 to 2500 m, where annual rainfall ranges from 800-1200-mm
Woreda	District
Wurch	(Cold highlands): Areas above 3000 meters and annual rainfall is above 2200-mm
Tanzania	
Charco Dam	Small Earth Storage Dam
Lambo	Charco Dam
Jaluba	bunded field
Uganda	
Matoke	Green banana cooked for food. Staple food in Uganda
Valley dam	On stream embankment for trapping and storing of surface runoff from a catchment area

Glossary of Terms and Definitions

	Definitions	Remarks
Efficient water use for agricultural production	The optimisation of water used in agriculture for acquiring the maximum crop production per unit of consumptive use and to minimise the amount of water diverted to the agricultural land to meet this consumptive use.	
Benchmark.	The designs value of process output (or performance indicator). The benchmark level is set by comparison with the best practices of comparable processes.	
Performance assessment (in irrigation & drainage)	A systematic observation, documentation and interpretation of activities related to irrigated agriculture with the objective of continuous improvement.	Benchmarking of schemes is important in this process
Best Practice (in Irrigation and Water Harvesting)	The Best Practice is one that gives optimum utilization of land and water resources for sustainable agricultural production and environmental management. A good example of what can be achieved in irrigation and drainage or Water Harvesting and can be used for Benchmarking of systems as well as providing models for wider dissemination.	Definition of best practice varies according to the purpose to which it is to be put. In irrigation & water harvesting it relates to 5 main issues: Technical; Economic; Social; Management, Operation & Maintenance (MOM); Institutional.
Irrigable area.	Area (in hectares) with physical infrastructure that enables the delivery of irrigation water.	
Irrigated area.	Part of the irrigable area to which water is actually delivered during the growing season of the irrigated crop	
Cropping intensity	$\frac{\text{Total area cultivated during the year}}{\text{Command area}}$	
Irrigation intensity	Number of irrigation seasons per annual cycle	
Delivery performance ratio or Management performance ratio	$\frac{\text{Actual supply discharge}}{\text{Target discharge}}$	
Depth of delivered water.	Volume of water delivered to a certain offtake divided by the size of this area.	This depth commonly has the same dimensions as precipitation and Evapotranspiration (e.g. mm/day).
Conveyance efficiency	$\frac{\text{Volume of water delivered (to tertiary unit)}}{\text{Volume of water diverted/pumped from source}}$	
Distribution efficiency	$\frac{\text{Volume of water received at field}}{\text{Volume of water delivered (to tertiary unit)}}$	
Field application efficiency	$\frac{\text{Volume of water needed by crop (crop } ET_P \text{ - effective rainfall)}}{\text{Volume of water received at field}}$	
Irrigation system efficiency	$\frac{\text{Volume of water received at field}}{\text{Volume of water diverted/pumped from source}}$	
On-farm efficiency	$\frac{\text{Volume of water stored in the root zone}}{\text{Volume of water received at field}}$	Expresses role of soil water holding capacity
Reference ET	ET of unstressed short clipped and well watered grass	Defined according to FAO 56 guidelines
Crop coefficient	factor that converts reference ET into potential ET	
Potential ET	Consumptive use of an unstressed crop	
Actual ET	Consumptive use of an stressed crop	Stress could be caused by water, salts and heat
Crop water stress	ETp - ETa	Deficit in consumptive use
Crop water requirements	ET_p - effective rainfall	
Effective rainfall	Amount of rainfall that is infiltrated into the soil profile and subsequently available for consumptive use	
Irrigation water requirements	Water requirements for crops and leaching	
Bio-physical crop water productivity (kg/m3)	$\frac{\text{Yield of harvested crop}}{\text{Consumptive use}}$	Consumptive use comprises rainfall, irrigation, capillary rise and moisture depletion
Economical crop water productivity (US$/m3)	$\frac{\text{Value of harvested crop}}{\text{Consumptive use}}$	

References

a/. Bos and Nugteren (1974; 1990)
b/. ICID (1978)
c/. IWMI (1987; 1993)
d/. Boss, M..G.; Burton, M. A.; Molden, D.J.; (2005)
e/. Proceedings of EWUAP Inception Workshop; Best Practices; Nov. 2007.
f/. FAO Irrigation and Drainage Paper 56

Unit conversion table

Length

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

Area

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

Volume

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

Capacity

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

Mass

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

Pressure

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

Energy

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

Power

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

Temperature

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

The information presented in this report reflects the views of the Consultants and does not necessarily represent those of the Nile Basin Secretariat. It has been compiled from data and information made available by the Project Management Unit (PMU) of the Efficient Water Use for Agricultural Production Project (EWUAP) together with published data obtained from international organisations and from the internet. This has been supplemented with the knowledge and experience of the Consultants who have worked in most of the Riparian states at some time over the last 35 years.

Preface

These guidelines aim to provide information and guidance on the processes to be followed in order to achieve best practice in community based small scale irrigation. As discussed in Chapter 3, , best practice needs to occur in all stages of an irrigation and drainage scheme's development, from planning through to operation, and in a variety of domains including technical, social, economic, institutional and environmental.

As shown in Part I – Best Practices in Community Based Small Scale Irrigation, there are examples of best practice in different aspects of I&D scheme development in Nile Basin countries. Some aspects are due to good technical design and construction, allied with good management and good markets; others are linked to relatively basic design and construction, but work as a result of strong institutions and good management, and are sufficient for the farmers' subsistence needs. As there is no one route to achieving best practice, these guidelines have evolved to cover key aspects related to planning and design, construction, management, operation and maintenance, and to aspects of the five domains mentioned above.

Areas where particular deficiencies or weaknesses were found in current practices has resulted in relatively more information being written into the guidelines on these aspects, as they did not appear to be covered adequately in the existing publications and reference material available in the Nile Basin countries. Key areas where deficiencies were identified included: farmers' participation and Water Users Associations; management, operation and maintenance (particularly maintenance); discharge measurement; performance assessment, monitoring and evaluation; and project implementation.

The guidelines are organised in two parts and eighteen chapters. Part A sets the scene with an introduction, an identification of the different components of community based small scale irrigation schemes, and a discussion on how to identify best practice in such schemes. From the work carried out by the National Consultants, and following discussions at the project workshops, it was apparent that there is an ongoing need to identify best practice in each country, and a need to provide robust procedures for identifying such practice. It is hoped that the discussion on this topic in Chapter 3 will enable these procedures to be established.

Part B of the guidelines deals with the various aspects involved in the development of a well-functioning, efficient, productive and sustainable community managed small scale irrigation scheme. There is considerable information already available in the public domain on many of the topics that need to be covered; the guidelines seek to draft the user's attention to this work, and to provide guidance on where information on key topics can be found. It is neither possible, nor sensible, to reproduce work which is already in the public domain and which has been used, and found useful by many practitioners. What is important is to bring together all the information and knowledge that was found to be available in the different countries in the Nile Basin, and to make it available in a structured format through these guidelines. To this end, allied to the text in these guidelines, 5 CD ROMs are provided at the back with a significant number of the references identified during this EWUAP project. In this context some of the text, figures, diagrams and tables in these guidelines have been sourced from these referenced works, where possible due acknowledgement has been given.

PART A

.1 Introduction

1.1 Community Based Small Scale Irrigation Guidelines

The purpose of these guidelines is to inform beneficiaries and practitioners at community and household level, so that proper use of the identified best practices in Nile Basin countries can eventually contribute to efficient use of water in the sector, and ultimately to increased availability of water. The guidelines therefore detail the key principles behind the identification, planning, design, management, operation and maintenance of irrigation and drainage systems to achieve optimum outputs and benefits from the development of land, water and human resources.

1.2 Community Based Small Scale Irrigation Definition and Classification

The definition of small-scale irrigation varies considerably across the Basin with some countries referring to small-scale schemes as those of less than 50 hectares and others as less than 100,000 ha[1]. The concept also varies with some using physical boundaries and others as management level. It has therefore been necessary to define a common concept for these Guidelines for Community Based Small Scale Irrigation

There are a wide variety of types of irrigation and drainage system. The guidelines are limited to community based small scale irrigation (and drainage)[2] systems where:

- The system is managed by the community (though it may have been designed and built by a government agency and then handed over to the community to manage);
- The system is small scale. The definition of small scale varies from country to country, but in general ranges from 5 ha to 500 ha.

Key features of community based small scale irrigation are:

- The communities are relatively small, and located within a relatively confined geographical area;
- Because of the relatively confined geographical area communication between members of the community is relatively good;
- Members of the community live in one or more small villages;
- There are a small number of hierarchies in any management structure;
- Members of the community are used to working with each other

A distinction needs to be drawn between traditional and government initiated irrigation systems. Traditional irrigation systems, such as those established by the Chagga on Mount Kilimanjaro, or the Pare in the Pare Mountains in Tanzania, have been established by the water users themselves over many decades, without government support. As such they will have established their own procedures for management, operation and maintenance which will have evolved through discussion and consensus amongst the community. On the other hand, government initiated schemes will generally have been recently established, and may have imposed management, operation and maintenance structures and procedures on the irrigation community.

[1] Agricultural Water in the Nile Basin – An Overview, Final Report, Ian McAllister Anderson, April 2008. Table 3.3 Definition of Irrigation Scheme Size by Nile Basin Country.
[2] Drainage is an important and integral part of an irrigation system.

1.3 Enabling Environment

Irrigation schemes will not be successful unless there is a suitable enabling environment to encourage change and to support the efforts of farmers. The Needs Assessment and Conceptual Design of the Nile Basin Decision Support System Consultancy[3] found that many of the Nile Basin countries still had much work to complete before suitable legislation is in place to encourage and support the development of Water Users Associations, the lack of which has been shown to be one of the key constraints on past poor performance of irrigations schemes. It is important that this issue is given appropriate support by government, and that they utilise the experience and knowledge that already exists within the Basin, especially in Tanzania and Ethiopia.

1.4 Other Reference Work and Design Manuals

In each chapter of this report, key and useful references have been identified to provide the reader with easy access to relevant published information. The Food and Agriculture Organisation of the United Nations (FAO) has been working in East and Southern Africa for many years. Using this experience they have prepared an excellent and comprehensive set of 14 Modules into an Irrigation Design Manual. Although this has been developed for the Zimbabwe context, they have much wider application and provide a good resume of what is required in irrigation systems and the development of community managed schemes. These guidelines draw heavily on these modules, but also supplement them with data from other sources, as well as professional experience in the region.

These guidelines incorporate a CD ROM with copies of the main references cited in the text, so that all users can have easy access to relevant published and freely available reference material.

1.5 Improving and Extending Community Based Small Scale Irrigation

In each Nile Basin country, experienced irrigation engineers have developed guidelines and manuals for their own environment. Many of these staff now occupy senior management positions and are unable to fully utilise the skills that they have learnt and developed. Depth of experience in the organisations is often not substantial, and there is a need to redress this situation through regular in-service training and secondment to schemes where best practice is exists.

A number of improvements can be achieved through the following:

- Better training of students through the inclusion of practical field based training materials relating to community based demands;
- Linking of training institutions and government extension services to improve the quality and relevance of design and extension material produced;
- Development of a hierarchy of linked training materials for all levels down to beneficiary/ community to cater for the various levels of education and the different needs;
- Improvement of the awareness of decision makers;
- More applied research to examine and adapt recognised irrigation and community based water management and other techniques to actual site conditions.

1.6 The Structure of these Guidelines as a toolkit for improved planning and design of CBSSI

In the following chapters of these **Guidelines for the Implementation of Best Practices in Community Based (Small Scale) Irrigation**, the main requirements are presented for the development of an irrigation scheme based on documented best practices, and that need to be taken into consideration when planning and implementing small scale irrigation projects. The aim is to provide basic information on the Best Practices that should be adopted and the factors that need to be

[3] Draft Inception Report, Main Report, hydrophil - consulting & knowledge development GmbH, October 2007.

considered to guide practitioners, with links provided to relevant and more detailed manuals, references and sources of information and data. It does not set out to provide complete details on everything, but provides references and links to other well documented sources, references, documents and manuals that can assist the reader with detailed design, construction and implementation. Important references cited in these guidelines are included in the attached CD ROMs.

It is most important that experiences, information and data available within the Basin are made widely available to all practitioners. This will facilitate the learning process and also take advantage of considerable past investments by donors in the preparation of manuals, guidelines and other tools to facilitate the implementation process. Each country should therefore examine their own guidelines and manuals (see CD Rom # 3) to see how the EWUAP Guidelines as well as those from other Nile Basin countries can be utilised, to provide a more comprehensive document for their own professionals and practitioners. These senior professionals should then produce practical implementation guidelines and manuals for their own CBSSI target groups.

1.7 Purpose of the CBSSI Guidelines

The focus of these guidelines is I&D planning, design and implementation for higher level professionals in each Nile Basin country. Many of the approaches are suitable for lower level professionals, **provided that** guidance and oversight is available from more experienced professionals. The concepts, approaches and cross references included are also suitable for programmes at sector level, for policy work and for all agricultural/ rural development projects including watershed management.

1.7.1 The Guidelines will assist to:

- Ensure that all practitioners are fully aware of materials available to make good decisions
- Improve quality and sustainability of works
- Ensure planners, designers, implementers and all involved in CBSSI engage fully with beneficiaries
- Provide a model to assist the communities and practitioners to meet their identified needs through their own professionals.

1.7.2 Constraints:

- Following a guideline is never mandatory
- These guidelines are an essential part of the larger process of governance
- Good guidelines do not make successful CBSSI
- Socio-economic factors are particularly important
- Assumes that users are suitably experienced, trained and qualified
- That peer review of planning, design and implementation decisions exists.

1.7.3 Aim of Guidelines

- Provide basic information on techniques, approaches and design materials available
- Guide experienced senior practitioners
- Make available to the senior practitioners a wider range of professional experience
- Provide links to relevant and more detailed manuals, references and sources of information both within the Nile Basin and also further a field
- Provide basis and sufficient information for riparian countries to complete their own practical implementation guidelines/manuals for their own CBSSI target groups.

1.7.4 Users of the Guidelines

The guidelines have been prepared for the following main groups of users:

- Government departments and agencies including policy makers and planning/design staff
- Senior professionals and practitioners within country (in government, private and NGO sector)
- Managers and staff responsible for project implementation, operation and management
- Stakeholders and external organisations providing assistance on project design, implementation and management
- Wider stakeholders from civil society with a legitimate interest in project sustainability and outcomes
- Financing agencies involved in agricultural water management.

1.8 How to use the Guidelines: approach and structure

The guidelines comprise a set of guiding principles and helpful resources. It is not intended to be a detailed instructional manual, although it may be used as a support to training in irrigation and drainage (I&D). The guidelines consist of seventeen chapters that have been divided into two parts.

Part A provides an introduction and overview for community based small scale irrigation. Links are made with the previous report on identified best practices within the Nile Basin countries (Part I_BP in CBSSI) and discusses the key elements of best practice and what the planner or designer should be looking for.

Part B provides a comprehensive discussion of all aspects of project planning, design, implementation and operation in fourteen separate chapters. Frequent references for further reading and research are provided to assist the reader in obtaining more detailed information if required. Key references are highlighted and links are provided to other useful and relevant information and web sites. Generic principles are set out that identify the aspects to be considered in the planning of irrigation and drainage developments and these are then followed by more detailed discussions of the main topics encountered in I&D developments.

It is recommended that readers new to the EWUAP project approach and outputs familiarize themselves with the preparatory studies on best practice (Part I_BP in CBSSI) to gain an overview of the issues and an understanding of the main terminology. Each report has been designed to be self contained stand alone documents and the guidelines are supported by 6 CD ROMs.

Figure 1 summarizes the 'Guidelines Roadmap' highlighting the basic way in which to use the guidelines and how it makes use of the main text as well as the supporting data on the internet links and on the CD ROMs. The focus of the guidelines is on what needs to be considered and '***how to do it'***.

In addition to the references and links contained within the text, Appendix A (**Part II Guidelines in CBSSI_Appendix A_References**) contains a range of references, resources and organizations that can be consulted to gain further information, data and know-how on most of the topics that arise.

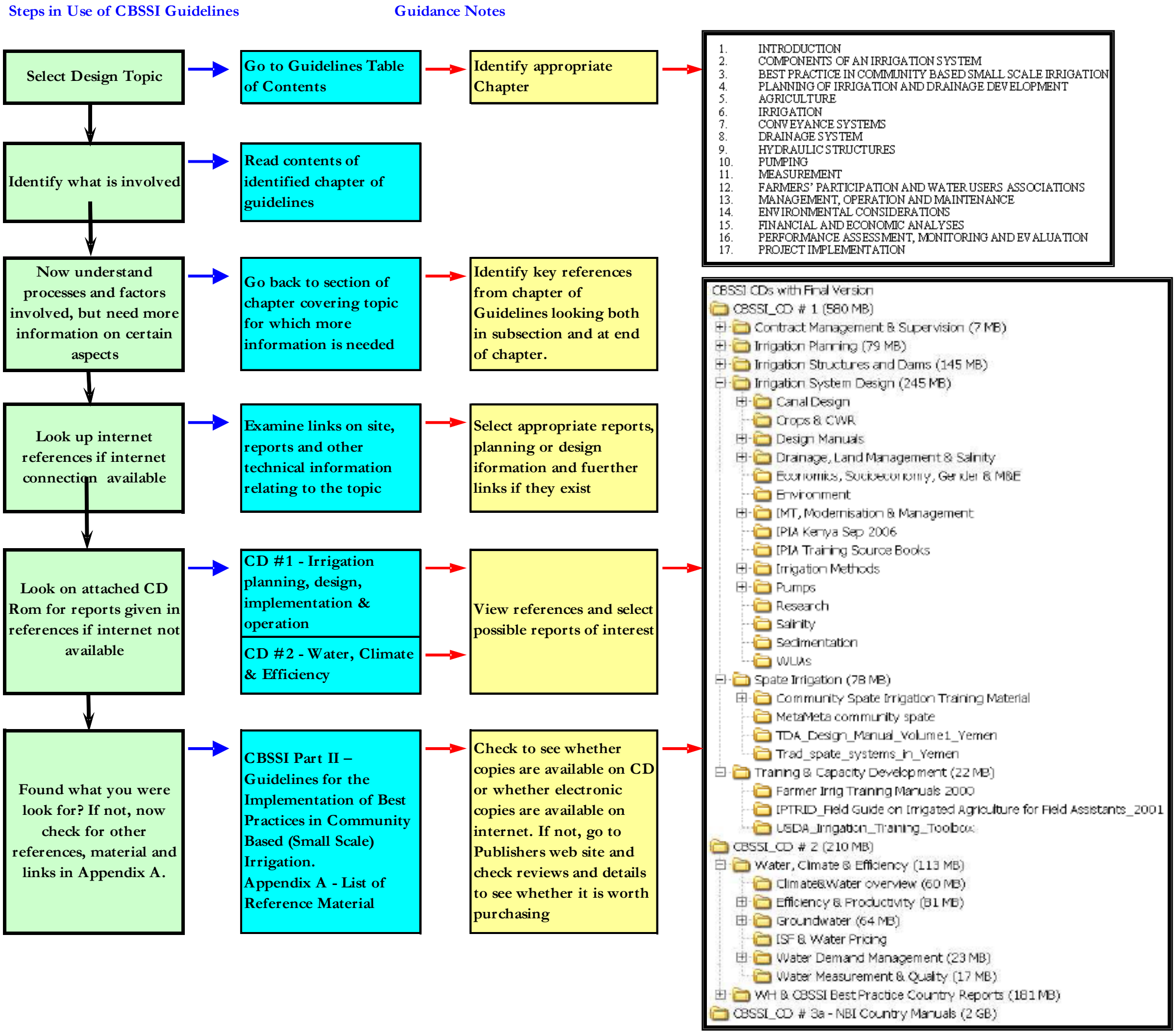


Figure 1.1 CBSSI Guidelines Roadmap

1.9 Application of the Guidelines

The guidelines can be used throughout the project cycle. They will be particularly useful at the early identification and preparation stages, because a good understanding of all of the factors involved together with full beneficiary participation can contribute to improved project design and sustainability. Additionally, guidelines will be practical during project preparation and appraisal, to ensure that all aspects have been considered. During implementation, they provide supervision and contract management information as well as the typical forms that need to be considered at such stages in a project.

1.10 Example of Use

In Figure 1.2, an example of the use of the guidelines is provided for someone who is planning a small scale irrigation scheme and wants to be sure that they have covered all of the details.

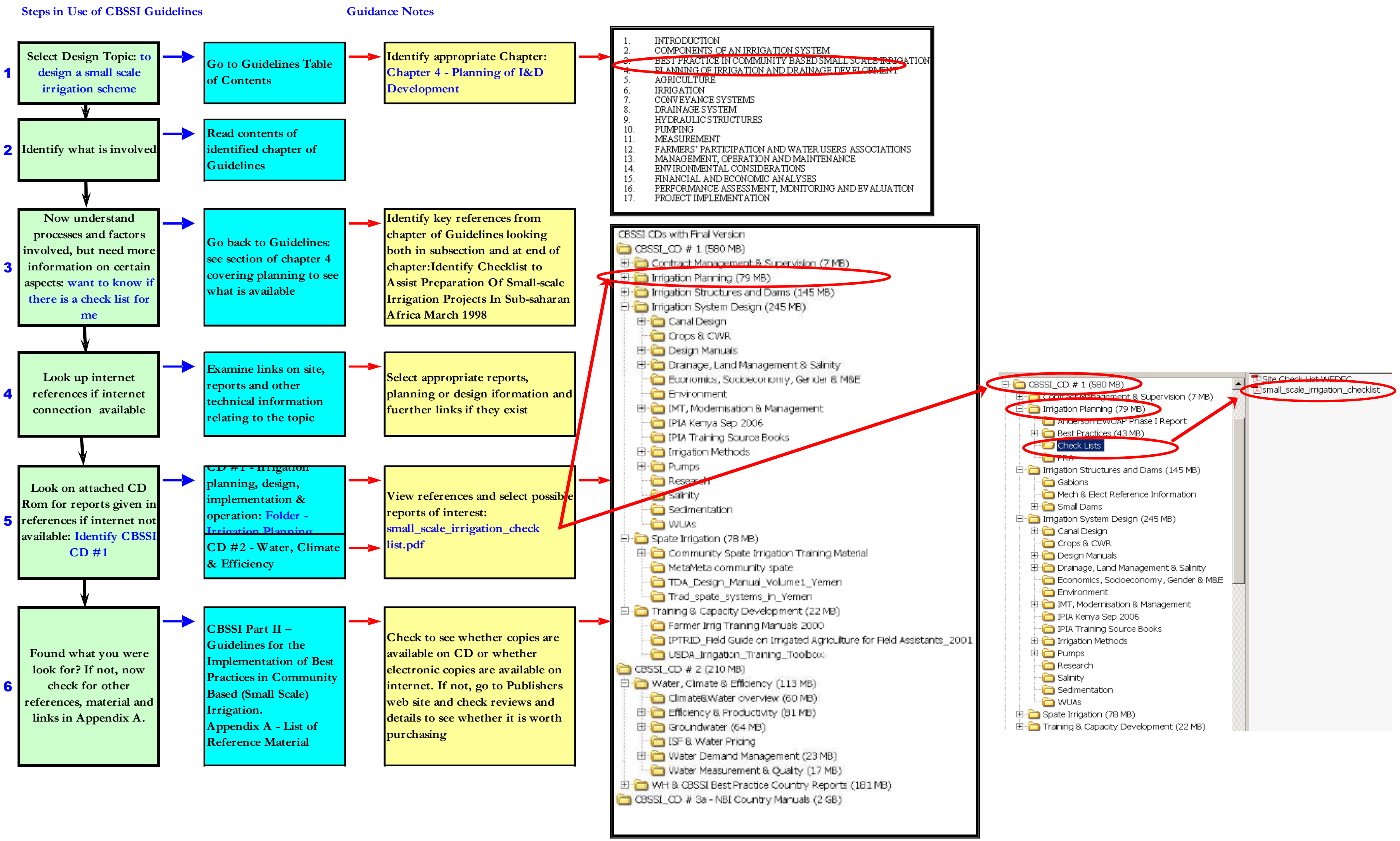


Figure 1.2 Example of Use of CBSSI Guidelines

.2 Components of an Irrigation Scheme

2.1 Objectives

As a first priority, it is important to be clear about the objectives of irrigation and drainage scheme, as these can differ substantially depending on the circumstances. The following are possible objectives:

- To increase agricultural productivity
- To protect agricultural production
- To sustain farmer livelihoods
- To grow cash crops for market

Sagardoy and others (1982) outlined a useful hierarchy of objectives for irrigation and drainage schemes, which set different goals at different levels in the chain of irrigated agricultural processes (Figure 2.1). The achievement of specified goals at the different levels enabled the attainment of goals at the higher level, up to the final goal of betterment of farmers' welfare.

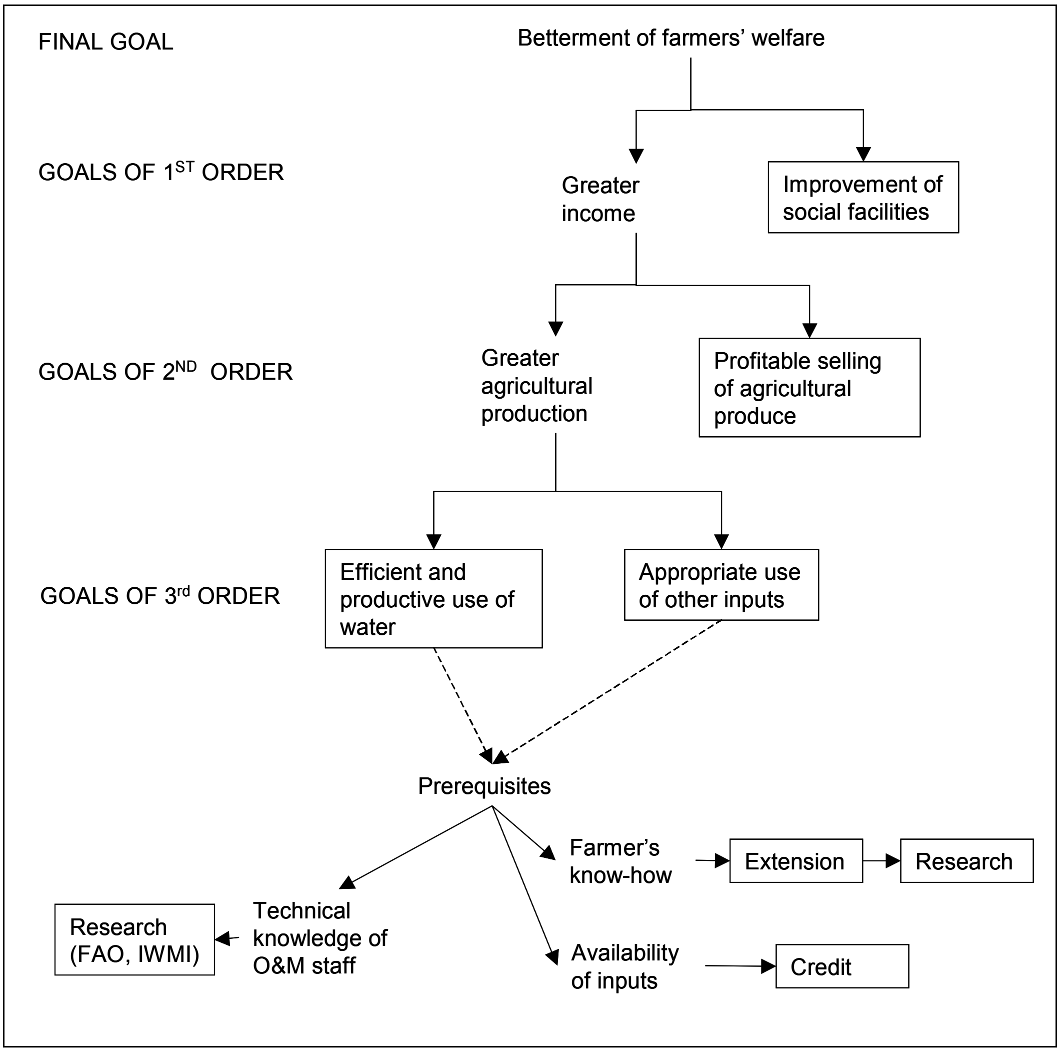


Figure 2.1 Hierarchy of objectives (Sagardoy, 1982)

This representation is, however, little simplistic, as different stakeholders in the process may have different objectives. Governments may have one set of objectives at the national level, scheme managers another set at the scheme level, and farmers another set again at the community level. Table 2.1 summarises possible objectives at these different levels.

Table 2.1 Objectives for irrigation and drainage schemes at different levels (after Jurriens, 1991)

Level	Possible objectives
National	• To increase national agricultural production • To provide the population with agricultural products • To achieve self-sufficiency in food • To supply industry with raw materials • To generate foreign exchange earnings • To create employment • To limit rural migration to cities • To raise the income of the rural poor and to achieve a more equitable income distribution • To establish social stability or social control
Irrigation and drainage scheme	• To maximize the agricultural output • To maximize the number of people settled on the irrigation/drainage scheme • Maximize financial return on the capital investment in infrastructure • Maximise financial return to farmers • To make efficient and productive use of land and water resources • To provide reliable, timely and equitable water distribution • To minimise adverse environmental impacts • To minimise waterlogging and salinity • To maintain the irrigation and drainage systems to enable proper operation • To cover the costs of management, operation and maintenance costs through service fee recovery from water users

Farmers	• To have a secure and stable life for themselves and their family
	• To be self-sufficient in food production
	• To earn a decent living (through the selling of agricultural products)
	• To obtain water:
	  o When, where and in the quantity needed
	  o Without difficulty
	  o When convenient
	  o Inexpensively – considering money and resource use (energy and time)

Service provision staff	• To have and keep a secure job • To do their job well • To have a secure and stable life
Operation of the irrigation system	To supply water: • In adequate quantity (discharge and duration) • At the correct time (in relation to crop growth stage and water demand) • Reliably • Equitably • Cost effectively • Efficiently
Maintenance of the system	• To keep the system in good operating condition at all times • To obtain the longest life and greatest use of the system's facilities • To achieve these two objectives above at the least possible cost

2.2 Components

The components of an irrigated farming system are presented in Table 2.2 and Figure 2.2. The key features of each of these components will be discussed in the subsequent sections of these Guidelines.

Table 2.2 Components of Irrigated Farming Systems

Component	Role
Physical	
Crop	The end product of the farming and water management activity. Determines the quantity and timing of irrigation water requirements.
Root zone	The storage reservoir for irrigation water. The greater the storage capacity the greater the interval that is possible between irrigations. The depth of the root zone is determined by the type of crop and its rooting characteristics.
Soil	The soil texture determines the water holding capacity of the soil. Heavier soils, such as clay, hold more water than lighter soils, such as sand. As a result, in general, lighter soils need irrigating more frequently than heavier soils.
Topography	The topography affects the irrigation method and whether drainage and erosion control is required. Irrigation systems located on hillsides will require different approaches to irrigation and drainage to systems located in flat valley floors.
Groundwater	The depth to groundwater can influence the irrigation needs of the crop. If the groundwater is within 2 metres of the soil surface there may be a contribution to the crop's water needs from ground water, thus reducing the demand for irrigation.
Climate (sunshine, temperature, rainfall, etc.)	The climatic conditions drive the evaporation of water from the soil surface and the transpiration of water from the crop. Evapotranspiration increases with temperature, wind speed, lowering of the relative humidity and sunshine hours (day length). Irrigation is required to replace the water lost to evapotranspiration.
Field layout and irrigation method	The field layout and irrigation method influences the efficiency and uniformity of irrigation. Various factors influence the choice of irrigation method, including the crop type, soil type, streamflow rates, topographic conditions, including land slope and topographic uniformity. Cost is also an important factor in determining the irrigation method.
Field size	The field size influences irrigation management. Smaller field sizes generally means more variation in the pattern of irrigation demand and increase the planning that is required to schedule irrigation water.
Irrigation channels	Irrigation water is conveyed to the fields by the on-farm irrigation channels, termed tertiary and quaternary canals. The condition of these channels (lined, unlined, piped, well/poorly maintained) influences the losses from the canals
Drainage channels	Drainage channels remove excess irrigation and rainfall from the fields and ensure that the soils are adequately drained.
Control structures	Control structures are required to divide and regulate the discharges entering each canal. Lack of on-farm control structures results in a limited ability to manage irrigation water.
Discharge measurement	Measurement of irrigation supplies is required to know how much water is being delivered and to assess if the supply is adequate or excessive in matching the crop needs.
Water source	The nature of the water source has a significant influence on water management. The pattern of flow in the river controls the cropping pattern within the irrigated area. The quantity of water can influence the water management activity, in water short systems water management is generally more carefully performed than in systems with adequate water supplies.
Managerial	
Farmer	The capability of the farmer has a significant influence on irrigation water management. A good farmer will know when to irrigate and with how much, and will apply the correct quantity of water to match the crop and soil needs.
Water Master	The water master is a central figure in water management, organising and overseeing the distribution of water between farmers. A good water master can have a very beneficial impact on the efficiency of water use.
WUA O and M engineer	The WUA operation and maintenance (O and M) engineer will work with the water master to plan and schedule irrigation water, and monitor its distribution. The better the planning and monitoring, the better the implementation.
WUA management	The WUA management can influence performance in relation to irrigation water management by monitoring the planning, allocation and use of irrigation water.
O and M procedures	The operation and maintenance procedures, both on- and off-farm influence the performance of irrigation water management. Well organised and systematic procedures lead to more efficient and productive water management.

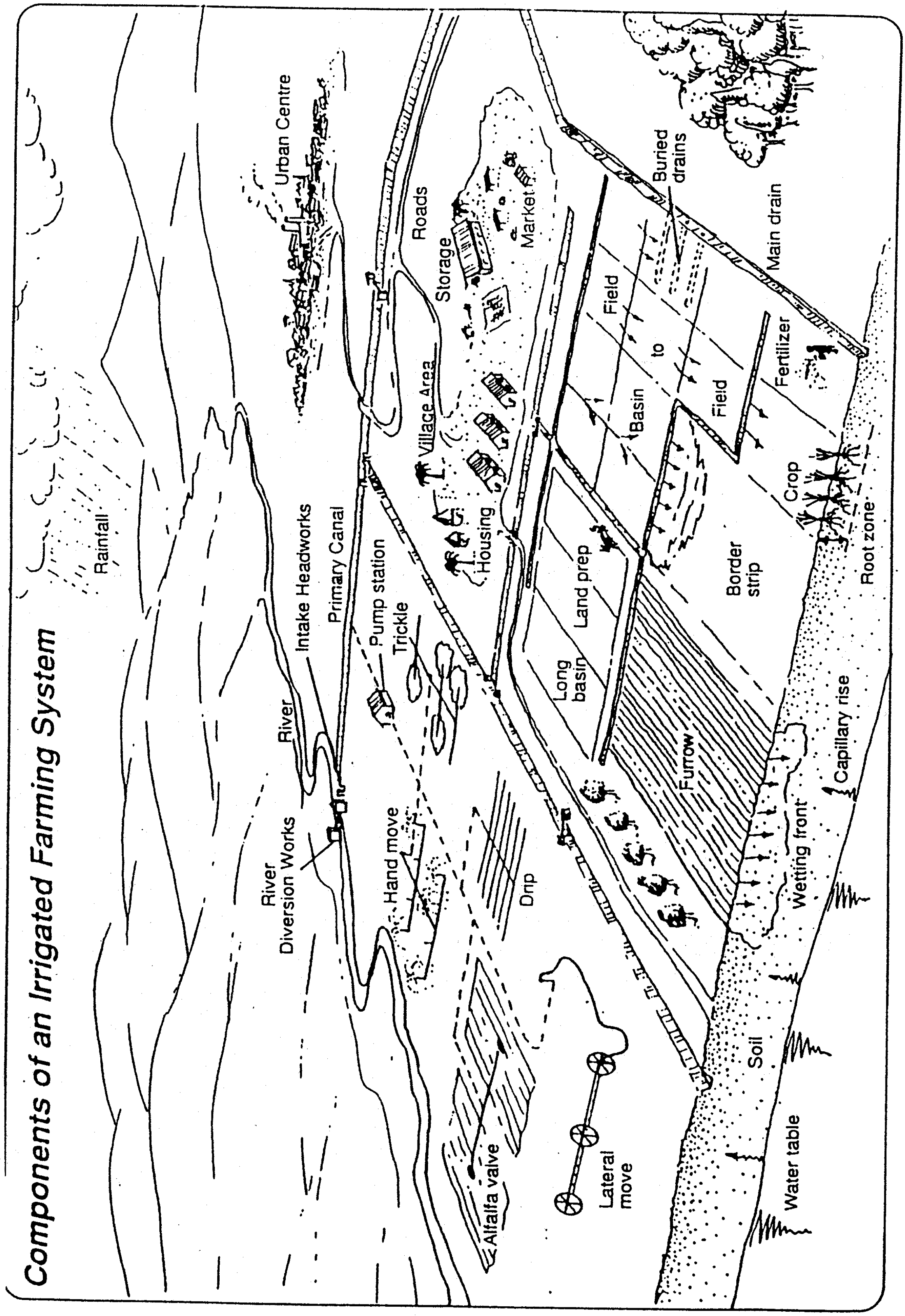


Figure 2.2 Components of an Irrigated Farming System

2.3 The Domains within an Irrigation Scheme

Chambers (1988) identified irrigation schemes as a complex mixture of physical, human and bio-economic domains. Figure 2.3 outlines these domains and the activities that go on. In the physical domain we are dealing with the climate, soils and physical infrastructure. On the other hand, the human domain deals with the irrigation agency personnel and with farmers, their families and other stakeholders. Similarly, in the bio-economic domain we are dealing with the crops, livestock, and markets. Overlying these three domains are the political, economic and legal domains.

Those involved with irrigation development need to be aware of, and understand, all these domains, and know which factors they can control and which are out of their control and influence. Politicians and government officials, for example, have control over the political, economic and legal domains, and have the ability to set the direction in terms of political support, legislation and economic policy to support the irrigated agriculture sector. Managers of irrigation systems have control over the physical domain, and can organise the capture and distribution of water. Within the human domain the irrigation staff is under the control of the scheme manager, whilst the farm households and labour are under the control of the water users themselves. The bio-economic domain is controlled by government policy on pricing, and on the markets.

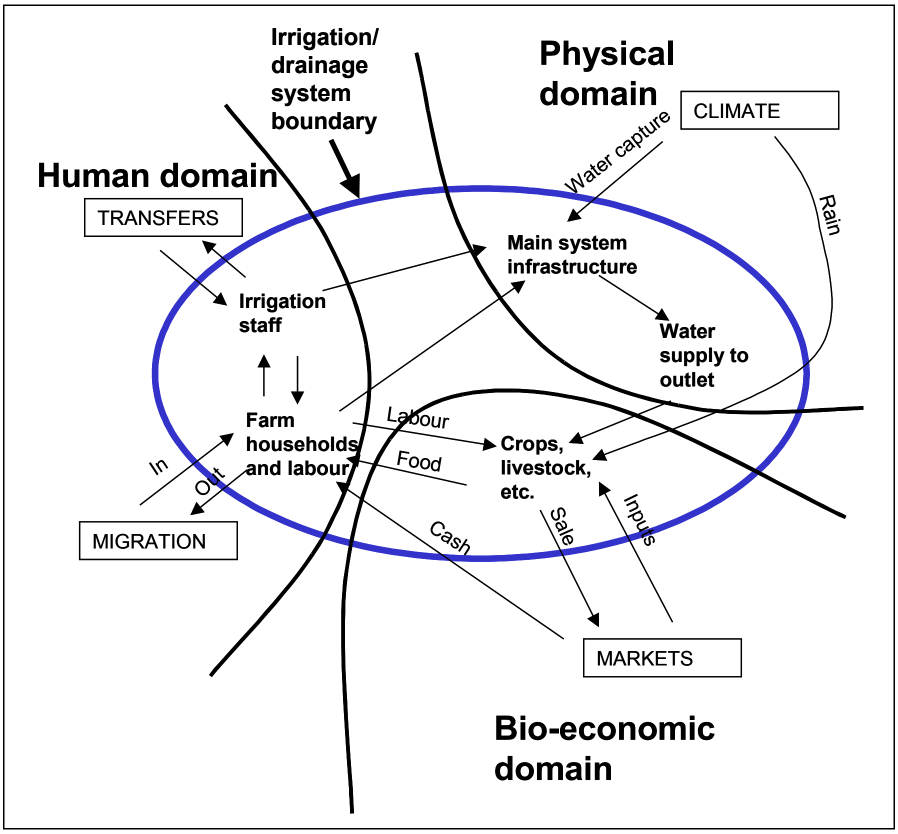


Figure 2.3 Domains related to irrigated agriculture (Chambers, 1988)

Building on this work by Chambers (and others) a useful categorisation of domains is:

- Technical
- Social
- Economic
- Institutional
- Environmental

Technical covers the physical infrastructure related to irrigation and drainage systems, the canals, drains, roads, field layouts, etc. and includes analysis of the physical environment to facilitate the design, construction and implementation of the irrigation and systems. Social covers the interaction of people within the irrigation schemes and the ways that they live and work together. Economic covers the financial and economic aspects of irrigated agriculture, the cost and value of inputs, resources and outputs. Institutional covers the political, legal and organisational frameworks influencing irrigated agriculture, whilst environmental covers the physical environment (the climate, soils, water resources, etc.) and health issues, both for the natural environment and for humans.

2.4 Types of Irrigation System

It is important to select the appropriate irrigation system. There are many factors to consider before selecting a particular irrigation system. These include water resources, topography, soils, climate, type of crops to be grown, availability and cost of capital and labour, type and appropriateness of a particular irrigation technology to farmers and its associated energy requirements, water use efficiencies, as well as socio-economic, health and environmental aspects.

2.4.1 Criteria for the selection of an irrigation system

It is not wise to use a single criterion for selection purposes. However, there are instances when one criterion can weigh heavily in favour of a particular irrigation system. The socio-economic impact of an irrigation system largely determines the success of the project. This embraces the socio-economic benefits, for and against, that can be derived not only by the government but also, more importantly, by the communities in which the project is located, and how these affect the sustainability of the project. Health and environmental aspects are also important. The introduction of irrigation in a particular area can not only improve health, but also introduce health hazards, if mitigation measures are not adequately addressed during the scheme design, implementation, operation and management. Irrigation development may also introduce other environmental risks, such as salinization and the deterioration of biodiversity. It is therefore necessary to obtain all available information and data and to carry out an analysis of all the factors before possibly ranking the criteria for purposes of selecting an irrigation system. In order for a project to be sustainable, all technical, socio-economic, health and environmental information should be analyzed in such a way that the system chosen is technically feasible, economically viable, socially acceptable and environmentally sound.

2.4.2 Types of irrigation systems

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

2.5 Phases of Development

It is useful to look at the processes involved in the development of irrigation and drainage schemes. Six relatively distinct processes can be identified:

- Planning
- Design
- Construction
- Operation
- Maintenance
- Support

These processes are similar to those used to describe "The Project Cycle", namely:

- Identification
- Preparation
- Appraisal
- Negotiations and Board Presentation
- Implementation and Supervision
- Operation and Maintenance
- Monitoring and Evaluation

The Project Cycle serves to outline the stages of the project; that is identification through to implementation, whilst the processes of development are not time bounded as with a project. Each of the processes in development of irrigation and drainage schemes are outlined in Table 2.3 below and then discussed in turn in the following sections.

Table 2.3 Project development stages and activities for smallholder irrigation

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

(adapted from: Chancellor and Hide, 1996)

2.5.1 Support

Support encompasses a variety of activities that permit the execution of the other five processes. It involves the organisational structure that is present through which the scheme is identified, planned, implemented and operated. Support activities include resource acquisition, personnel management, accounting and management.

In order for an irrigation scheme to be developed, some form of organisation needs to exist to conceive of the idea and follow it through to completion. This can be a group of farmers or a government agency, a combination of the two, or a private enterprise. The essential feature is that some element of **cooperation and organisation** is required.

2.5.2 Planning

Planning is the process of identification of the potential for irrigation and selection of the best approach for its development. Planning will look at the feasibility of the development in technical, economic, physical, social and environmental aspects. Questions to be asked will include:

- Can it be done?
- How will it be done?
- What will it cost and who will pay?
- What are the likely consequences and impacts of the development?
- What will the benefits be?
- How will it be organised?
- Who will be responsible for it?
- What are the objectives for the scheme?

Though the planning stage is crucial to the long term success of the scheme it is often the case that insufficient time and resources are spent on it. It is also the stage at which the least is known about the scheme, its people and the environment in which it will have to function. It is important at this stage to be clear about the objectives for the development, is it for political, economic, and financial or livelihood purposes. Some schemes are established for political purposes (to settle areas and lay claim to them and to resettle farmers from overpopulated areas). Such schemes might be uneconomic, but are a political necessity.

In the planning stage a feasibility study will be carried out to ascertain the feasibility and likely cost and benefits of the development. Thereafter, outline designs will be prepared to enable realistic cost estimates to be made, and funding will be sought. In addition, time frames for development will also be prepared. An important part of irrigation development, especially in areas with existing agriculture, is the active participation of the intended beneficiaries in the development process. Failure to involve beneficiaries at the planning stage has been found to have serious and detrimental effects on the subsequent stages of development, and the scheme's long term sustainability.

2.5.3 Design

Once the development has been planned full designs will be prepared. These may require further data collection. The design stage may include the following:

- Topographic surveys
- Design of scheme layout, including canals, drains, villages, water supply, roads
- Determination of the scheme's cropping pattern
- Estimation of crop and irrigation water requirements leading to canal sizing
- Estimation of surface runoff leading to drain sizing
- Selection of irrigation method
- Specification of scheme organisation, management, operation and maintenance
- Costing
- Preparation of tender documents (specification, bills of quantities and album of drawings)
- Implementation work planning

2.5.4 Construction

After finances have been secured construction can commence. Construction includes the following processes:

- Establishing a construction camp
- Bush clearance
- Setting out of the works
- Construction of infrastructure (canals, drains, structures, roads, villages, etc)
- Certification for payment (monthly and final)
- Commissioning
- Handing over of the completed scheme

Different procedures will be followed, depending on whether the scheme is constructed by a contractor or by the developer with assistance from the beneficiaries. Generally speaking, large scale irrigation schemes are constructed by contractor, whilst small scale irrigation schemes are developed through beneficiary participation.

2.5.5 Operation

For operation a set of procedures, rules and regulations will be required if the system is to operate efficiently and conflict is to be avoided. Procedures will be required to plan and manage the water distribution as the irrigation water demand is constantly changing. Operation activities will include:

- Planning cropping patterns
- Determining crop and irrigation water demands
- Estimating available irrigation supply
- Making adjustments to match supply and demand
- Making water allocations
- Monitoring and evaluating performance
- Liaising with water users
- Conflict resolution

2.5.6 Maintenance

Maintenance is an integral part of scheme operation, without it the scheme will deteriorate and productivity decline. Despite the very close relationship between performance and maintenance it is often the case that inadequate funds are allocated for maintenance. Maintenance activities will include:

- Identification and reporting of maintenance needs
- Planning and budgeting for maintenance
- Carrying out maintenance
- Monitoring and evaluation of work done
- Payment
- Liaising with farmers on maintenance
- Reporting work carried out

2.5.7 Rehabilitation

A further process which has become all too common is that of rehabilitation of irrigation schemes. This arises from a failure to properly operate and maintain schemes, though sometimes modernization programmes are, incorrectly, termed rehabilitation projects. Unfortunately, it is not too uncommon to find that rehabilitated schemes need rehabilitation after some years, the issue of recurrent funds for maintenance not having been resolved. Rehabilitation projects are in vogue at present, as the economic return to the investment appears good, with possible improvements in production being achieved through relatively small investments (existing infrastructure being taken as "sunk costs").

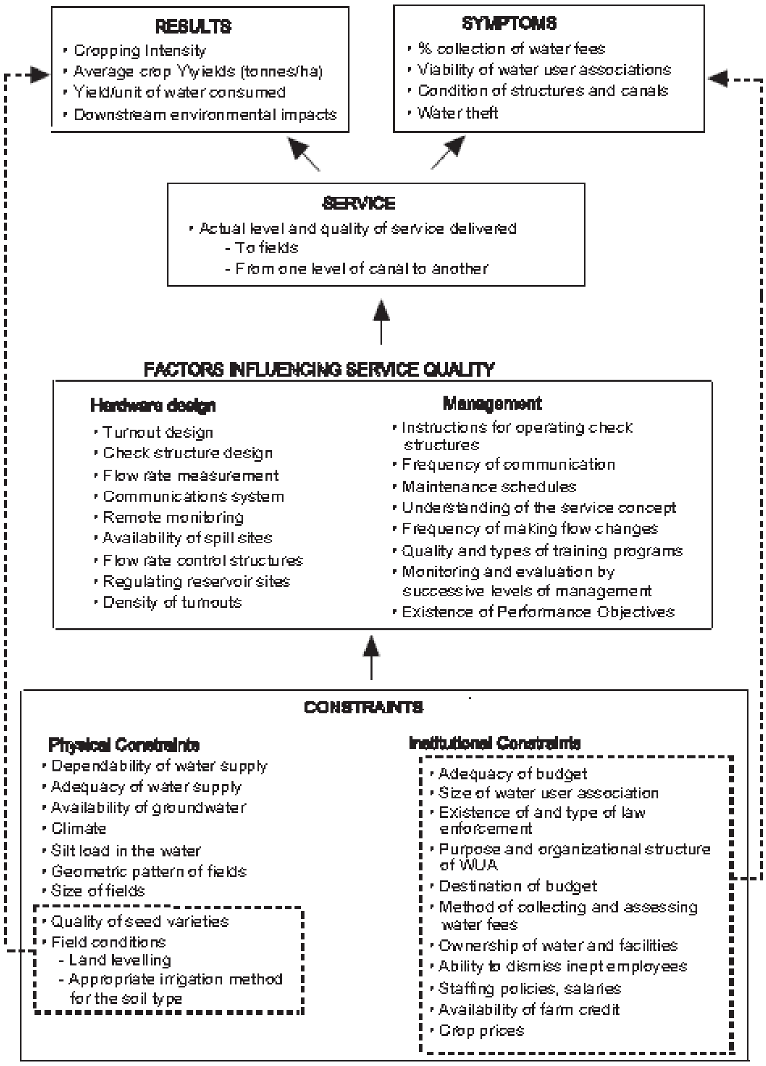


Figure 2.4 Factors affecting output (results) and symptoms from irrigation projects

Source: Modernizing irrigation management – the MASSCOTE approach Mapping System and Services for Canal Operation Techniques. FAO Irrigation and Drainage Paper. No. 63. Rome, 2007

2.6 Definition of roles of stakeholders

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

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

There is a need to clearly define the role of each stakeholder in order to avoid the possibility of role conflict. Usually, the main players are the farmers and the irrigation agency, normally a government institution.

The responsibilities of the agency are technical in nature. They include field surveys, such as water resources assessment, topographic, soil and socio-economic surveys, designs, technical and financial project appraisal, the supervision of construction and irrigation extension.

On their part, farmers provide the land for irrigation, organize finance for development (if not provided by the government or donors), provide labour for surveys and construction activities and any other assistance that the project may require. The farmers should form an Irrigation Management Committee (IMC) or a Water Users Association (WUA) to act as the contact between them and other stakeholders. Such committees operate based on bye-laws established and adopted by the farmers during general meetings, and also oversee the operation and maintenance of the irrigation infrastructure.

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

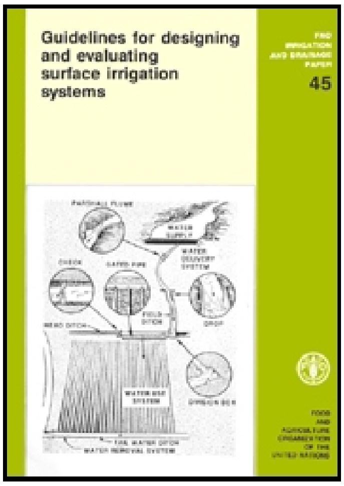
Of paramount importance are regular stakeholder meetings to update each other on developments and chart the way forward. Taking minutes of all meetings and approving and signing such minutes is imperative for use as reference when and if problems are later encountered. The presence of an extension agent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

2.7 Farmers' participation in scheme planning and development

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

2.8 References

Chambers, R. 1988. Managing canal irrigation: Practical analysis from South Asia., Cambridge University Press.



FAO. 1989. Guidelines for designing and evaluating surface irrigation systems. FAO Irrigation and Drainage Paper 45, W.R. Walker. FAO. Rome. http://www.fao.org/docrep/T0231E/T0231E00.htm

This guide is intended to serve the needs of the irrigation technician, for the evaluation of surface irrigation systems. The scope is focussed at the farm level. A limited series of graphical and tabular aids is given to relieve the user of some burden of computation. Unfortunately, the number of variables associated with surface irrigation prevents this from being completely practical. There are also two matters of philosophical nature that have led to the approach presented. First, the irrigation technician and engineer must understand the fundamental interactions characterizing surface flow in order to evaluate, improve, design and manage effectively. A mathematical presentation which briefly and concisely portrays these interrelationships is suggested. This guide omits nearly all theoretical development and presents the most basic mathematical description. Nevertheless, the complexity of the problem still requires an extensive mathematical analysis, even at this basic level. The expertise required of the technician is that of at least a secondary education, and the engineer whose training needs to be at approximately the BSc level. The procedures outlined have been presented so they can be applied directly via computer.

Jurriens, M. 1991. Lecture Notes: Rehabilitation and Management of Irrigation Projects short course. Institute of Irrigation Studies, University of Southampton, United Kingdom.

.3 Best Practice in Community Based Small Scale Irrigation

3.1 Overview

This chapter summarises the work carried out in identifying the best practice sites in the Basin[4] and draws together this work to provide a summary of the processes involved in identifying best practice in community based small scale irrigation.

3.2 Definition of best practice

There are several definitions of best practice, a proposed definition is provided below:

"An approach or method of carrying out a function or process to achieve a specified output that is recognised as being superior to that used in other organisations or businesses. Such an approach or method lends itself to replication by others who wish to gain the benefits provided by the best practice model".

Thus, best practice looks at the level of the outputs attained, and the processes by which these outputs are achieved. The interest in identifying best practice arises from a desire to single out its component parts and to emulate it and its achievements. Moreover, the process also implies comparison of one or more organisation's processes with those of another, and raises the concept of using best practice as a benchmark against which to gauge performance and opportunities for improvement.

3.3 Elements of best practice

The Final report of Phase I of the project[5] concluded that the main issues related to efficient water use for agricultural production included:

- Current water use and practices
- Returns to water/productivity
- Water measurement
- Water use efficiency
- Water pricing
- Irrigation management transfer (IMT)
- Management at the appropriate level
- Asset management
- Operation and maintenance

At the EWUAP inception workshop on Best Practices[6] held in Nairobi in November 2007, delegates identified the following general criteria for best practice:

Technical domain

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[4] Identification of Best Practice (BP) in each Nile Basin Country sites requires detailed knowledge of all irrigation sites in that country and the conditions under which they are planned, designed, built and operated. It is most important that readers understand that snapshots of sites do not identify the Best Practices in a country, but provide inputs into the country's analysis of BP. The identification of BP sites in these CBSSI documents are based on the reports of the National Consultants that have been reviewed, adjusted and endorsed by the very experienced professional staff in each country entrusted with irrigation and drainage development.

[5] Ian McAlister Anderson. April 2008. Agricultural Water in the Nile Basin – An overview, Final report. EWUAP.

[6] Proceedings of the EWUAP Inception Workshop: The Identification, Selection and Description of Best Practices, Best Practice Sites and Centres of Excellence in Water Harvesting, Community Managed and Public/Private Managed Irrigation. Lenana Conference Centre. Nairobi, Kenya. 27–28 November 2007.

- Sustainability of water source in terms of systems (durability, quantity and quality management, water control technique)
- Efficiency of the conveyance system
- Efficiency of water distribution system in the field to check whether the system within the best practice is being adequately involved
- Improved agronomic practices (that includes but not limited to nutrient management, pest and diseases)
- Soil properties (chemical and physical) that provide for efficient crop water use
- Harvesting technology i.e. the type of technology

Institutional

- Field water management (users attitude, organization, equity and reliability)
- Institutional and legal framework (WUAs, private sector, Government / Government agencies involved in scheme management
- Participatory approaches in irrigation development and management (that there should be a participatory approach at all levels).

Socio-economic

- Yield per unit area and/or per unit volume of water used
- Post harvesting management
- Marketing and marketing issues
- Financial management- whether there are any forms of financial managements and the issues revolving around transparency and accountability of financial management
- Monitoring and evaluation system and review/implementation of new recommendations

Proforma for data collection for both Water Harvesting and CBSSI was prepared for National Consultants carrying out the BP studies together with guidelines for execution of the work and follow up reporting. This aimed to ensure standardisation of information collected across the Nile Basin to enable accurate comparison and further follow up analysis of best practice sites in each of the nine countries[7]. A summary of the information requested is provided in Table 3.1. The data included information on the technical, institutional, social, economic and environmental conditions of the site, together with commentary on the nature of the identified best practices and their applicability to other locations in the Nile Basin.

The National Consultants who examined the best practices each prepared a system for ranking their projects using the above criteria. The main considerations for ranking CBSSI were identified and are summarise in Table 3.2, with community involvement and adoption by the community found to be considered as central to the success and sustainability of the scheme. Using the nationally developed ranking systems, best practices and best practice sites were initially identified by the Consultants through data review and discussions with a wide range of stakeholders familiar with the schemes. Results were confirmed through selected field visits and site discussions. National Project Coordinators and experienced professionals in both the public and private sector provided the necessary peer reviews and comments. Some sites did not fulfil all the criteria for best sites but have outstanding attributes over and above other practices/sites in the country. Table 3.3 provides an example of the identification of best practice sites and the reasons for selection.

[7] Anderson., Ian McAllister; Burton., Dr Martin. January 2009. Water Harvesting Final Report. Part I – Best Practices in Water Harvesting. Appendix J. EWUAP. Nairobi.

Table 3.1 Data requirements for identifying best practice

Date of visit and location of site	**Overview of the site and its technical development**
Date of Visit	Technical description:
Category:	Technical details:
Name of Site:	Useful in:
Geographic location of site:	Limitations:
Sketch map of site	Geographical extent of use:
GPS Coordinates:	Effectiveness:
General characteristics	Other Sites where used:
Description of the community:	**Costs and benefits**
Characteristics of the area:	Cost:
Period of year during which used:	Benefits:
Period of year during which benefits utilised:	**Best practice features**
Climate	**Advantages:**
Climate (AEZ) + Description:	Disadvantages:
Average annual rainfall (mm)	Scaling Up:
Months of Short Rains:	What is potential for applying all/parts of initiative elsewhere?
Months of Main Rains:	I - Transfer of practice to another group/culture/land-use system, etc.
Mean annual ref. crop evapotranspiration (mm):	II - Easy to transfer the practice, but with minor adaptations for local conditions
Physical characteristics	III - Transfer possible, but significant modifications/prerequisites to consider.
Predominant soil type:	IV - Difficult to transfer the practice. Need experienced support.
Topography:	V - It would be impossible to transfer the practice. Too site specific.
Slope:	Other specific remarks:
Erosion:	**Lesson learnt**
Water source, infrastructure and irrigation	Planning:
Water source:	Design:
Irrigated area:	Construction:
Method of water abstraction:	Implementation:
Water delivery infrastructure:	O&M:
Type of water distribution:	Beneficiary involvement:
Predominant on-farm irrigation practice:	Realisation of benefits:
Major crops (with percentages of total irrigated area):	Other remarks or observations:
Average farm size:	**Contact details**
Type of management:	Contact organisation:
Management, operation and maintenance	Type of organisation:
Stakeholders and beneficiaries:	[ ] government organization
Operation and Maintenance arrangements:	[ ] private organization
Water User Association or User Group:	[ ] NGO &/or CBO
Enabling environment:	[ ] international agency
Training support:	[ ] other:
Extension support:	Contact person:
Social/Cultural acceptability:	Contact details
Environment benefits:	Person completing form:
	Contact details:

Table 3.2 Ranking of CMI, SSI and PPMI practices - All Countries

Community	Technical Solution	O&M	Cost/Economics	Sustainability
Community participation	Level of solution to problem	Organization set-up	Cost /initial cost	Sustainability (recent to > 8 yrs)
Sustainability: (recently introduced to indigenous)	Existing irrigated area/potential area	Decentralization of decision making	Cost effective	Replicability
Social factors	Technical implementation (simple to complex)	Operation and maintenance arrangements and simplicity	Economic & Financial benefits & Viability (Benefit/Cost Ratio or EIRR)	Efficiency (water use, application)
Organized community leadership/WUA	Water abstraction method	Effective O&M system	Yield increase/profits %	Socioeconomic (diversity) importance of the irrigated crops
Socio-cultural acceptability	Sustainability of water sources (durability, quantity and quality)	Establishment of O&M committee	Water use efficiency	Adoption rate (number of community members that adopt technology)
Population benefiting	Suitability (topography; land use; water availability; etc)	Status of operation/maintenance of the scheme	Affordability	Food security assurance in scheme villages
Socio-cultural acceptability	Protection against drainage and flooding problems	Training for O& M	Accessibility to markets	Physical improvement of the delivery system
Well adopted and owned by the local community	Technical skills required by implementers	Spare parts availability	Improve socio-economic return and marketing	Implementation of integrated water/land management
Farmers participation (WUAs), and Institutional reform	Complexity in construction/ implementation	Lining of irrigation canals	Accessibility to site	Improve farmer health conditions and general awareness
	Efficiency (water use, application)		Delivered proven successful results (multiple benefits)	
Potential for out scaling	**Support Services**	**Institutional**	**Environmental impacts**	
Potential for out scaling	Technical support	Acceptability by government and other institutions	Notable positive environmental impact	
Range of climatic conditions	Vicinity to support institutions	Upstream-downstream committees	Environment friendly	
Area coverage compared to the potential	Capacity building of community	Government support in policy and finance	Water-borne diseases	
Technical skills required	Improved agronomic practices	Capacity building of community	Water quality	
			Sedimentation	
			Salinity and alkalinity of soils	

Source: Anderson, Ian McAlister, Agricultural Water in the Nile Basin – An overview, Final report. EWUAP, April 2008.

Table 3.3 Identified best practice sites for CBSSI in Ethiopia

Site/Ownership	District	Crops /Practice
Mai Negus	Tigray; Laelay Maichew	High application efficiency; high income per cropped area and output per unit water
Godino	Oromia; Adaa	Increased income and living standard of Irrigators
Chole	Oromia; Ambo	Good irrigation management and strong WUA
Indris	Oromia; Ambo	Good irrigation management and strong WUA
Taltale	Oromia; Ambo	Expanded irrigable area
Kobo-Alewuha	Amhara; Kobo	Good irrigation management and strong WUA
Burka Weldiya	Oromia; Jarso	Deficit irrigation and effective traditional WUA

Source: Anderson, Ian McAlister, Agricultural Water in the Nile Basin – An overview, Final report. EWUAP, April 2008l

3.4 Criteria used in studies of best practice

Different countries used different procedures during the study to identify, rank, and classify best practice in community based small scale irrigation. The procedure adopted in Burundi is presented in Tables 3.4 and 3.5. The selected criteria are allocated a range of scores, mostly based on qualitative rather than quantitative assessments (Table 3.4), and each scheme was then evaluated against these criteria (Table 3.5).

Table 3.4 Setting the values for weighting criteria for best sites in Burundi

Area of the irrigable zone	C_i : rate of site i A_i : area of site i	$C_i = \frac{A_i * 10}{A_{max}}$
Availability of water	Sufficient quantity at low cost	10
	Sufficient quantity at moderate cost	9
	Sufficient quantity at high cost	8
Socioeconomic importance of the irrigated crops	Very high	8
	High	7
	Low	6
Population involvement	Very active	8
	Active	6
	Less active	4
Output (yield)	Very high	7
	High	6
	Medium	5
Marketing and marketing issues	Near the centre of greater consumption (Bujumbura the capital of Burundi)	7
	Less than 100 km of the Capital	6
	More than 100 km of the capital	5
Diversity of the crops	Mixed crops	6
	Single crops	4
Accessibility	Very good	6
	Good	5
	Difficult	4

Table 3.5 Multi-criteria assessment of best sites in Burundi

Sites	Criteria								
	Area of the irrigable zone	**Availability of water**	**Socioeconomic importance of the irrigated crops**	**Population involvement**	**Output (yield)**	**Marketing and marketing issues**	**Diversity of the crops**	**Accessibility**	**Total points**	**Rank**
	/10	**/10**	**/8**	**/8**	**/7**	**/7**	**/6**	**/6**		
RDCI	10.0	8	8	8	7	7	6	6	60.0	1
Mparambo	3.9	9	8	8	6	6	6	4	50.9	2
Rukoziri	1,5	9	8	4	5	5	6	4	42.5	6
Rumonge	1,9	8	6	6	7	6	4	4	42.9	5
Nyabiho	0.4	10	8	8	6	5	4	5	46.4	4
Murambi	0.5	10	8	8	6	6	4	6	48.5	3

In Kenya, a similar approach was adopted, although a greater number of evaluation criteria were used (Table 3.6). Key criteria were allocated points within the range 0-10, whilst other criteria were given a different weighting by scoring in the range 0-8. This approach gives a fairly quick and transparent assessment, with the areas of strengths and weaknesses clearly shown for each scheme.

Tanzania evaluated different irrigation technologies using six criteria (Tables 3.7), from which it came up with a ranking of these technologies (Table 3.8). For individual schemes seven criteria were used in the best practice assessment (Table 3.9). From this assessment Lekitatu scheme scored the highest mark followed by Mwega and Mombo schemes. Lekitatu was ranked highly due to the fact that the scheme has a strong farmer's organization with three functioning committees for O&M, environment and agriculture, and finance and planning. Training was also seen as an important part of the success of this scheme.

In Uganda, the irrigation technologies were assessed against six criteria (Table 3.10), and the individual schemes against another set of six criteria (Table 3.11). The classifications were in text rather than numeric format.

Table 3.6 Ranking criteria and scores for best practice sites for CBSSI in Kenya

Salient features for selection of best practice site	Classification and scores			Site							
	Low score	Medium score	High score	Kibirigwi	Mitunguu	Wahambla	Ngura	Alaranyahoda	Asunda	Alungo	Abwao
Major salient features (Maximum 10 points)	**2 points**	**5 points**	**10 points**								
Technical design	Not clear	Average clarity	Clear, followed and maintained	10	10	5	5	5	5	5	5
Sustainability	two to ten years	ten to twenty years	more than 20 years	10	10	10	10	5	10	5	5
Co-operative society	absent	limited	highly active	10	10	5	5	5	5	5	5
Impact on environment	negative	average	positive	10	10	5	5	5	5	5	5
Water productivity	low	average	high	5	10	5	5	5	5	5	5
Accessibility to markets	poor	average	good	10	10	2	5	10	2	5	2
Operation and maintenance	low	medium	high	10	10	5	5	5	5	5	5
Dependency on external funding	high	average	low	10	10	5	5	5	5	5	5
Water quality	poor	average	good	10	10	5	5	5	5	5	5
Other salient features (Maximum 8 points)	**2 points**	**4 points**	**8 points**								
Population benefiting	low	medium	high	4	4	4	4	4	4	4	4
Capacity building of community	low	average	high	8	8	4	4	4	4	4	4
Water Users Association	absent	average	many	2	4	2	2	4	4	4	4
Organized community leadership	absent	limited	highly active	8	8	4	4	8	8	8	8
Vicinity to support institutions	absent	average	high	4	4	4	4	4	4	4	4
Status of operation	poor	medium	good	8	8	4	4	4	4	4	4
Ease of implementation	low	medium	good	4	4	4	4	4	4	4	4
Current condition of scheme	poor	average	good	4	4	4	4	4	4	4	4
Government support in policy and finance	low	medium	high	4	4	4	4	4	4	4	4
Total points				**131**	**138**	**81**	**88**	**94**	**91**	**89**	**80**
Ranking				**2**	**1**	**7**	**6**	**3**	**4**	**5**	**8**

Table 3.7 Ranking criteria for commonly used irrigation practices in Tanzania

Criteria	Scores			
	Very high	**High**	**Med**	**Low**
Water use efficiency	20	15	10	5
O&M		2	5	10
Labour requirement		2	5	10
Environmental impact		2	5	10
Possibility of upscaling		20	15	10
Criteria		**Complex**	**Somewhat complex**	**Simple**
Technical requirement		1	5	10

Table 3.8 Ranking of irrigation practices in Tanzania

No.	Irrigation practices	CRITERIA						Total	Rank	Example of scheme
		Water use efficiency	O&M	requirementTechnical	Labour requirement	impactEnvironmental	upscalingPossibility of			
1	Gravity, open channel (semi-lined), level basin	10	10	10	2	2	20	54	1	Mombo
2	Pumped, piped, lateral drip	20	2	1	10	10	10	53	2	Kibena Tea
3	Gravity, open channel (lined), level basin	10	10	10	5	2	15	52	3	Lower Moshi
4	Gravity, open channel (unlined), level basin	5	10	10	2	2	20	49	4	Lekitatu
5	Pumped, piped, movable sprinkler	20	2	1	5	10	10	48	5	Kilombero sugar 1
6	Pumped, open channel/ piped, pivot	15	2	1	10	5	10	43	6	Kilombero sugar 2
7	Pumped, open channel/ piped, movable sprinkler	15	2	1	5	5	10	38	7	Kibena tea
8	Pumped, open channel (unlined), level basin	5	5	5	2	2	15	34	8	Dakawa

Table 3.9 Ranking of community-managed irrigation schemes in Tanzania

Scheme	Ranking Criteria							Total points
	Technical factors (15 points)	(18 points)Economic Factors	(12 points)Possibility of Environmental status factor	Ease of implementation (5 points)	(24 points)Social factors	(20 points)Regional condition	(6 points)Water use efficiency	
Lekitatu	9	14	9	5	23	16	2	79
Mwega	9	15	8	5	21	14	3	75
Mombo	9	13	8	5	23	10	3	71
Kikafu Chini	10	13	6	3	23	14	0	69
Mkindo	7	13	6	3	21	16	0	66
Lumuma	11	14	8	1	19	8	0	61
Lower Moshi	4	17	6	5	12	11	5	60
Dakawa Rice Farm	7	8	3	3	21	12	0	54

Table 3.10 Assessment of irrigation technologies/practices found in Uganda

Irrigation Technology/practice	Crops	Example location of practice	Attributes					
			Benefit	Maintenance management	Cost	Spare parts availability	Technical support	Water use efficiency

Furrow	Vegetables, cotton, maize	Mubuku scheme	Increased yield	Poor	Low	Local		Low
Basin	Rice	Pallisa, Tororo, Kimbimba, Doho	Increased yield	Average	Low	Local		Low High
Sprinkler	Fruits, vegetables, flowers	Kiige, Ongom	Increased yield	Poor	High	Kampala		High Average Average
Drip	Flowers	Kampala, Entebbe	Increased yield	Poor	High	Kampala	District MAAIF NARO	Low
Treadle pump	Vegetables	Rural, peri – urban (Jinja)	Increased yield	Poor	Low	Kampala		
Watering can/ bucket	Vegetables, nurseries	Urban, rural areas	Increased yield, but small production	High	Low	Town Kampala		
Gravity flow/ flooding	Various	Where elevation difference exists, rural areas	Increased yield	Average	Low	Local		

Table 3.11 List of best practice community managed (small scale) irrigation sites in Uganda

Irrigation Site/ Ownership	Location (District)	Crops	Criteria					
			Environment management	Maintenance Management	Yield increase	Management structure	availabilityMarket	efficiencyWater use
Iganga Paddy rice growers communities	Iganga	Rice	Average	Average	High	Average	Good	Low
Pallisa Paddy rice growers communities	Pallisa	Rice	Average	Average	High	Average	Good	Low
Tororo Paddy rice growers communities	Tororo	Rice	Average	Average	High	Average	Good	Low
Mr.Sembusi Richard Bulenge Village Buwunga sub county Private/community	Masaka	Coffee, banana, pineapple, coffee nursery, fish pond	Good	Good	High 2 ton/ acre	Average	Good	Low
Mr. Mpinde Livingstone Katolerwa village Kibinge sub county. Private	Masaka	Coffee, coffee nursery	Good	Good	High	Average	Good	Low

3.5 Identification of processes involved in “best practice” CBSSI

The examples shown in Section 3.4 show the range of criteria used for the identification of best practices in different countries. This section seeks to draw these criteria together, and provide a general framework for identification and understanding of best practice.

As outlined in Chapter 2 above irrigation and drainage functions across five domains:

- Technical
- Social
- Economic
- Institutional

- Environmental

Some characteristics of best practice in these five domains are presented in Table 3.12, and show that best practice has to occur in a wide range of areas before an irrigation and drainage scheme can itself be described as "a best practice scheme".

Table 3.12 Characteristics of best practice in the five domains of irrigation and drainage

Domain	Best practice characteristic
Technical	• Adequate water supply • Functioning system • Well designed • Well built • Well operated • Well maintained
Social	• Cohesive • Work together • Help each other • Limited conflict
Economic	• Profitable agriculture • Accessible markets (at reasonable cost) • Good prices for agricultural produce • Adequate levels of fee recovery to cover MOM costs
Institutional	• Adequate legislation (Water law, WUA law, water rights, Environment law) • Political support for irrigated agriculture • Political support for irrigation management turnover and water users associations • Functioning systems of governance (government agencies, WUAs, etc.) • Functioning educational systems (primary through to tertiary education) • Functioning, knowledgeable and adequately resourced extension service • Functioning, knowledgeable and adequately resourced I&D agency • Functioning, knowledgeable and adequately resourced water users associations (staffed, trained, skilled in MOM, ISF fees recovered)
Environmental	• Favourable physical environment (soils, water resources, climate, topography, etc.) • Not degrading resources (erosion, over-abstraction of surface or groundwater, etc.) • Limited runoff and pollution of land and water resources from agriculture • Favourable health environment (in relation to waterborne disease)

The elements outlined in Table 3.12 are linked together in a series of processes. The fundamental process for irrigated agriculture is the abstraction, delivery, application and removal of water to a farmer's plot of land (Figure 3.1). This is a technical process, which becomes a technical/institutional process if the management of the water delivery and removal is added. An additional economic dimension is added if the process of planting, harvesting and consumption or marketing of the crop are considered (Figure 3.2). The process of generating financial or economic benefit from the process results in the community's ability to adequately resource and sustain (either with cash, labour or in-kind payments to O&M personnel) the I&D system.

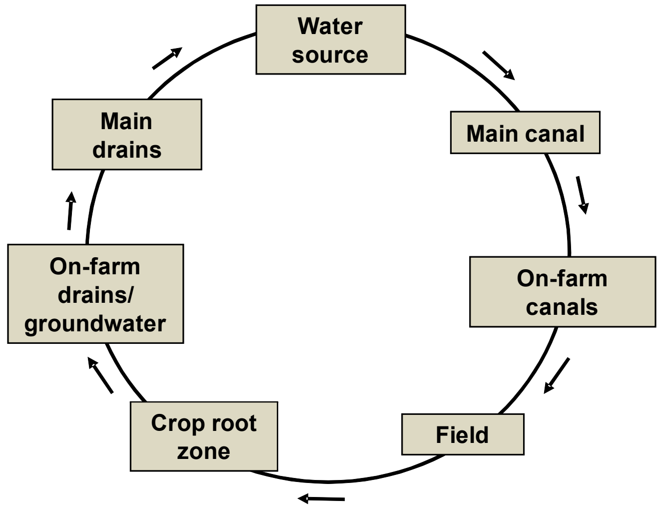

Figure 3.1 Technical process of water conveyance and removal to/from the farmer's field

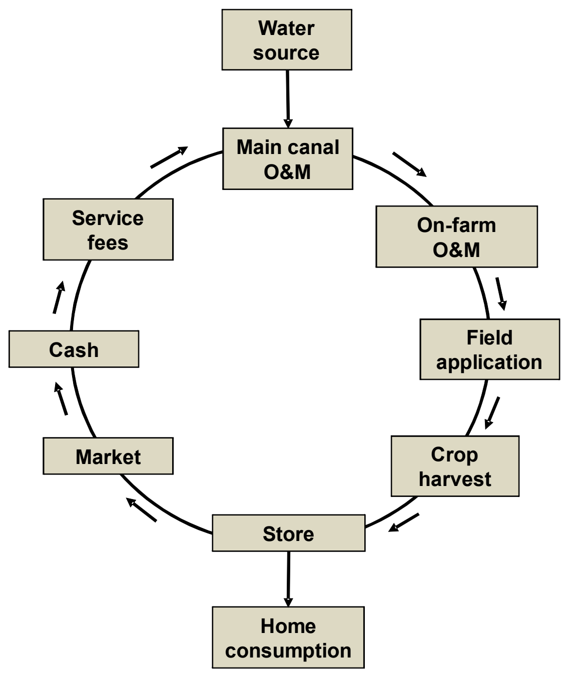

Figure 3.2 Technical, institutional and economic process of water supply, cropping and marketing

A number of these processes can be identified, leading to the nested systems analysis proposed by Small and Svendsen (1992; Figure 3.3). In this model, each system or process is nested within a wider system or process. The irrigation system feeds into the irrigated agricultural system, with water being one of the inputs to the irrigated agriculture system. The crops produced from the irrigated agriculture system combine with other inputs such as crop price, markets, etc. to form the agricultural economic system, which in turn feeds into the rural economic system and then the political-economic system.

These nested systems thus provide a chain of inputs, processes and outputs leading to beneficial outcomes. For farmers the key outcomes are food security and financial returns, for government the key outcomes are food security and economic development.

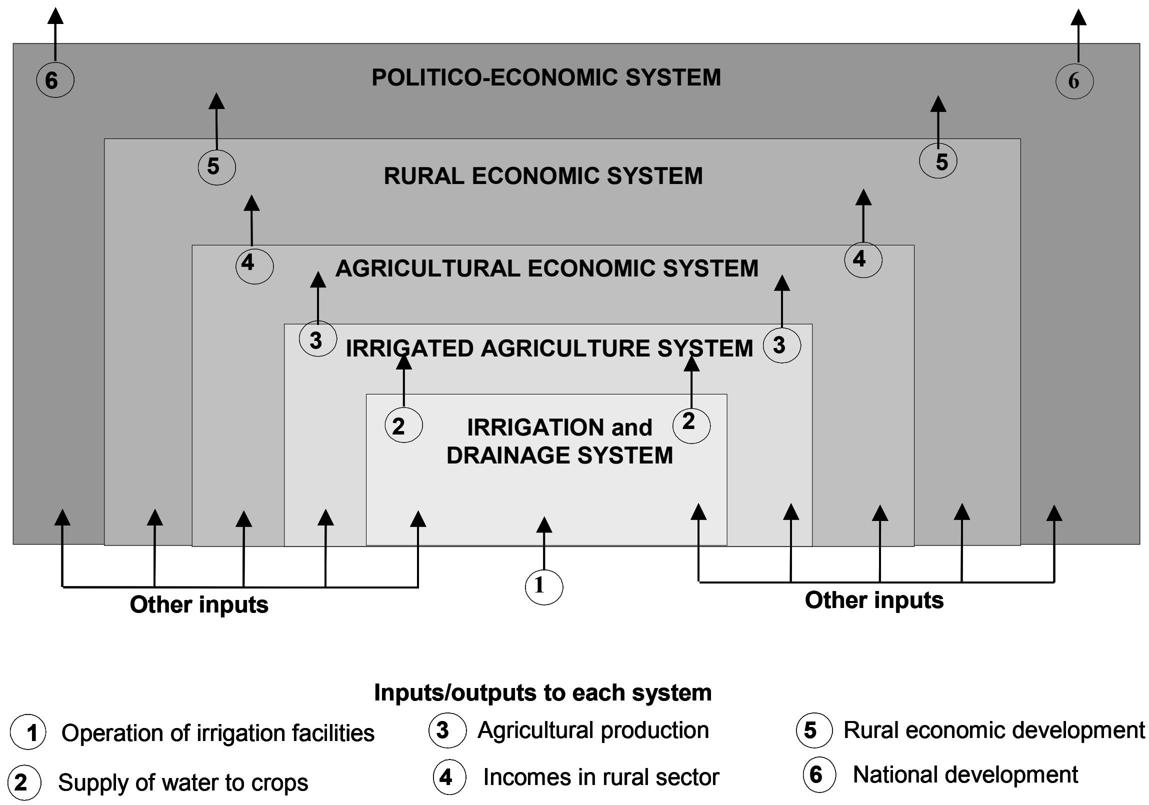

Figure 3.3 Irrigation in the context of nested systems (Small and Svendsen, 1992)

3.6 Summary of procedures for identification of best practice in CBSSI

From the discussion above the following procedures can be used to identify best practice in community based small scale irrigation:

- Identify key processes involved
- Identify suitable indicators
- Collect data/information on indicators
- Analyse and report on the data.

Table 3.13 summarises some of the main processes involved in community based small scale irrigation, and possible indicators for use in analysing these processes. The indicators shown here are necessarily broad, more detailed indicators will be required in some areas (e.g. measurement of soil and water salinity and alkalinity to determine water/soil quality).

Thus, the task of identifying the key processes and the components of these processes helps to identify the chain of actions required to achieve the desired outcomes from irrigated agriculture. Understanding and measuring the performance of each of these actions and processes enables identification of best practice and areas of weakness. Once identified, these areas of weakness can be addressed and the links in the chain strengthened.

3.7 References

Anderson, Ian McAlister; April 2008. Agricultural Water in the Nile Basin – An overview, Final report. EWUAP.

Anderson, Ian McAllister; Burton, Dr Martin. January 2009. Water Harvesting Final Report. Part I – Best Practices in Water Harvesting. Appendices. EWUAP. Nairobi. [The information in these Appendices is taken from the draft Best Practice Reports prepared by National Consultants and commissioned by EWUAP – PMU. These are available on the EWUAP web site: (http://ewuap.nilebasin.org/index.php?option=com_docman&task=cat_view&gid=43&Itemid=44 For further information, the EWUAP PMU should be consulted.

Small, L.E. and Svendsen, M. 1992. A framework for assessing irrigation performance. IFPRI Working Papers on Irrigation Performance No.1, International Food Policy Research Institute, Washington, D.C., August.

Table 3.13 Key processes and related indicators linked to identifying best practice in CBSSI

Process	Processes	Possible indicators			
		1	2	3	4
Water abstraction, delivery and removal	Water source	Water availability	Reliability of supply		
	Main canal	Conveyance efficiency	Flow capacity		
	On-farm canals	Distribution efficiency	Flow capacity		
	Field	Application efficiency			
	Crop root zone	Soil water salinity	Depth to groundwater		
	Groundwater/On-farm drains	Depth to groundwater	Days of submergence		
	Main drains	Depth to groundwater	Flow capacity		
Agricultural crop production	Purchase inputs	Availability of inputs	Price of inputs	Quality of inputs	
	Store inputs	Quality of storage	Incidence of damage/deterioration		
	Prepare land	Quality of land preparation	Timeliness of land preparation		
	Plant seed and apply other inputs	Timeliness of planting/application	Area cropped		
	Tend growing crop (irrigate, weed, etc.)	Quality of crop management	Quantity/timing of irrigation	Quantity/timing of applications	
	Harvest crop	Crop yield	Crop production	Production per unit of water	Degree of crop/yield loss
	Store produce	Quality of storage	Incidence of damage/deterioration		
Financial and economic	Purchase inputs	Cost of inputs	Quality of inputs		
	Store inputs	Quality of storage	Incidence of wastage		
	Produce crop	Quantity of crop	Quality of crop		
	Store produce	Quality of storage	Incidence of wastage		
	Transport produce	Distance to market	Quality of packing	Quantity of produce lost/damaged	
	Sell produce	Crop quantity	Crop quality	Crop price	Crop/farm budget
	Purchase goods and services	Types and value of purchases	Payment of debts	Payment of service fees	
Institutional framework	Political support	Evidence of political support	Awareness by politicians of role of irrigation in the economy	Awareness by politicians of role of WUAs in irrigation management	
	Legal framework	Existence & quality of Water Law	Existence and quality of WUA Law	Existence and quality of Tax Code	Existence of water rights
	Main system management	Quality of main system service provider	Quality of system operation	Quality of system maintenance	
	On-farm management	Quality of on-farm system service provider (WUA)	Quality of system operation	Quality of system maintenance	Level of water user participation
	In-field management	Quality of in-field water management	Quality of farm management decision-making		
Sustainability	Crop land & apply inputs (seed, water, etc.)	Area cropped	Quality/quantity of inputs purchased		
	Grow and harvest crops	Crop area harvested	Crop area lost during growing period	Crop yield	
	Consume or sell crops	Adult and child nutrition levels	Adult and child health	Crop income	Farm budget
	Pay Irrigation Service Fee	Level of ISF	Collection ratio of ISF	Total ISF collected	
	Manage, operate and maintain I&D system	Expenditure on management	Expenditure on operation	Expenditure on maintenance	
Planning, design and construction	Planning	Evidence of planning capability	Quality of planning & decision making		
	Design	Availability & quality of design manuals and procedures	Quality of designs		
	Construction	Availability & quality of construction manuals and procedures	Quality of construction		
Environmental management	Physical environment	Quality of physical environment			
	Human and animal health	Incidence of waterborne disease	Public health	Water quality	

PART B

.4 Planning of Irrigation and Drainage Development

Overall performance of 'irrigation and drainage' (also implying reclamation and water control) investments, has too often fallen short of the expectations of planners, governments and financing institutions. Publicly financed irrigation and drainage investment projects have too often performed poorly. Sometimes the reasons have been unforeseeable or unavoidable, but in many cases shortcomings resulted from inadequate consideration given by planners and designers to institutional constraints, as well as practical implementation problems, or because there was insufficient commitment by governments or users to the developments proposed. Delays, dilapidation, waste of scarce water and adverse social and environmental impacts have been among the familiar consequences. Lessons have been learned from these setbacks, and these guidelines endeavour to assist the planner or designer to both learn from the past, and also to be aware of what needs to be considered.

This chapter gives an indication of the broad areas to be considered, which will be discussed in more detail in subsequent chapters. Building stronger participation and commitment in the detailed planning process is essential and although there has been much written on this, a good deal is forgotten or ignored after the initial consultation process. Irrigated agriculture can and does make a major contribution to food production and security, provided that longer term requirements of participation by the users and regular training of both users and support staff are given adequate and continued support for much longer than the initial capital investments.

Useful work on the appraisal of small-scale irrigation projects was prepared in 1998 (Field and Collier, 1998)[8] through the joint cooperation of the Department for International Development UK (DFID), the International Commission on Irrigation and Drainage (ICID) and the Food and Agricultural Organisation of the United Nations (FAO). The document produced provides a comprehensive check list of aspects to be considered, which should be consulted by those preparing projects for new or rehabilitated small scale irrigation. At the end of this section, a list of references that can assist is provided. In Appendix A[9] further references are provided.

Since the ultimate success of an investment is largely determined by the quality of the upstream process of planning, it is pertinent to consider lessons learned from experience, and their implications for future planning. A number of these lessons include:

- water is an increasingly scarce resource for which there are many competing demands that are more profitable, socially and economically, than irrigation;
- low world prices for basic food and fibre crops, together with typically high development costs, have made new irrigation development increasingly difficult to justify.
- world food supply will depend even more on irrigation in the next decades than in the past century

Future irrigation investment must therefore focus on lower cost solutions, both for new development and for rehabilitation, on making better use of existing irrigation facilities, and on increasing output value per unit of water used. Planners and designers should seek to establish the conditions that will promote this focus.

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[8] Checklist to Assist Preparation of Small-Scale Irrigation Projects in Sub-Saharan Africa. W P Field, F W Collier, HR Wallingford, Institute of Hydrology. DFID/ICID. March 1998.

[9] Part II – Guidelines for the Implementation of Best Practices in Community Based (Small Scale) Irrigation, Appendix A - List of Reference Material.

4.1 Climate and Water resources

The most important climatic data are rainfall, maximum and minimum temperatures, maximum and minimum relative humidity, wind and sunshine hours. Climate is an important factor in crop production. Different crops have different requirements in terms of temperature, humidity and light. Occurrence of frost at certain times may exclude a number of crops from the cropping programme. The analysis of climatic data with respect to crop production is thus needed before a cropping programme can be prepared. Accurate estimates of crop water also rely heavily on the availability of accurate meteorological data. Errors of only 20% in crop water requirement estimates can significantly affect the economics of the project, especially in Africa where the water development cost is high; hence the need for long-term accurate meteorological data, especially long-term rainfall data.

4.1.1 Water quantity and timing

The available discharge from the source and the timing are very important. Lesser discharges favour irrigation systems that incorporate frequent applications with small quantities of water. Large discharges are required for systems that irrigate crops, with greater water demand on heavier soils that require less frequent irrigation with higher quantities of water. The seasonality of water supply also influences the choice of the irrigation system and crops. This will also affect the cropping intensity and the balance between the irrigated areas in the rainy season, and that in the dry season. Distribution systems, based on rotational delivery, provide large intermittent flows, thus favouring the selection of surface irrigation, where large irrigation depths are normally applied, compared with sprinkler or drip irrigation systems. When the water supply is from underground resources, costs of pumping play an important role and will guide the selection of the most efficient application method, with optimum well yield being related to crop water demand and application efficiency. On-farm storage reservoirs may be required, but this additional cost also influences the choice of the irrigation system.

4.1.2 Water quality

Water quality tests are needed before a decision is made on the type and capacity of a particular type of irrigation system (see Section 5.8). Chemical composition of the water and the sediment load carried will influence the choice of irrigation method.

- The presence of elements such as sodium (Na), Chlorine (Cl) and Boron (B), beyond a certain level, can cause leaf burn and defoliation under sprinkler irrigation.
- The total concentration of salts in irrigation water affects the leaching requirements and increases the amount of water needed for irrigation.
- Generally, poor quality water requires more frequent and larger applications than good quality water as additional water is needed to ensure adequate leaching.

These all affect the choice of the irrigation system and equipment used. For example, furrow irrigation of certain crops may not be recommended where salt concentrations are high due to accumulations in the soil at the top of the furrow, and drip irrigation may be constrained by the sediment load carried in the irrigation water, with the need to select an appropriate dripper to avoid clogging Similarly, sediments increase the wear of pumps and other components of sprinkler irrigation systems.

4.2 Maps and Topographical Surveys

Topography is one of the most important elements that affect the irrigation system selection process. Of particular importance are the location and elevation of the water source relative to the field, land slopes and uniformity and micro relief. Land slope may limit the selection of surface irrigation systems as it affects the erosive force and hence the length of run and labour required for the system operation. Generally, surface irrigation systems require uniform field slopes up to 2% but certainly less than 5%. Steep lands are not favourable for surface irrigation, and if adopted require costly land levelling and care not to remove fertile topsoil. If these fertile soils are removed, greater amounts of expensive fertilizer are needed to achieve predicted crop yields. Sprinkler and localized (drip) irrigation systems can cope with much steeper lands than surface irrigation systems, with application rates related to infiltration rates of soils rather than land slope.

4.3 Soils and Land Use Potential

Soil texture, structure, depths and profiles as well as drainage and soil salinity all affect the choice farm irrigation system (see Section 5.1). These will affect available soil moisture (field capacity minus permanent wilting point), infiltration rate of the soils and required water application rates and amounts. Available soil moisture capacity affects the frequency of irrigation and hence the adopted irrigation method. Infiltration rate affects the length of run and size of borders, furrows and basins as well as the application rates from sprinkler and localized (drip) irrigation systems. Generally, coarse textured soils have high intake rates, require more frequent water applications and have low soil moisture holding capacity. They are thus less suitable for surface irrigation, necessitating shorter run lengths for furrow and borders and smaller basins for flood irrigation (implying more canals and higher costs). Heavier textured soils tend to favour surface irrigation, with light soils being more suitable for the adoption of sprinkler or localized (drip) irrigation. Not only do textural characteristics relate to how and when water should be applied, but also to land preparation and types of sprinkler system selected. The traction ability of heavy irrigation systems such as centre pivot sprinkler irrigation systems need soils that do nor rut and create ridges pushed up by the wheels.

4.4 Drainage and soil salinity

Whether drainage is natural or achieved through the provision artificial facilities, it is essential that drainage systems are included to complement irrigation facilities (see Section 8). Over-irrigation and neglect of drainage of irrigated soils has caused many of the problems experienced in schemes with poor productivity in the Nile Basin. Drainage, in combination with adequate irrigation scheduling, allows not only for the evacuation of excess water due to rain or poor/incorrect irrigation applications, but also the maintenance of optimum ground water levels and the correct water balance for crop productivity. It is also essential for the leaching of excess salts from the plant root zone. Surface and subsurface soil characteristics affect the ability of a soil to drain excess water away with the better-draining soils suiting irrigation systems with higher application rates. Poorer drained soils require much more careful design relating irrigation intervals and application rates to intake rates, with drainage provision considering crop rooting depth and optimum water table depth beneath the soil surface. Systems that can apply smaller amounts of water that are directly related to plant needs, such as drip irrigation, are suitable to soils that have excessive or very slow infiltration rates. Under such conditions, irrigation systems that can provide good water control and management are needed to reduce excess application and runoff.

Soil salinity is another consideration in selecting the appropriate irrigation system (see Section 5.9). Soils with salinity problems require leaching which, depending on the salinity level, are required before and/or during cropping. Certain systems, such as furrow systems, do not provide for the basic requirements of uniform leaching and may even promote the concentration of salts within the most active part of the root zone depth. In these cases, crops need to be planted on the side and not on the top of furrows.

4.5 Agriculture

The cropping pattern for a project should be such that the selected crops can be successfully grown under the prevailing climate and soil conditions and are marketable at economic prices. It is therefore necessary that cultivating practices for these crops should be well understood, and that the planned irrigation system is compatible with these practices as well as with the physical constraints prevailing at farm level (see section 5). Rice grown under paddy conditions, for example, requires partial submergence of the rice plants for most of the growing period. To achieve this, they are grown under surface irrigation using basins. If these are not well levelled and flat, poor water distribution occurs and only part of the farm land will be irrigated under optimum and design conditions. Thus, predicted yields and returns will not be achieved.

Most vegetable crops have a shallow effective root zone depth and respond better to low moisture depletion levels and more frequent irrigation. Surface, sprinkler and drip irrigation are all suitable for such crops, but the selected system must be able to deliver small amounts of water at short regular intervals. Germination of seeds requires frequent and light water applications and where soils are light or where water is derived through pumping, sprinkler or drip irrigation may be more suitable.

Selection of irrigation method, interval and applications are important where crops such as tomatoes and cucumbers are negatively affected when the product rest on wet soils. Other conditions unfavourable to crop growth such as ponding of water near trees must be avoided (see Section 6.3) as this promotes diseases and rotting of trees such as citrus. Systems that enable water to be applied away from the tree trunk such as drip and furrow irrigation are preferable. Under warm and/or desert climates, cooling may be required for certain crops in summer and protection against frost in winter, especially in some key stages of crop growth. Sprinkler irrigation systems can often provide a suitable alternative in both cases by creation of a micro climate around the crop lowering the temperature in summer, and raising the temperature of the growing fruit in winter.

When selecting and considering the cropping pattern and irrigation method, crop budgets, farm income and O&M costs must all be closely considered in relation to capital costs and farmers' expertise (see section). Returns to labour and the availability of local labour are important considerations. Irrigation equipment costs and the availability and cost of labour for the irrigation development, are all major elements that influence the selection of the irrigation method and system. In general, the costs of irrigation and drainage systems increase with the level of sophistication of water control and also where locally available materials and labour are not utilised.

4.6 Improved engineering, including enhanced river diversion

River diversions are the most common means of diverting water into canals systems. In many areas, farmers have been involved in traditional irrigation practices which allow them to integrate modern irrigation schemes into the existing farming system. Feasibility studies regarding socio-economic viability and down-river impact are conducted prior to approval of the schemes. Permanent concrete diversion structures are constructed so as to resist flood peaks during the rainy season. Layout of canals requires accurate topographic surveying. Both, design and construction require external expertise and funding.

Modern river diversions bring about considerable new challenges that need to be addressed by both the communities and facilitating agencies:

1) The management of larger schemes require a higher degree of community organisation and the formation of water users associations (WUAs).
2) Irrigated agriculture increases family manpower requirement during the dry season. Where individual plots exceeded 0.5 hectares, additional manpower has to be employed to assure proper crop management.
3) A substantial increase in production beyond subsistence needs demands for market-oriented production and crop diversification.
4) Market-oriented production and the adoption of new crops makes improved management practices necessary. This involves the adoption of improved agronomic practices and utilisation of external inputs. This is only possible with an efficient extension service and access to credit.

5) Due to the low purchasing power of the local population in food insecure areas, local markets are quickly saturated and new market outlets have to be found in order to avoid the collapse of local market prices.
6) The formation of cooperatives is needed in order to benefit from higher prices at regional markets and to acquire basic marketing infrastructure, such as stores and trucks. Again, training is needed in cooperative management, which has to be provided by the District or Regional Offices.
7) Economically feasible water fees have to be paid to cover maintenance and replacement cost of irrigation structures. Guidelines are needed from the Government to assist communities in assessing, collecting and administering such fees.

The above points underline the importance of the introduction of modern irrigation schemes such as river diversions. These diversions bring about a dramatic intensification of the farming system with a wide range of new skills that have to be learned by the communities. Such skills can only be transferred to the communities effectively with a high level of coordination between the respective government agencies. A number of critical socio-economic and administrative issues are associated with modern river diversions and modern irrigation schemes:

1) A community can get divided into "winners" and "losers" if only a fraction of the households are included in a communal irrigation scheme. This is often the case when previous individual land holdings remain unchanged during the transfer to irrigation. The issue of land reallocation is very sensitive and requires skilful facilitation by the District Offices. Any solution to land disputes should meet the approval of the majority of the community.

2) **Family labour shortage** occurs quickly, when individual land holdings exceed 0.5 hectares. In such cases farmers tend to enter **crop-sharing agreements** with households, which are not included in the scheme. Since such agreements are often arranged on the basis that the owner obtains 50% of the crop, the sharecropper tends to cultivate the land with minimal input resulting in poor management and low yields. Moreover, sharecroppers are often not members of water users associations (WUAs) and are more inclined to violate community rules, such as irrigation schedules. Where crop-sharing agreements are common, considerable social friction may occur. To avoid this, WUAs should be assisted in developing crop-sharing rules to assure adequate crop management and compliance of all users with community rules.

The criteria for the selection of an irrigation scheme vary at each stage of the planning process, with various alternatives deriving from a series of technical evaluations and assessments. Topography, soils, availability and suitability of water, appropriateness of different crops to the identified soils, efficiency of the system, capital investment required, labour requirements, farmers experience and preferences, capital and running costs are just some of the factors to be considered. What is most important is that the system chosen meets the technical capacity of the users of the system for management, operation and maintenance (MOM). In addition, the configuration obtained should give adequate returns to meet not only the full costs, capital and operation costs, but also provides sufficient returns to the farming communities so that they are encouraged to utilise the system fully. In the following chapters, technical, social, environmental and management factors are all discussed in relation to meeting the most appropriate scheme development. Selection criteria and design considerations are discussed to consider not only the in-field irrigation methods but also conveyance and distribution of water.

Overall efficiency of surface irrigation (see Section 6.2), even with lined conveyance and field canals, generally does not exceed 50%. In spite of this, most systems found in the small scale irrigation sector are surface gravity systems that relate easily to the conditions prevailing in rural areas and the capacity of the farmers using them. Whereas alternative sprinkler and drip systems seem to be encouraging from a technical viewpoint, many considerations including the capital and running costs and availability and cost of spare parts preclude the use of such systems on a wide scale at this time. For smallholder farmers who are resource poor and who often benefit from government support for capital investments, management, operation and maintenance (MOM) costs are very important. Whereas sprinkler and drip systems may seem the best technical solution and provide high overall efficiencies, they are in most cases beyond the capacity of the farmers to both operate and to maintain. Energy demands, availability and cost of spare parts are just some of the factors that must be taken into account.

The design and construction of surface irrigation schemes is less complex than other alternatives (Table 4.1), it still requires appropriate training and experience. For example, to establish the length of run and the appropriate stream flow, bearing in mind that most soils are not uniform horizontally or vertically, requires experience because of the unknown factors. Constructing lined canals and carrying out land levelling are equally complex and precise processes. The design and construction of sprinkler irrigation systems can be straightforward, but capital costs are higher than surface systems and design also requires a good engineering knowledge of the types of systems available and their particular characteristics (see Section 6). Useful references are shown in each of the following sections of this toolkit to assist the designer and there is no "one fits all" approach or reference.

Table 4.1 Scheme development factors affecting the selection of irrigation method

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

Source: Keller and Bliesner (1990)

4.7 Social aspects

A project's objectives and expectations cannot be realized unless farmers' considerations on benefits and costs, feasibility and desirability and their priorities in life match that which the project requires of them. In many cases, smallholders' priorities differ from the project's priorities and thus it is important to align these as much as possible (see Sections 12 and 13). The need to work closely with the beneficiaries at all stages of any CBSSI development is thus of paramount importance. Similarly, the nature of the population must be understood in order to match the rate of development with the absorptive capacity. Elements such as the level of literacy, farming knowledge and skills, past experience with irrigation, gender issues and attitudes to change are among the several parameters to be considered when analyzing the social aspects of the project. Irrigation development can bring cultural shock to a smallholder community as a result of the additional organisation, collaboration and discipline required. With monomodal rainfall conditions, smallholders work for a few months in a year under rainfed conditions and utilise the other time in casual employment to supplement their relatively limited and variable incomes. Irrigated crop production requires almost daily attention throughout the year if it is to be profitable. This can conflict with the farmers accepted working calendar that may be considered by outsiders to give very poor returns to labour (see Section 15.3). How the community adjusts to these and other changes becomes critically important, and should be thoroughly discussed with the farmers.

Under smallholder conditions, experience has shown that up to 80% of irrigation development cost comprises of the cost of water resources development, such as the construction of a diversion weir and main canal or a small to medium size dam. Construction costs (cost per m^3 of water; cost per net ha) have been increasing annually, and have been substantial, as many of the best sites have already been developed. In parallel to this, growing population pressure on land has meant that more marginal lands are being considered for development, resulting in higher development and operational costs. Arguments for the necessity of irrigation development aim to not only reduce the dependence upon the vagaries of unreliable rainfall, but also to transform the subsistence farmer into a commercial farmer, moving into the mainstream of the economy of developing countries. To achieve this, it is important to make irrigation available to as many smallholders as possible, and for them to actively participate in the irrigation development. If this is achieved, the desired improvements in productivity will derive due to the pressures that will be put on the existing resources, the high cost per unit volume of water and the need to satisfy the high demand for irrigation. Systems with higher efficiencies will form examples of best practice and provide the tool for addressing this matter, both in terms of economics as well as in terms of social and political desirability. These higher efficiencies are often achieved with conventional systems which incorporate improved communication and management procedures. As such, they deserve serious consideration in the process of selecting an irrigation system as well as alternative application methods.

4.8 Management, operation and maintenance (MOM)

An analysis of the structures and competence of the agencies or bodies responsible for the organization and management of a project is essential (see Section 13). A number of problems or difficulties should be expected during the planning, construction and operation of CBSSI projects and interventions. Community based small scale irrigation involves a number of major stakeholders including rural authorities, traditional leaders, farmers, relevant government departments or ministries and consultants and contractors. The need for the establishment or development of competent agencies to manage the planning and implementation of the project and the subsequent MOM at central, district and farmer level needs early consideration and careful discussion with the beneficiaries. The same agency, through established procedures, would be responsible for providing guidance and criteria for the selection of the contractor and sub-contractors. As a rule, selection of inexperienced contractors on the basis of a cheaper offer does not always cost less with delays from one contractor having a snowball effect on other contractors and on the project as a whole.

Longer term and regular training for both professionals and farmers is often omitted from irrigation development plans. Although included in some projects, they are dependent upon grants and loans from donors and other organisations that determine the investment life of a project life that is usually 5 to 7 years. With the types of irrigation development proposed, longer term support is needed (10 to 15 years) especially as most irrigation systems are costly when compared with rainfed and conservation interventions. It is therefore crucial that a longer term view is taken so that investments are productively utilized, and that once project pressure is removed, training and capacity building still continues. Institutionalisation of both is essential, with provisions made from the feasibility study stage onwards for the necessary trained engineers, agronomists and technicians to be available on time. Equally important is the assessment of the farmers' training needs, which will enable them to make well-informed decisions and to undertake the operation, maintenance and management of the on-farm and off farm works depending on the system and the capacity of the farmers' organisation.

4.9 Health and environmental issues

Often, the issue of health risks related to one or another irrigation system is overlooked and the most sensitive part of the population (women and children) is negatively affected. Since rural women are the major users of irrigation infrastructure, the sensitivity of the different technologies to health aspects should be analyzed and taken into consideration during the decision-making process. In many parts of the Nile Basin, two waterborne diseases are cause for concern: malaria and bilharzia. It is therefore necessary to avoid or modify systems that promote these diseases. Surface irrigation with unlined canals provides ideal breeding grounds for snails that carry the bilharzia parasites. Through the introduction of concrete-lined, free-draining canals the risk from these diseases can be substantially reduced. The adoption of pressurized irrigation systems, such as sprinkler and localized irrigation, reduces the risks further. However, when going into the water themselves, people are exposed to the disease. The trend of treated wastewater reuse for irrigation adds another dimension to the selection of an irrigation system in view of the additional hazards from the diseases such as parasitic worms, typhoid, cholera and salmonella.

The environmental impact of different irrigation systems has to be taken into consideration when selecting an irrigation system. What should happen with the drainage water? Should it be disposed of in a nearby land depression, causing ideal conditions for mosquito breeding and thus malaria for the people of the project? Should it be discharged into the same stream from where it was originally extracted, thus increasing the salinity and chemical pollution downstream? Or should alternative systems with built-in water management and thus minimum drainage effluent be adopted? How would the one or the other choice affect fishing in the river on the short and long run? These are some questions that emerge if one is to avoid negative environmental and health impacts of irrigation development, and ensure long term benefits and sustainability of irrigation. When planning irrigation projects, the importance of biodiversity should always kept in mind. The ecosystem is a self-contained and balanced system of inter-dependent living organisms and their physical development. A change, necessitated by infrastructure development, will unavoidably have consequences on the living organisms and their diversity. In order to predict environmental impacts of irrigation development, an Environmental Impact Assessment (EIA) should be carried out prior to the establishment of a project, and be used as one of the criteria to approve the implementation of the project and to select the irrigation system (see Section 14).

River basin planning is important in order to minimize within one catchment the negative impact of one project on another and on living organisms. Within a river catchment, there are upstream and downstream water users. There are habitats alongside the river where a diversity of species derive their livelihood. Good planning and environmental management will protect the environment.

4.10 Credit and marketing

Irrigated crop production is a high-input high output system. Smallholders need to procure seeds, fertilizers and chemicals in order to optimize their production system. However, the poor cash flow from conventional rainfed farming is too low for such an investment and farmers new to irrigation require both support and credit.

Marketing potential is an overriding factor in any irrigation development. As a result, benefits will not be realised unless market linkages are established during project preparation. An assessment of the existing markets and transport system and road infrastructure, as well as their potential for development, is essential. Market prices, transport costs and farm prices must be predicted, as related to the expected increased volume of production. In addition, processing and/or storage facilities should be considered as part of a marketing strategy. The choice of crops to be grown and the cropping patterns must therefore be realistic and relate to demand for the crops proposed. This in turn will influence the field layout and irrigation method.

4.11 Economic and financial analysis

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

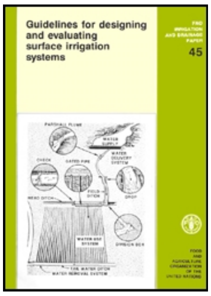
4.12 Extension services

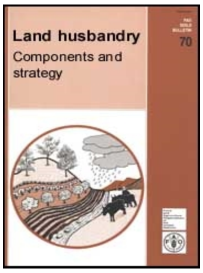
The overview of water use in the Nile Basin countries clearly established that one of the main weaknesses in all Nile Basin countries was the lack of an appropriate extension service for both rainfed and irrigated agriculture. This is especially critical in the more remote rural areas where many of the CBSSI schemes are located. The training of farmers and the adoption of new farming practices is the mandate of the country's extension services. However, most extension agents in sub-Saharan Africa are not familiar with irrigated crop production. To improve on the level of extension know-how, it is no longer feasible to rely upon government extension staff. Experienced farmers from within the targeted communities can and should provide the appropriate support to the less experienced farmers, but this requires a systematic process of providing the training needed by experienced farmers acting as the extension staff. While the success of achieving the desirable results will greatly depend on the adaptability of farmers, no effort should be spared in developing and implementing the appropriate training for the smallholders. Establishment of on-farm research, demonstrations, farmers' field schools and the provision of advisory services with back up from specialists are some of the means to be considered (see Section 18).

4.13 References

Key References:

International Commission on Irrigation and Drainage. 1998. Checklist to Assist Preparation of Small-scale Irrigation Projects in Sub-Saharan Africa, W.P. Field - F.W. Collier HR Wallingford. DFID. ICID. FAO.





FAO. 1995. Guidelines for the Design of Agricultural Investment Projects. FAO Investment Centre Technical Paper No. 7. Rome.
These guidelines have been prepared to help in the design of agricultural investment projects in developing countries. The intended users are FAO Investment Centre staff, trainees and consultants, but much of the material may also be useful to staff in governments, financing agencies and consulting firms who are responsible for designing or appraising such projects. The guidelines address the need for projects to be conceptually coherent, relevant to national needs and capabilities, technically sound, viable in economic and financial terms, attractive to the participants, socially acceptable, and environmentally and fiscally sustainable. The publication is divided into three main parts: the first covers the principles and processes of project design, the second provides more detail on the analysis and reporting of project proposals and the third consists of a comprehensive outline for a project preparation report. A separate file contains the sample figures and tables published in the 1995 print edition.

FAO. 1989. Guidelines for designing and evaluating surface irrigation systems. FAO Irrigation and Drainage Paper 45. W.R. Walker. Rome.
This guide is intended to serve the needs of the irrigation technician for the evaluation of surface irrigation systems. The scope is focussed at the farm level. A limited series of graphical and tabular aids is given to relieve the user of some burden of computation. The irrigation technician and engineer must understand the fundamental interactions characterizing surface flow in order to evaluate, improve, design and manage effectively.

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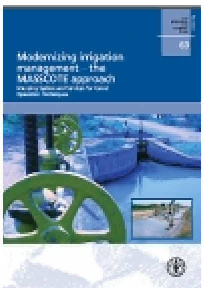


FAO. 2007. Modernizing irrigation management – the MASSCOTE approach. Mapping System and Services for Canal Operation Techniques. Renault, Daniel; Facon, Thierry; Wahaj, Robina. Irrigation and Drainage paper no. 63. FAO. Rome.

The MASSCOTE methodology has been developed to assist technical experts, irrigation managers and irrigation professionals engaged in the difficult task of modernizing or reengineering the irrigation management of medium-to-large irrigation canal systems.

International Water Management Institute's (IWMI's) Global irrigated area map (GIAM) and associated products and data. http://www.iwmigiam.org/info/main/index.asp .
This is version 2.0 (May 2007) of IWMI's GIAM and associated products and data that are produced using time-series data of: (a) AVHRR 10-km monthly (1997-1999), (b) SPOT 1-km monthly (1999), (c) GTOPO30 1-km elevation, (d) CRU 50-km grid monthly precipitation (1961-2000), (e) AVHRR derived 1-km forest cover, and (f) AVHRR 10-km skin temperature.

.5 Agriculture

5.1 Soil

The type of soil has a significant influence on the agricultural and irrigation practices. Lighter soils are easier to work with farm machinery, but have a limited water-holding capacity, and thus require irrigating more frequently. Heavier soils are more difficult to cultivate, but have a high water holding capacity and thus require irrigating less frequently. The soil type needs to be identified at the design stage and its characteristics taken into account in the design. Heavier soils, such as clay, are suited to cultivation of rice, whereas lighter soils are less well suited to rice cultivation. In some cases, the soil type may rule out irrigation, such as with heavy clay soils in low lying land where the water has a relatively high salt content. In this situation, irrigation would not be recommended as the salts will tend to build up in the clay and cannot be removed by leaching.

5.1.1 Soil texture

The texture of the soil is defined by the proportions of sand, silt and clay that it contains (Table 5.1).

Table 5.1 Definition of Soil Texture

General terminology		Soil terminology	Particle size
Coarse	Light	Sand	0.05 – 2 mm
Medium	Medium	Silt	0.002 -0.05 mm
Fine	Heavy	Clay	<0.002 mm

In coarser (lighter) soils there are a larger number of sand particles, with large pore spaces between the particles allowing easier passage for water. In finer (heavy) clay soils there are a higher concentration of cohesive clay particles, and less space between the pores, thus restricting the passage of water. The mix of these different particle sizes in the soil allows it to be classified as either: clay; sand; silt; sandy clay; silty clay; sandy clay loam; clay loam; silty clay loam; sandy loam; loam; silt loam; or loamy sand; following the soil textural triangle classification system (Figure 5.1).

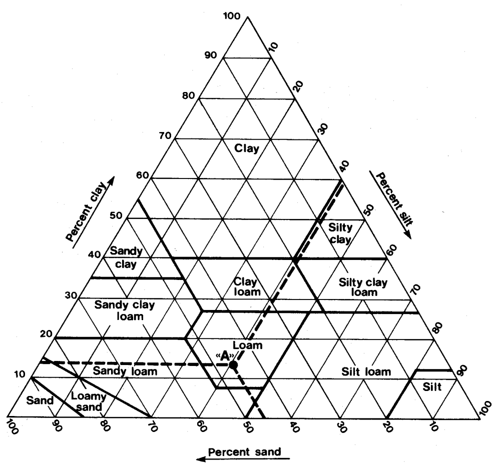


Figure 5.1 Soil textural triangle classification systems

The texture of a soil can be accurately determined by analysis in a soils laboratory. There are also several methods to determine the texture based on the "feel" of the soil when rubbed in the hand (Figure 5.2):

a) **Sand** is free flowing with individual grains, which can be seen or felt when rubbed between thumb and forefinger. If squeezed in the hand when dry, the soil will disintegrate when the hand is opened. If squeezed when moist, it will form the shape of the clenched hand but will disintegrate when touched.
b) **Sandy loam** contains a large proportion of sand, but has sufficient silt and clay to make it slightly cohesive. The sand grains can be felt when the soil is rubbed between thumb and forefinger. If squeezed when dry, it will form a shape that will easily fall apart when the hand is opened; if there is some moisture in the soil the shape will remain without disintegrating too easily.
c) **Loam** is a soil which has a mix of all three grades such that no one grade predominates. The sand particles can be felt when the soil is rubbed between thumb and forefinger, and the soil feels slightly plastic and malleable when moist. A dry soil when squeezed will hold its shape when handled, whilst a moist soil can be handled quite freely and retain its shape after being squeezed.
d) **Silt loam** has a low percentage of sand particles and a low percentage of clay particles. When dry it forms into lumps, which can easily be broken up. The soil is smooth and soft when rubbed between thumb and forefinger, and feels rather like ground flour. When dry or moist it can be squeezed into a cylinder which can be handled a fair bit without breaking up. If moistened and rolled into a cylinder it will not, however, hold together, and will break up.
e) **Clay loam** is a fine-textured soil which breaks into lumps when it is dry. When moist it feels soft and silky when rubbed between thumb and forefinger. It is difficult to squeeze into a shape when dry, but when moist will easily take a shape and can be handled a fair amount lot without breaking up. If moistened and rolled out into a cylinder it will hold its shape but will break up if it is manipulated to form a circle.
f) **Clay** is fine textured soil that forms into large hard lumps or clods when it is dry, and becomes difficult to work. When moist it feels soft and silky when rubbed between thumb and forefinger, and can be rolled into a thin cylinder which can be formed into a circle without breaking up. Soils with a high percentage of clay are very plastic and sticky when wet.

5.1.2 Soil structure

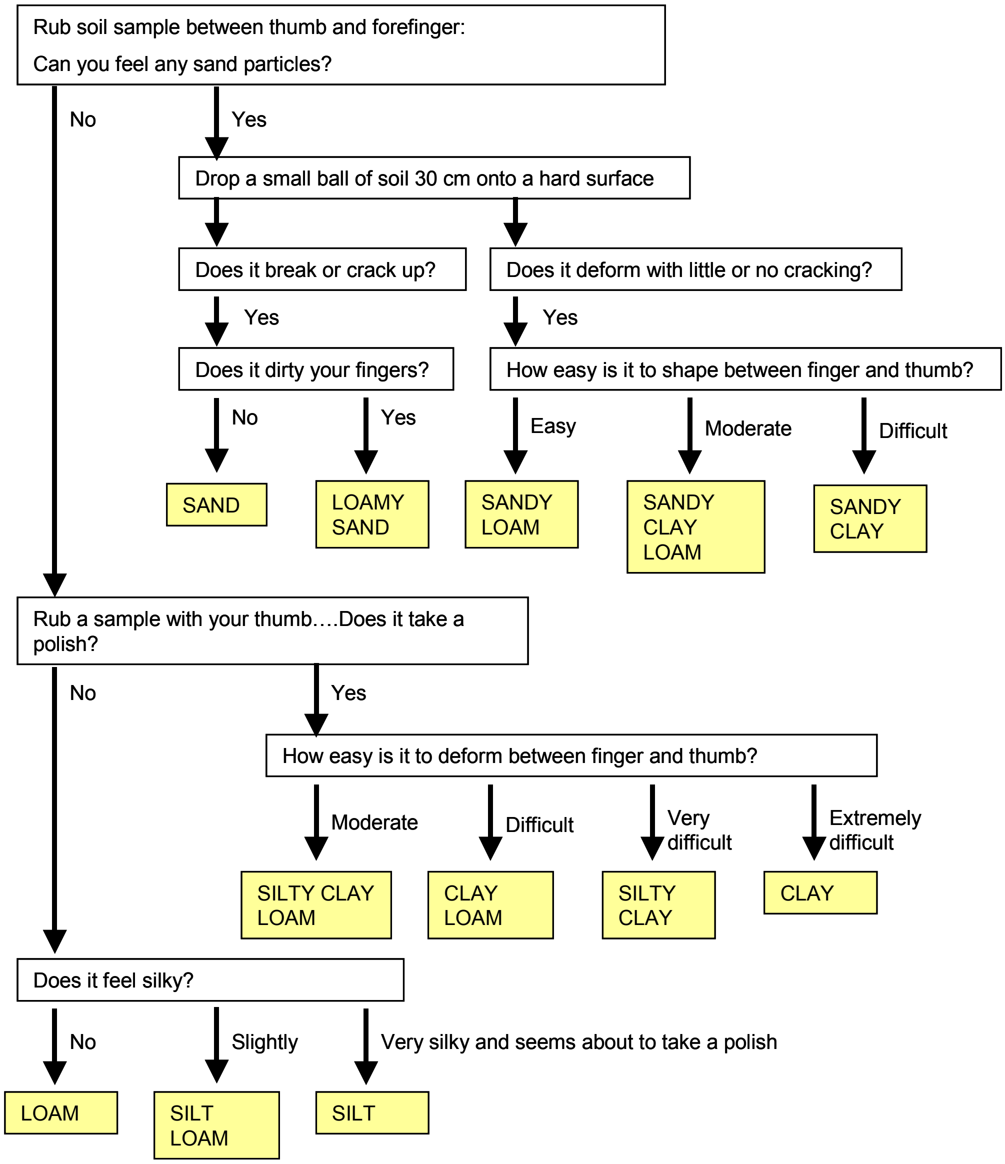
The soil structure refers to the adhesion between the soil particles and the arrangement of soil particles into larger blocks. The structure of the soil affects its permeability; single grain soils such as sand are highly permeable whereas plate-like structures, such as heavy clays, have low permeability. Unlike soil texture the soil structure can be changed by farming practices. Working on soils when they are wet can compress them and reduce permeability; working on soils when they are too dry can turn the soil to powder. The chemical content of the soil can affect the structure, and high concentrations of alkali salts cause deterioration of soil structure and make it impermeable.

5.1.3 Soil moisture holding capacity

The ability of the soil to store water is central to irrigation scheduling. The more water that can be stored in the soil, the less frequent the number of irrigations required by a crop, and the less risk that the crop will suffer a shortage of water. From an irrigation point of view there are different levels of water content in the soil, and four terms are used to identify each water content level:

- Saturation
- Field capacity
- Permanent wilting point
- Available water

Saturation: During and immediately after irrigation all the pore space in the soil is filled with water and the soil is saturated. There is little air in the soil, and for most crops (other than rice), if the soil stays saturated the crop will be damaged due to this lack of air for the roots to breath. If there are no drainage problems the water in the soil will drain away under gravity following irrigation, leaving space for air in the soil's pore space.



Source: Silsoe College Short Course Notes, Silsoe, UK

Figure 5.2 Flowchart to determine soil texture by feel

Field capacity: Field capacity is the quantity of water held in the soil once the water has drained away from the saturated soil. This water is held to the soil particles by surface tension forces, and much of it is available for taking up by the plant's roots. The volume of water held by the soil at field capacity depends primarily on its texture and structure. At field capacity a cubic metre of sandy soil will typically hold 135 litres of water, a loam soil will hold about 270 litres of water and a clay soil will hold 400 litres of water.

Permanent wilting point: Water can be removed from the soil by the plant's roots exerting a greater pull or tension than the surface tension holding the water to the soil particle's surface. At some point, termed the permanent wilting point, the suction exerted by the plant's roots is not sufficient to remove the water from around the soil's particles. At this point, if additional water is not added by rainfall or irrigation, the crop will become stressed, the yield will be reduced and the crop may perish. At permanent wilting point a crop's leaves may droop or wilt, in some crops, such as fruit trees, there will be a change in appearance in the leaf colour. Drooping or wilting of a crop's leaves does not always signify that the permanent wilting point has been reached; in some cases this is caused by the crop's inability to withdraw water quickly enough from the root zone. This is typified by drooping or wilting of a crop's leaves in the afternoon and recovery over-night, particularly on very hot days when evapotranspiration rates are high. The permanent wilting point is affected by the soil texture in the same way as with field capacity, thus for fine-textured soils the moisture content at permanent wilting point is higher than for coarse-textured soils.

Available moisture: The water available to the plant is the difference between the moisture content at field capacity and that at the permanent wilting point. Though there may still be water in the soil at the permanent wilting point it cannot be removed by the plant, and is thus unavailable. The objective of irrigation is to allow the soil moisture to reduce to a safe limit (above the permanent wilting point) and then to irrigate the soil to bring it back to field capacity. The interval between irrigation will thus depend on the available moisture in the soil and the rate at which the soil water is abstracted by the crop. Table 5.2 summarises the soil moisture situation for different soil types. It is worth noting that clay has a total available soil moisture content per metre depth almost four times that of sand. A loam soil holds almost twice as much water as a sandy soil.

Table 5.2 Typical moisture content levels for different soil textures

Soil texture	Bulk density	Soil moisture content			Total available moisture
		Saturation	Field capacity	Permanent wilting point	
		(mm/m)	(mm/m)	(mm/m)	(mm/m)
Sand	1.65	380	150	70	80
Sandy loam	1.50	430	210	90	120
Loam	1.40	470	310	140	170
Clay loam	1.35	490	360	170	190
Silty clay	1.30	510	400	190	210
Clay	1.25	530	440	210	230

Figure 5.3 presents the data from Table 5.2 for a 1 metre depth of soil. The difference in the total available water for each soil type can clearly be seen.

5.1.4 Field estimation of soil moisture status

It is possible to make assessments of the soil moisture status in the field through taking samples of the soil at different depths in the root zone. For this a simple soil auger is useful, with soil samples typically being taken at depths from 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. The moisture content can be estimated by the feel of the soil in the hand. The soil is squeezed in the palm of the hand three or four times, and the behaviour of the soil observed to see how it behaves when formed as a ball and tossed in the air, and when it is rolled into a cylinder. Table 5.2 can then be used to assess the status of the soil moisture, based on the soil texture.

In good irrigation practice, the soil moisture content is checked before and after each irrigation to see that the water has penetrated the full depth of the root zone. Checking the soil moisture status before and after irrigation provides the farmer with valuable information on the amount of irrigation water to apply each irrigation, and helps to reduce wastage through over-irrigation. To check the depth of penetration the soil samples at different depths should be taken 1(for sand) to 3 (for clays) days after irrigation, as the water takes time to percolate through the soil horizon.

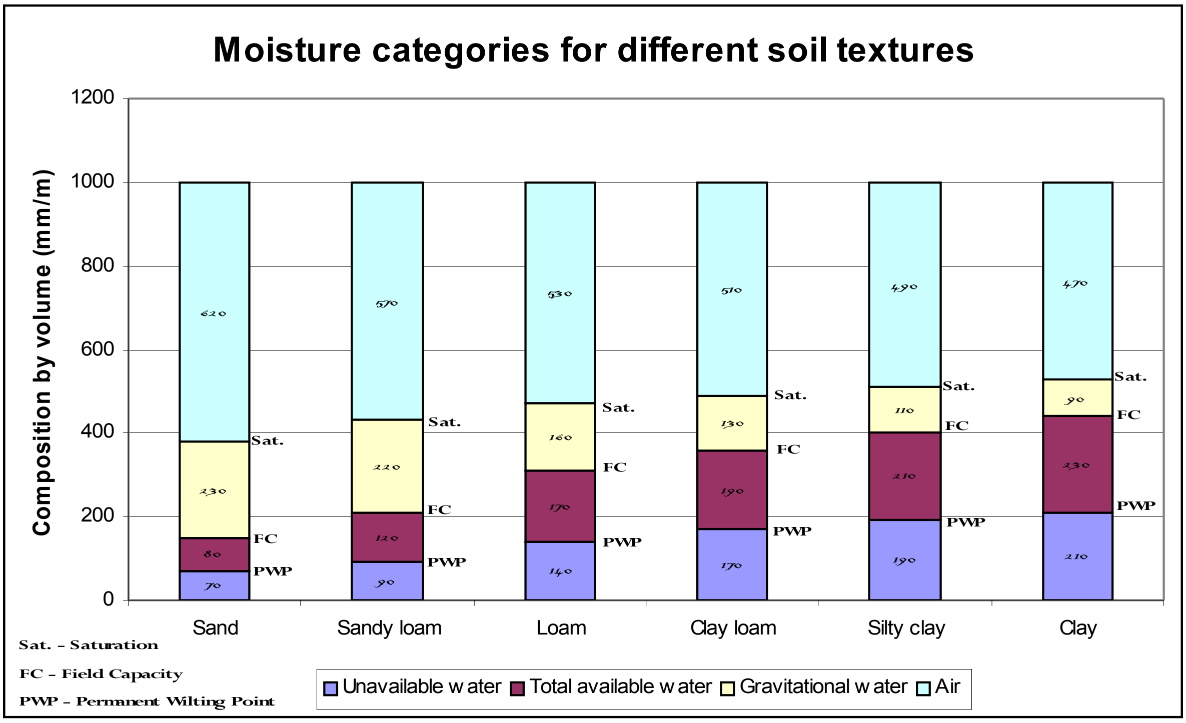


Figure 5.3 Moisture categories for different soil textures

5.1.5 Wetting profiles for different soil textures

The wetting profile varies with the soil texture. For sandy soils, the water tends to move quickly down vertically under gravity, for clay soils the vertical movement is less rapid and the water tends to spread horizontally as well as vertically. Figure 5.4 shows typical wetting profiles for a sandy loam and a clay loam, together with the depth the water has infiltrated over different time frames. The wetting profile affects the irrigation application. Furrow spacing needs to be closer on sandy soils compared to clay soils, and basin sizes will need to be smaller on sandy soils compared to clay soils.

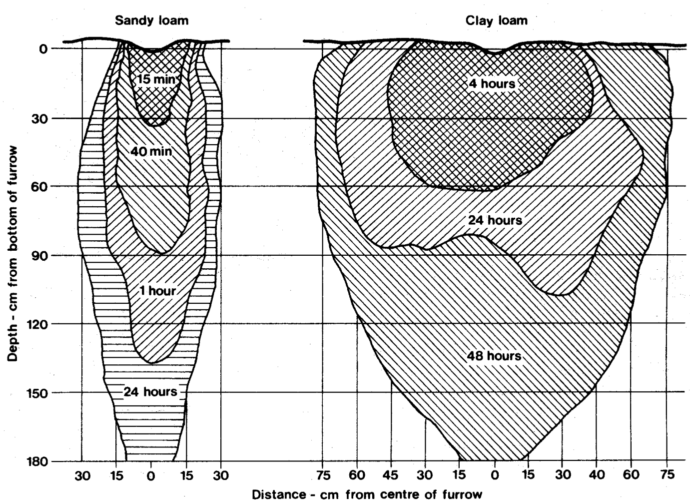


Figure 5.4 Distribution of soil water in different soils using furrow irrigation

5.2 Soil-Water-Plant Relationship

Soil intake/water infiltration is the process of water entering the soil at the soil/air interface. Water enters the soil through pores, cracks, worm and decayed root holes, and through cavities introduced by tillage. Infiltrated water may evaporate again from the soil surface; may be transpired by the plants or may percolate downward beyond the plant roots and contribute to groundwater. Water applied to the soil (by rain or irrigation) infiltrates the soil. If the rate of application exceeds the infiltration rate, water will be ponding on the surface or moving over the surface through runoff. The infiltration rate determines the amount of water entering the soil and amount that will subsequently be stored in the root zone.

Table 5.3 Factors affecting the infiltration rate

Modifying factors	Increase in infiltration rate	Decrease in infiltration rate
Initial water content	Low initial water content	High initial content
Surface crusting		Surface sealing
Compaction		Compaction results in higher density with less pore to space hold water
Organic content	High organic content improves soil structure and promotes good soil condition	Low organic content provides for a more massive soil structure
Vegetative cover	Root penetration promotes improved soil structure and lower soil density. Worm activity increases, providing macropores for water to follow	Bare soil tends to puddle under sprinkler systems using large droplet sizes increasing soil density at the soil surface
Salinity and sodicity	Calcium salts can flocculate the surface	Sodium salts can disperse and puddle the soil
Cracking	Cracking increases initial intake. Intake rate can be high until cracks close because of added moisture causing soil particles to swell.	On highly expansive soils, intake rate can be very slow after cracks close because the soil particles swell
Hardpan		A very dense layer
Gravel or coarse sand layer, near surface		The soil layer above an abrupt boundary of coarse material must be saturated before water will move into the coarse material below
Ripping, sub-soiling	Ripping when soil is dry can break up hardpans, shatter dense soils, and in general improve the soil condition below the plough depth. The effect is temporary unless the cause of increased density is eliminated	
Soil erosion		Erosion exposes subsurface layers that are lower in organic content, have poor structure, can have increased salinity or sodicity and generally have higher densities
Sediments in water		Colloidal clays and fine sediment can irrigation accumulate on the soil surface

Source: USDA, 1997

Soil water can be depleted through evapotranspiration with the amount depending upon the availability of the soil water (see Section 5.6). Although water is theoretically available until wilting point, crop water uptake is reduced well before wilting point is reached. When the soil is sufficiently wet, the soil supplies water fast enough to meet the atmospheric demand of the crop and water uptake equals crop evapotranspiration (Etc). As the soil water content decreases, water becomes more strongly bound to the soil matrix and is more difficult to extract. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to transpiration demand and the root begins to experience stress (FAO, 1998a). The fraction of the total available moisture (SMta) that a crop can extract from the root zone without suffering water stress is the readily available moisture (SMra):

$$\mathbf{SMra = P \times SMta}$$

Where:

SMra = Readily available soil moisture

P = Allowable depletion or average fraction of the total available soil moisture that can be depleted before moisture stress (reduction in ETc) occurs

SMta = Total available soil moisture = FC - PWP

According to Hansen and Israelsen (1967), maximum production can be obtained on most crops if no more than 50% of available soil moisture (= FC-PWP) is removed from the soil during the vegetative, flowering and wet fruit stage. This rule of irrigation at 50% depletion is generally used in the region. However, according to FAO (1984), with an ETc of less than 5 mm/day, evapotranspiration of most field crops will not be affected or likely to be little affected at soil tension of up to 1 atmosphere. This would correspond to 30% of available soil moisture (by volume) for clay, 40% for loam, 50% for sandy loam and 60% for loamy sand. In other words, in order to maintain the ETc for optimum growth and yield, the depletion should not exceed the above values when ETc < 5 mm/day.

On the subject of depletion, irrigation practices should also be brought into the picture. Under surface irrigation, in particular border strip and basin irrigation, a situation of saturated flow in the whole area takes place, and for a while (until FC is approaching) root aeration is in short supply. To compensate for this, higher depletions are usually allowed. For furrow irrigation, however, since the saturated flow is only in part of the soil, lower depletions can be used as exchange of gases is easier. Under sprinkler irrigation, because of the intermittent water supply to the soil, a non-saturated flow of oxygenated water prevails. Therefore, there is a tendency to use lower depletions. Localized (drip) irrigation provides the ideal conditions for very low depletions. It combines the limited area of wetting with the unsaturated flow. Considerable research work has demonstrated that when this system is combined with very low depletions (0.15-0.20 atmosphere soil tension) high yields are obtainable.

The type of crop is another factor to be considered in depletion. While for some crops low depletions are necessary, other crops can take higher depletions. Because of inconclusive results as indicated above, it is recommended to use the fractions of available soil water shown in Table 5.4. It should be noted, however, that for the lower fractions (meaning a lower allowable portion of available moisture permitted for depletion by the crop before the next irrigation) especially careful water management is needed.

5.2.1.1 Effective root zone depth

In addition to crop water and irrigation requirements (described in Section 5.6) and soil, the root zone depth is the third parameter to be considered when preparing irrigation schedules. Published data on the depth from where the crops extract most of their water differ greatly. As a rule, for most field crops 40% of the water uptake takes place from the first quarter of the total rooting depth, 30% from the second quarter, 20% from the third quarter and 10% from the fourth quarter (Figure 5.5). According to FAO (1984), ETc is not affected even when rooting depth is severely restricted, as long as plants are sufficiently anchored and proper growing conditions, including available water, nutrients, soil aeration, soil temperature and soil structure, prevail. Table 5.4 provides data on root zone depth and allowable soil moisture depletion levels for different crops.

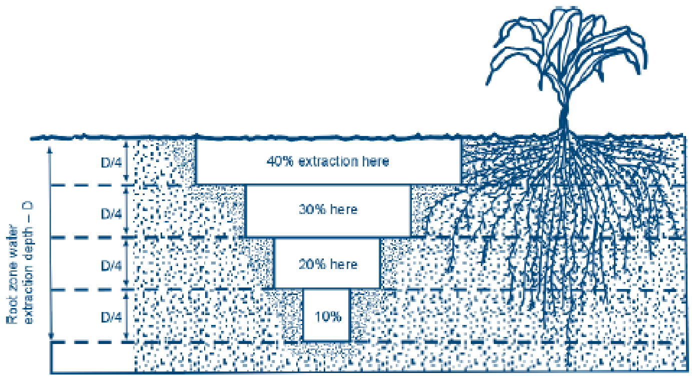


Figure 5.5 Average Water Extraction Patterns in a Soil without Restrictive Layers
(Source: USDA, 1997)

Table 5.4 Maximum effective root zone depth & allowable soil water depletion for common crops

Crop		Root zone depth (RZD)[1] (m)	Allowable soil moisture depletion (P)[2]
a. Small vegetables			
Broccoli		0.4-0.6	0.45
Brussels sprouts		0.4-0.6	0.45
Cabbages		0.5-0.8	0.45
Carrots		0.5-1.0	0.35
Cauliflowers		0.4-0.7	0.45
Celery		0.3-0.5	0.20
Garlic		0.3-0.5	0.30
Lettuce		0.3-0.5	0.30
Onions	– dry	0.3-0.6	0.30
	– green	0.3-0.6	0.35
	– seed	0.3-0.6	0.35
Spinach		0.3-0.5	0.20
Radishes		0.3-0.5	0.30
b. Vegetables – Solanum Family (*Solanacea*)			
Eggplant		0.7-1.2	0.45
Sweet peppers (bell)		0.5-1.0	0.30
Tomatoes		0.7-1.5	0.40
c. Vegetables – Cucumber Family (*Cucurbitaceae*)			
Cantaloupes		0.9-1.5	0.45
Cucumbers	– fresh market	0.7-1.2	0.50
	– machine harvest	0.7-1.2	0.50
Pumpkin, winter squash		1.0-1.5	0.35
Squash, zucchini		0.6-1.0	0.50
Sweet melon		0.8-1.5	0.40
Watermelon		0.8-1.5	0.40
d. Roots and tubers			
Beet, table		0.6-1.0	0.50
Cassava	– year 1	0.5-0.8	0.35
	– year 2	0.7-1.0	0.40
Parsnips		0.5-1.0	0.40
Potatoes		0.4-0.6	0.35
Sweet potatoes		1.0-1.5	0.65
Turnips (and Rutabaga)		0.5-1.0	0.50
Sugar beet		0.7-1.2	0.553
e. Legumes (*Leguminosae*)			
Beans, green		0.5-0.7	0.45
Beans, dry and pulses		0.6-0.9	0.45
Beans, lima, large vines		0.8-1.2	0.45
Chick peas		0.6-1.0	0.50
Fababeans (broad bean)	– fresh	0.5-0.7	0.45
	– dry/seed	0.5-0.7	0.45
Garbanzo		0.6-1.0	0.45
Green gram and cowpeas		0.6-1.0	0.45
Groundnuts (peanuts)		0.5-1.0	0.50
Lentil		0.6-0.8	0.50
Peas	– fresh	0.6-1.0	0.35
	– dry/seed	0.6-1.0	0.40
Soybeans		0.6-1.3	0.50

Note: Above values are for no stress situation.

Table 5.4 (Cont'd) Maximum effective root zone depth & allowable soil water depletion for common crops

Crop		Root zone depth (RZD)[1] (m)	Allowable soil moisture depletion (P)[2]
f. Perennial vegetables (with winter dormancy and initially bare or mulched soil)			
Artichokes		0.6-0.9	0.45
Asparagus		1.2-1.8	0.45
Mint		0.4-0.8	0.40
Strawberries		0.2-0.3	0.20
g. Fibre crops			
Cotton		1.0-1.7	0.65
Flax		1.0-1.5	0.50
Sisal		0.5-1.0	0.80
h. Oil crops			
Castorbeans (Ricinus)		1.0-2.0	0.50
Rapeseed, Canola		1.0-1.5	0.60
Safflower		1.0-2.0	0.60
Sesame		1.0-1.5	0.60
Sunflower		0.8-1.5	0.45
i. Cereals			
Barley		1.0-1.5	0.55
Oats		1.0-1.5	0.55
Spring wheat		1.0-1.5	0.55
Winter wheat		1.5-1.8	0.55
Maize, field (grain) (field corn)		1.0-1.7	0.55
Maize, sweet (sweet corn)		0.8-1.2	0.50
Millet		1.0-2.0	0.55
Sorghum	– grain	1.0-2.0	0.55
	– sweet	1.0-2.0	0.50
Rice		0.5-1.0	0.204
j. Forage			
Alfalfa	– for hay	1.0-2.0	0.55
	– for seed	1.0-3.0	0.60
Bermuda	– for hay	1.0-1.5	0.55
	– spring crop for seed	1.0-1.5	0.60
Clover hay, berseem		0.6-0.9	0.50
Rye grass hay		0.6-1.0	0.60
Sudan grass hay (annual)		1.0-1.5	0.55
Grazing pasture	– rotated grazing	0.5-1.5	0.60
	– extensive grazing	0.5-1.5	0.60
Turf grass	– cool season[5]	0.5-1.0	0.40
	– warm season[5]	0.5-1.0	0.50
k. Sugarcane		1.2-2.0	0.65
l. Tropical fruits and trees			
Bananas	– 1st year	0.5-0.9	0.35
	– 2nd year	0.5-0.9	0.35
Cacao		0.7-1.0	0.30
Coffee		0.9-1.5	0.40
Date palm		1.5-2.5	0.50
Palm tree		0.7-1.1	0.65
Pineapples		0.3-0.6	0.50
Rubber tree		1.0-1.5	0.40
Tea	– non-shaded	0.9-1.5	0.40
	– shaded	0.9-1.5	0.45
m. Grapes and berries			
Berries (bush)		0.6-1.2	0.50
Grapes	– table or raisin	1.0-2.0	0.35
	– wine	1.0-2.0	0.45

Table 5.4 (Cont'd) Maximum effective root zone depth & allowable soil water depletion for common crops

Crop		Root zone depth (RZD)[1] (m)	Allowable soil moisture depletion (P)[2]
Hops		1.0-1.2	0.50
n. Fruit trees			
Almond		1.0-2.0	0.40
Apple, cherry, pear		1.0-2.0	0.50
Apricot, peach, other stone fruit		1.0-2.0	0.50
Avocado		0.5-1.0	0.70
Citrus	– 70% canopy	1.2-1.5	0.50
	– 50% canopy	1.1-1.5	0.50
	– 20% canopy	0.8-1.1	0.50
Conifer tree		1.0-1.5	0.70
Kiwi		0.7-1.3	0.35
Olive (40-60% ground coverage by canopy)		1.2-1.7	0.65
Pistachio		1.0-1.5	0.40
Walnut orchard		1.7-2.4	0.50

1 *The larger values for RZD are for soils having no significant layering or other characteristics that can restrict rooting depth. The smaller values for RZD may be used for irrigation scheduling and the larger values for modelling soil water stress or for rainfed conditions.*

2 *The values for P apply for $ET_c \approx 5$ mm/day. The value for P can be adjusted for different ET_c according to $P = P_{table\ 54} + 0.04 \times (5 - ET_c)$.*

3 *Sugar beet often experience late afternoon wilting in arid climates, even at P < 0.55, with usually only minor impact on sugar yield.*

4 *The value for P for rice is 0.20 of saturation.*

5 *Cool season grass varieties include Bluegrass, Ryegrass and Fescue. Warm season varieties include Bermuda grass, Buffalo grass and St. Augustine grass. Grasses are variable in rooting depth. Some root below 1.2 m while others have shallow rooting depths. The deeper rooting depths for grasses represent conditions where careful water management is practiced with higher depletion between irrigations to encourage the deeper root exploration.*

While for surface irrigation systems there is a tendency to accept deeper root zone depths, when selecting root zone depths for pressurized systems, the decision is based on the majority of feeder roots. Through this approach, water-soluble nutrients such as nitrogen are directed to the majority of feeder roots instead of being leached to depths of smaller concentration of roots. Rainbird International provides the guide for plant feeder root depths (effective root zone depth). Knowing the crop water requirements, the type of soil and the root zone depth, the readily-available moisture for the crop can be calculated, which is the amount of water that can be extracted by the crop in the root zone without suffering water stress.

5.3 Cropping Pattern and Crop Rotation

A cropping pattern diagram is used to show:

- the area under each crop type at any time
- the percentage of the total area that is cropped
- the cropping intensity

Knowing the cropping pattern is an essential prerequisite for determining the water requirements for the irrigation season. A typical cropping pattern diagram is shown in Figure 5.6.

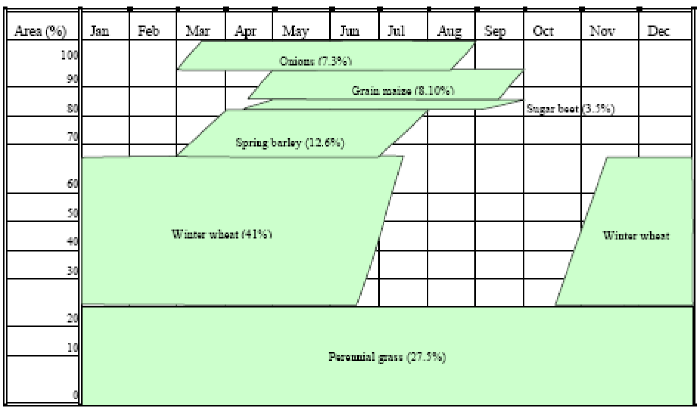


Figure 5.6 Example of a Cropping Pattern Showing Percentage of Area Planted

The data collected for plotting the diagram in Figure 5.7 is given in Table 5.5 below. The area of each crop shown can be plotted either as the actual area with the maximum point on the y-axis being the total command area (2,109 ha in this case), or as a percentage of the total command area. What is important is to show the relative scale of the different areas and the fraction or percentage of total command area that is planted.

In order to plot the cropping pattern diagram the following information is required:

- the crop types
- for each crop type, the:
    - start and end date of planting
    - total area planted
    - crop growth duration
    - start and end date of harvesting

The difference between the start and end date of planting is called the "crop stagger". This spread avoids all farmers planting on the same date and reduces peak demands for labour or land preparation machinery. Crop stagger will vary by each crop type and can last several days to several weeks.

Table 5.5 Tabulation of Cropping Pattern Data

Crop	Area planted		Planting period		Total crop growth period (days)	Harvesting period	
	(ha)	(%)	Start	End		Start	End
Winter wheat	864	41.0%	15 Oct	15 Nov	240	15 June	15 July
Spring barley	266	12.6%	1 Mar	1 Apr	140	1 July	1 Aug
Sugar beet	73	3.5%	15 Apr	1 May	150	15 Sept	1 Oct
Grain maize	170	8.1%	15 Apr	1 May	150	15 Sept	1 Oct
Perennial grass	581	27.5%	15 Mar	1 Apr	365	15 Mar	1 Apr
Onions	155	7.3%	1 Mar	15 Mar	180	15 Aug	15 Oct
Total	2109	100%					

Cropping patterns are generally plotted on graph paper. To plot the data for each crop, mark the start and end dates of planting and the start and end dates of harvesting. The start and end date marks should be separated by a vertical distance equal to the crop area planted. Connect the four points in a parallelogram. Repeat the process for each crop. Plotting cropping patterns becomes more complicated when farmers plant more than one crop per year. If for the data above, farmers follow the winter wheat with 210 ha of carrots, then the cropping pattern diagram be modified as shown in Figure 5.7 below.

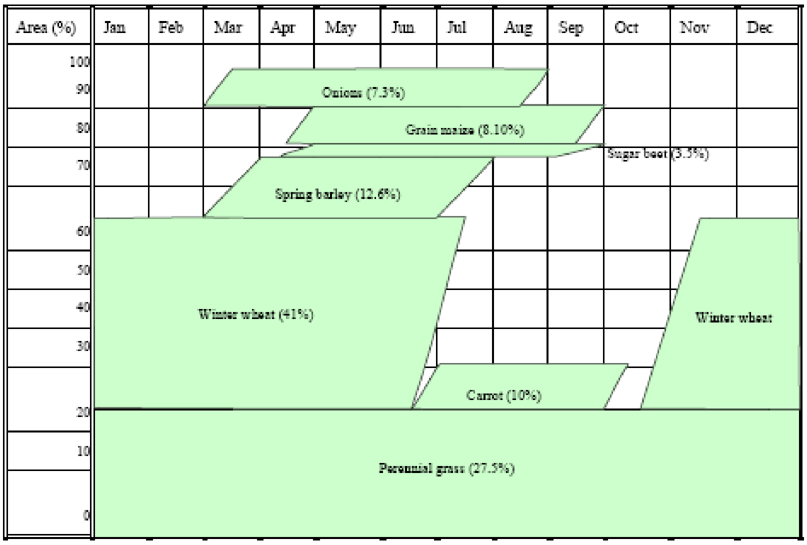


Figure 5.7 Cropping pattern with double cropping

In the first case (Figure 5.7) the cropping intensity is 100%, as all the total command area of 2,109 ha has been cultivated in the year. In the second case (Figure 5.8), a cropping intensity of 110% results as an additional area of 210 ha of carrots has been planted immediately following the harvesting of winter wheat.

5.4 Crop Yields and Response to Water

Water is essential for crop production, and best use of available water must be made for efficient crop production and high yields. This requires a proper understanding of the effect of water - rainfall and/or irrigation - on crop growth and yield under different growing conditions. When water supply does not meet the crop water requirements, ETc will decrease. Under this condition, water stress will develop in the plant, which will adversely affect crop growth and ultimately crop yield. The effect of water stress and crop growth and yield depends on the crop species and variety on one hand and the magnitude and the time of occurrence of water deficit on the other. The effect of magnitude and timing of water deficit on crop growth and yield is of major importance in scheduling when available water supplies are limited over the growing periods of the crops, and in determining the priority of water supply between crops during the growing season (FAO, 1986).

The most common effect of water stress is a decreased rate of growth and development of foliage. This has a cumulative effect through the season, as plant stress early in crop development results in a reduced leaf area. This means that light interception is reduced, carbon assimilation is reduced and therefore the rate of leaf growth is reduced. Water stress also affects the quality of the produce. Freedom from water stress encourages production of fresh, crisp foliage. In some crops this is desirable (for example lettuce). Crops suffering from intermittent stress tend to be irregular in shape - carrots have forked roots, tomatoes have split skins - and will result in lower prices at the market. By contrast, some crops need to be stressed at certain times to encourage flowering for example. While water stress may negatively affect the crop, there are also negative effects of over-watering. Over-watered root crops tend to be bland in flavour.

5.4.1 Critical growth periods

When water deficit occurs during a particular part of the total growing period of a crop, the yield response to water deficit can vary greatly depending on how sensitive the crop is at that growth stage. In general, crops are more sensitive to water deficit during emergence, flowering and early yield formation than they are during early (vegetative, after establishment) and late growth stages (ripening). Critical periods for plant moisture stress are given in Table 5.5, but local knowledge is invaluable in determining actual critical growth periods for crops.

5.4.2 Estimating yield reduction due to water stress

A simple, linear crop-water production function was introduced in FAO (1986) to predict the reduction in crop yield when crop stress was caused by a shortage of soil water:

$$[1 - (Ya/Ym)] = Ky \times [1 - (ETc\ adj / Etc)]$$

Where:

Ky relates relative yield decrease [1 - (Ya/Ym)] to relative evapotranspiration deficit [1 - (ETc adj / Etc)]

Ky = Yield response factor
Ya = Actual crop yield
Ym = Maximum crop yield when there is no water stress and ETc adj = ETc
ETc = Crop evapotranspiration for standard conditions (see Section 5.6.2)
ETc adj = Adjusted (actual) crop evapotranspiration (see Section 5.6.3)

Ky values are crop specific and may vary over the growing season. In general, the decrease in yield due to water deficit during the vegetative and ripening period is relatively small, while during the flowering and yield formation periods it will be large. Table 5.6 gives values of the yield response factor Ky for different crops and different growth stages. Ky values can also be obtained from field experimental data. In the final evaluation of Ky values, use is also made of known yield responses to soil salinity, the depth of the groundwater table and agronomic and irrigation practices.

Table 5.6 Critical periods for plant moisture stress (Source: USDA, 1997)

Crop	Critical period	Comments
Beans, dry	Flowering through pod formation	Is also sensitive to over-irrigation
Beans, green	Blossom through harvest	
Broccoli	During head formation and enlargement	
Cabbages	During head formation and enlargement	
Cauliflowers	During entire growing season	
Citrus	During entire growing season	Blossom and next season fruit set occurs during harvest of the previous crop
Maize (grain)	From tasseling through silk stage and until kernels become firm	Needs adequate moisture from germination to dent stage for maximum production. During ripening, depletion of 80% or more can be allowed
Cotton	First blossom through boll maturing stage	Any moisture stress, even temporary, ceases blossom formation and boll set for at least 15 days after moisture again becomes available
Fruit trees	During the initiation and early development period of flower buds, the flowering and fruit setting period (maybe the previous year), the fruit growing and enlarging period, and the pre-harvest period	Stone fruits are especially sensitive to moisture stress during last 2 weeks before harvest
Wheat and barley	During boot, bloom, milk stage, early head development and early ripening stages	Critical period for barley is at soft dough stage to maintain a quality kernel
Groundnuts	Throughout season	
Lettuce	Head enlargement to harvest	Water shortage results in sour and strong lettuce. Crop quality at harvest is controlled by water availability to the plant. Recommended allowable depletion P is < 30%
Watermelons	Blossom through harvest	
Onions, dry	During bulb formation	Maintain P at 30-35%. Let soil dry near harvest
Onions, green	Blossom through harvest	Strong and hot onions can result from moisture stress
Peas, dry	At start of flowering until pods are swelling	
Peas, green	Blossom through harvest	
Potatoes	Flowering and tuber formation to harvest	Sensitive to irrigation scheduling. Restrict P to 30-35%. Low quality tubers result if allowed to go into moisture moisture stress during tuber development and growth
Soybeans	Flowering and fruiting stage	
Sugarcane	During period of maximum vegetative growth	
Tobacco	Knee high to blossom	
Tomatoes	When flowers are forming, fruit is setting and fruits are rapidly enlarging	
Vine crops	Blossom through harvest	

Table 5.7 Yield response factor Ky (Source: FAO, 1986)

Crop		Vegetative period			Flowering period	Yield formation	Ripening	Total growing period
		Early	Late	Total				
Alfalfa				0.7-1.1				0.7-1.1
Bananas								1.2-1.35
Beans				0.2	1.1	0.75	0.2	1.15
Cabbages		0.2				0.45	0.6	0.95
Citrus								0.8-1.1
Cotton				0.2	0.5		0.25	0.85
Grapes								0.85
Groundnuts				0.2	0.8	0.6	0.2	0.7
Maize				0.4	1.5	0.5	0.2	1.25
Onions				0.45		0.8	0.3	1.1
Peas		0.2			0.9	0.7	0.2	1.15
Peppers								1.1
Potatoes		0.45	0.8			0.7	0.2	1.1
Safflower			0.3		0.55	0.6		0.8
Sorghum				0.2	0.55	0.45	0.2	0.9
Soybeans				0.2	0.8	1.0		0.85
Sugarbeet	– beet							0.6-1.0
	– sugar							0.7-1.1
Sugarcane				0.75		0.5	0.1	1.2
Sunflower		0.25	0.5		1.0	0.8		0.95
Tobacco		0.2	1.0					0.9
Tomatoes				0.4	1.1	0.8	0.4	1.05
Watermelons		0.45	0.7		0.8	0.8	0.3	1.1
Wheat	– winter			0.2	0.6	0.5		1.0
	– spring			0.2	0.65	0.55		1.15

In general, for the total growth period (last column in Table 5.6), the decrease in yield is proportionally less with the increase in water deficit (Ky<1) for crops such as alfalfa, groundnuts, safflower and sugarbeet, while it is proportionally greater (Ky > 1) for crops such as bananas, maize and sugarcane.

Application of the yield response factor for planning, design and operation purposes allows the quantification of water supply and water use in terms of crop, yield and total production for the scheme. Both the likely losses in yield and the adjustments required in water supply to minimize such losses can be quantified (FAO, 1986). Similarly, such quantification is possible when the likely yield losses arise from differences in Ky for individual growth periods. Under conditions of limited water distributed equally over the growing season and involving crops with different Ky values, the crop with the higher Ky value will suffer a greater yield loss than the crop with a lower Ky value. For example, the yield decrease for maize (Ky = 1.25) will be greater than for sorghum (Ky = 0.9). Similarly, the yield response to water deficit in different individual growth periods is of major importance in the scheduling of available but limited supply in order to obtain highest yields.

Key Reference: *Yield response to water, Irrigation and Drainage paper No. 33, FAO, Rome. 1979.*

This publication lays down some of the important principles involved in water management in relation to crop production and presents a methodology to quantify yield response to water through aggregate components which form the 'handles' to assess crop yields under both adequate and limited water supply. The method is presented in Part A and takes into account maximum and actual crop yields as influenced by water deficits using yield response functions relating relative yield decrease and relative evapotranspiration deficits. Part B gives an account of water-related crop yield and quality information for twenty-six crops. Application of the method provides the user with:

- guidance in selection of irrigated crops under different growing conditions;
- assessment of crop yield under different water supply regimes;
- criteria, in terms of crop production, on which to base priorities for allocation of limited water to crops both between and within projects;
- directives for field water management for optimum crop production and water efficiency.

5.5 Crop management

Irrigated crops are susceptible to **pests and diseases**. In schemes where most farmers apply the same cropping pattern, crop losses can be high. In such cases, crop protection pesticides with low metabolic toxicity are needed for all affected crops to control the outbreak effectively. However, pests and diseases cannot be controlled by pesticides alone and suitable crop rotations are important to maintain soil fertility and to prevent the building up of plant pathogens.

Where irrigation schemes are located far from villages, crop damage caused by wildlife or **uncontrolled grazing of livestock** can be devastating. This problem has been reported mainly from lowland areas where acute seasonal forage shortage is common. In such cases, around-the-clock guarding of the schemes has to be organised by the water users association.

5.6 Crop Water Requirements

5.6.1 Reference crop evapotranspiration

The reference crop evapotranspiration (ETo) is the evapotranspiration from a reference surface (a hypothetical grass reference crop with specific characteristics) not short of water. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. It removes the need to define a separate evapotranspiration level for each crop and stage of growth. The concept of ETo was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development stage and management practices. As water is abundant at the evapotranspiring surface, soil factors do not affect evapotranspiration with climatic parameters being the only factors affecting ETo. As a result, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors.

5.6.2 Crop evapotranspiration under standard conditions

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions. The values of ETc and CWR (Crop Water Requirements) are identical, whereby ETc refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. ETc can be calculated from climatic data by directly integrating the effect of crop characteristics into ETo. Using recognized methods, an estimation of ETo is made. Experimentally determined ratios of ETc/ ETo, called crop coefficients (Kc), are used to relate ETc to ETo as given in the following equation:

$$\mathbf{ETc = ETo \times Kc}$$

Where:

ETc	=	Crop evapotranspiration (mm/day)
ETo	=	Reference crop evapotranspiration (mm/day)
Kc	=	Crop coefficient

Differences in leaf anatomy, stomata characteristics, aerodynamic properties and even albedo (solar radiation reflected by the surface) cause ETc to differ from ETo under the same climatic conditions. Due to variations in crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest.

5.6.3 Crop evapotranspiration under non-standard conditions

The crop evapotranspiration under non-standard conditions, ETc adj, is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. When cultivating crops in the field, the real crop evapotranspiration may be different from ETc due to non-optimal conditions such as occurrence of pests and diseases, soil salinity, poor soil fertility and waterlogging. ETc adj is calculated by using a water stress coefficient (Ks) and/or by adjusting Kc for all other stresses and environmental constraints on crop evapotranspiration. The calculation procedures for ETc adj are available in the following reference that presents an updated procedure for calculating reference and crop evapotranspiration from meteorological data and crop coefficients.:

FAO. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Richard G. Allen, Luis S. Pereira, Dirk Raes and Martin Smith. Water Resources, Development and Management Service. FAO. http://www.fao.org/docrep/X0490E/x0490e01.htm#preface

The procedure, first presented in 1977 in the FAO Irrigation and Drainage Paper No. 24 'Crop Water Requirements', (see section 5.6.4) is termed the 'Kc ETo' approach, whereby the effect of the climate on crop water requirements is given by the reference evapotranspiration ETo and the effect of the crop by the crop coefficient Kc. Since then, advances in research and more accurate assessment of crop water use revealed the need to update the FAO methodologies for calculating ETo as the FAO Penman method was found to frequently overestimate ETo while the other FAO recommended equations, namely the radiation, the Blaney-Criddle, and the pan evaporation methods, showed variable adherence to the grass reference crop evapotranspiration.

5.6.4 Crop water and irrigation requirements

Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. FAO (1984) defined crop water requirements as ‘the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment’. Irrigation engineers and practitioners might need to estimate the crop water requirements for several irrigation projects at any given time, the whole process becomes very long if carried out manually. FAO developed a computer programme CROPWAT to facilitate the process of estimation of ETc or CWR and this programme can be downloaded from the FAO website (http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/CROPWAT.stm) together with guidance details and other relevant information. The programme uses monthly climatic data (temperature, relative humidity, wind speed, sunshine hours, and rainfall) for the calculation of reference evapotranspiration. It has also four different methods to calculate effective rainfall but to be able to do this it requires dependable rainfall as input. Through the input of crop data (growth stages, Kc factors, root zone depth and allowable soil moisture depletion factor), the programme calculates the crop water requirements on a decade (10-day) basis.

Irrigation requirements (IR) refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement.

5.6.5 Irrigation scheduling

Once the crop water and irrigation requirements have been calculated, the next step is the preparation of field irrigation schedules. Three parameters have to be considered in preparing an irrigation schedule:

- The daily crop water requirements
- The soil, particularly its total available moisture or water-holding capacity

- The effective root zone depth

Plant response to irrigation is influenced by the physical condition, fertility and biological status of the soil. Soil condition, texture, structure, depth, organic matter, bulk density, salinity, sodicity, acidity, drainage, topography, fertility and chemical characteristics all affect the extent to which a plant root system penetrates into and uses available moisture and nutrients in the soil. Many of these factors influence the water movement in the soil, the water holding capacity of the soil, and the ability of the plants to use the water. Hence, the irrigation system used should match all or most of these conditions. Additionally, the values in local soil databases need to be continuously refined to fit the actual field conditions. In the field, the actual value may vary from site to site, season to season and even within the season. Within the season, it varies depending on the type of farm and tillage equipment, number of tillage operations, residue management, type of crop and water quality. Soils to be irrigated must also have adequate surface and subsurface drainage, especially in the case of surface irrigation. Internal drainage within the crop root zone can either be natural or from an installed subsurface drainage system.

CROPWAT will also facilitate the accurate determination of an irrigation schedule according to the water needs of the crops. Ideally, at the beginning of the growing season, the amount of water given per irrigation application, also called the irrigation depth, is small and given frequently. This is due to the low evapotranspiration of the young plants and their shallow root depth. During the mid season, the irrigation depth should be larger and given less frequently due to high evapotranspiration and maximum root depth. Thus, ideally, the irrigation depth and/or the irrigation interval (or frequency) vary with the crop development. With surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the schedule all the time. Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval; in other words, to keep the irrigation depth and the interval constant over the growing season. When sprinkler and drip irrigation methods are used, it may be possible and practical to vary both the irrigation depth and interval during the growing season. With these methods it is just a matter of turning on the tap longer/shorter or less/more frequently.

Key Reference: *Chapter 6, Irrigation Manual, Module 4, Crop Water Requirements and Irrigation Scheduling, Developed by Andreas P. SAVVA and Karen FRENKEN, Water Resources Development and Management Officers, FAO Sub-Regional Office for East and Southern Africa, Harare, 2002.*

The Water Team of FAO's Sub-regional Office for East and Southern Africa in Harare, Zimbabwe, has developed an Irrigational Manual for irrigation practitioners, resulting from several years of field work and training of irrigation engineers in the sub-region. It deals with the planning, development, monitoring and evaluation of irrigated agriculture with farmer participation. It consist of 14 Modules, regrouped in five volumes (Volume 1: Modules 1-6; Volume 2: Module 7; Volume 3: Module 8; Volume 4: Module 9; Volume 5: Modules 10-14), with an emphasis on engineering, agronomic and economic aspects of smallholder irrigation, but it also introduces the irrigation engineers to social, health and environmental aspects of irrigation development, thus providing a bridge between the various disciplines involved in irrigation development. For on-line reading, click one of the following: Cover page, Module 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

5.7 Irrigation Scheduling and Requirements

In most CBSSI projects within the Nile Basin, the quality of irrigation water is good and most soils are sandy with good natural drainage. As a result, soil salinity is not an issue, except where there are serious drainage problems. Leaching requirements are therefore generally ignored when estimating irrigation requirements unless salinity problems have been identified. In addition, due to irrigation system inefficiencies, water losses due to deep percolation normally satisfy any leaching requirements.

5.7.1 Calculating net irrigation requirements

The gross irrigation requirements account for losses of water incurred during conveyance and application to the field. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements, as shown below:

$$IRg = IRn/E$$

Where:

IRg = Gross irrigation requirements (mm)
IRn = Net irrigation requirements (mm)
E = Overall project efficiency

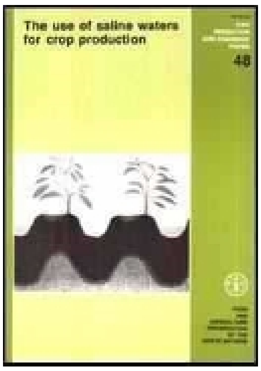
More detailed information on the different types of efficiencies (overall project, conveyance, field canal, distribution system, farm, field application efficiency) are given in Chapter 6.2. Different efficiencies are attributed to different irrigation systems and Table 5.8 suggested values for overall project efficiency that can be used.

Table 5.8 Efficiencies for different irrigation systems

Irrigation system	Overall efficiency
Surface	45%
Sprinkler	75%
Localized	90%

5.8 Water Quality

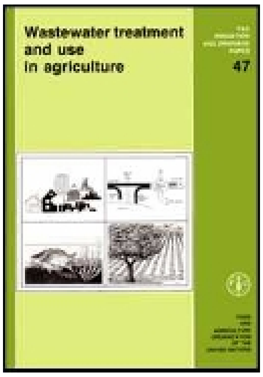
Irrigation water is in increasingly short supply and a number of Nile Basin countries are approaching full utilization of their conventional surface water resources. They also suffer from declining quality of water supplies, and are thus increasingly looking towards the use of water with marginal quality such as saline groundwater and drainage waters. In October 1989, FAO convened an Expert Consultation to seek answers to the pertinent questions: "can agriculture make use of marginal quality water such as saline water in a way that is technically sound, economically viable and environmentally non-degrading; in other words, is it a viable proposition to use saline water for agricultural production?" The conclusion of the Expert Panel was that there is good potential for the safe use of saline water for crop production. The Panel recommended the integrated management of water of different qualities at the levels of the farm, irrigation system and drainage basin, with the explicit goals of increasing agricultural productivity, achieving optimal efficiency of water use, preventing on-site and off-site degradation and pollution and sustaining long-term production potential of land and water resources. The resultant publication on the use of saline waters for crop production (see below) draws heavily on the papers presented in the Expert Consultation, as well as on the recommendations that came out of the Consultation. It provides guidelines to assist countries to manage their saline waters for productive purposes in a sustainable manner.



FAO. 1992. The use of saline waters for crop production - FAO irrigation and drainage paper 48, J.D. Rhoades, A. Kandiah and A.M. Mashali. Land and Water Development Division. Rome. http://www.fao.org/docrep/T0667E/T0667E00.htm

In connection with the above, the use of treated wastewater in agriculture is also pertinent and another FAO publication produced at the same time provides a guide to the use of treated effluent for irrigation and aquaculture:

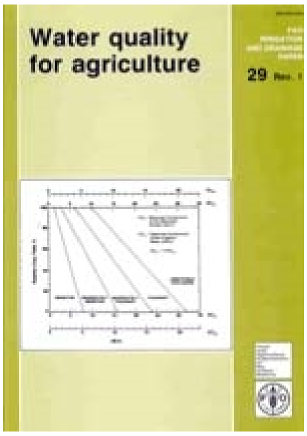
FAO. 1992. Wastewater treatment and use in agriculture - FAO irrigation and drainage paper 47. M.B. Pescod. FAO. Rome. http://www.fao.org/docrep/T0551E/T0551E00.htm



This publication presents views on health risks, environmental hazards and crop production potential associated with the use of treated wastewater. It draws on the WHO Guidelines for health protection measures considered appropriate under various conditions. It explains the basis for conventional wastewater treatment processes and introduces natural biological treatment systems as viable alternatives in developing countries, particularly in hot climate regions. Recharge of aquifers as a means of treatment and indirect use of wastewater is covered in some detail. One chapter concentrates on the important aspect of wastewater irrigation and deals with water quality requirements for optimum crop production and potential impacts on soils and crops.

5.9 Leaching Requirements

In lowland areas with high evaporation rates, soil salinity can build up gradually. In highland areas with high rainfall peaks during the rainy season, soil salinity does not pose a major risk. The main cause for the development of soil salinity and alkalinity are a) high evaporation rates b) poor drainage c) use of saline irrigation water, d) deposition of salts in the top soil from high sub-soil water table, e) seepage from canals. The reclamation of a saline soil depends on the efficiency of removal of salts from the upper to lower layers and is thus relatively simple if drainage is not restricted. The simplest procedure is leaching by flooding the field after increasing the permeability of the soil by deep ploughing. The reclamation of alkali soils is more difficult because such soils have a very low permeability, and they require the replacement of excessive exchangeable sodium by calcium. In some countries, the least costly reclamation method of alkali soils is the application of gypsum.



Water quality testing is required for all irrigation schemes prior to implementation. In semi-arid and arid zones where the risk of soil salinity and alkalinity is highest, periodic soil analysis by experts is required. Soil laboratories are available in most regional towns and in capital cities. Furthermore, in such areas it is recommended to consider the introduction of efficient irrigation systems such as drip irrigation or sprinkler irrigation. The salinity in the root zone is directly related to the water quality, irrigation methods and practices, soil conditions and rainfall. A high salt content in the root zone is normally controlled by leaching. An excess amount of water is applied during the irrigation, where necessary, for the purposes of leaching. This excess amount of water for leaching purposes is called the Leaching Requirement (LR). To estimate LR, both the irrigation water salinity (ECw) and the crop tolerance to salinity, which is normally expressed as electrical conductivity of the soil saturation extract (ECe), have to be known. The ECw can be obtained from laboratory analysis, while the ECe should be estimated from the crop tolerance data given in Table 4 of *FAO. 1985. Water quality for agriculture. R.S. Ayers and D.W. Westcot. Irrigation and Drainage Paper 29, Rev. 1. Rome.* http://www.fao.org/DOCREP/003/T0234E/T0234E00.HTM. This table gives an acceptable EC_e value for each crop appropriate to the tolerable degree of yield loss (normally a reduction in yield of 10% or less is accepted).

The necessary leaching requirement[10] (LR) can be estimated from:

[10] 'leaching fraction (LF)' and 'leaching requirement (LR)' are used interchangeably in different references. They both refer to that portion of the irrigation that should pass through the root zone to control salts at a specific level. While LF indicates that the value be expressed as a fraction, LR can be expressed either as a fraction or percentage of irrigation water

$$\mathbf{LR} = \frac{\mathbf{EC_w}}{\mathbf{5\,(EC_e) - EC_w}}$$

where:

LR = the minimum leaching requirement needed to control salts within the tolerance (ECe) of the crop with ordinary surface methods of irrigation

EC_w = salinity of the applied irrigation water in dS/m

EC_e = average soil salinity tolerated by the crop as measured on a soil saturation extract. It is recommended that the EC_e value that can be expected to result in at least a 90% or greater yield be used in the calculation. For water in the moderate to high salinity range (>1.5 dS/m), it is better to use the EC_e value for maximum yield potential (100%) since salinity control is critical to obtaining good yields.

The total annual depth of water that needs to be applied to meet both the crop demand and leaching requirement can be estimated from:

$$\mathbf{AW} = \frac{\mathbf{ET}}{\mathbf{1 - LR}}$$

where:

AW = depth of applied water (mm/year)

ET = total annual crop water demand (mm/year)

LR = leaching requirement expressed as a fraction (leaching fraction)

When estimating LR, it is important to consider the leaching efficiency (Le). This varies with the soil type, internal drainage properties of the soil and the field. The value of Le varies from 30-100% and must, therefore, always be measured for the area under investigation. For sandy loam to clay loam soils with good drainage and where rainfall is low, the leaching requirement can be obtained through the following equations:

For surface and sprinkler irrigation method:

LR(fraction) = (ECw / (5 ECe – Ecw)) x 1/Le

For localized irrigation and high frequency (near daily) sprinkler:

LR(fraction) = (ECw /(2 Max ECe)) x (1/ Le)

Where:

LR(fraction) = The fraction of the water to be applied that passes through the entire root zone depth and percolates below

ECw = Electrical conductivity of irrigation water (dS/m)

ECe = Electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (dS/m)

Max ECe = Maximum tolerable electrical conductivity of the soil saturation extract for a given crop (dS/m)

Le = Leaching efficiency (in decimals)

5.10 Crop Budgets

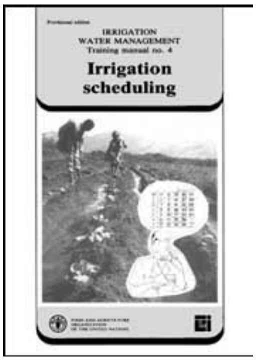
Gross crop returns (see Chapter 15.2) should be calculated based on yield estimates compiled from different sources such as statistical published data, farmer interviews in irrigation schemes and horticulture experts. Low input management and improved management are distinguished. Low input management is not considered equal to crop negligence that would result in considerably lower yields.

It is perceived as a well-managed crop under indigenous management with low external inputs of fertilizer and mainly local seed varieties. Appropriate agricultural extension is required to realise the calculated production level.

Improved management requires intensive agricultural irrigation extension and provision of improved in-puts, currently not available in many irrigation schemes. However, the calculated yields do not present maximum production levels comparable with commercial schemes. The producer prices show significant seasonal and regional differences. Regional producer price levels generally increase with distance from the main markets and from the largest production areas. Seasonal producer prices are usually lowest shortly after harvest but depend also on regional pre-harvest yield assessments. Some crops, can achieve very high prices shortly before religious and cultural festivities.

The returns to labour are an important consideration as these reflect the competition between the irrigation schemes and other sources of employment.

5.11 Other References



Brouwer. C.; Heibloem. M. Irrigation Water Management: Irrigation Scheduling, Training manual no. 4, FAO Land and Water Development Division. 1989.

Irrigation scheduling is the fourth in a series of training manuals on irrigation. The manual describes briefly the influence of water shortages on the yields of various crops. It provides some simple methods to determine the irrigation schedule of field crops. A separate chapter is devoted to the determination of the irrigation schedule for paddy rice. This manual is partially based on FAO Irrigation and Drainage Papers 24 "Crop water requirements" and 33 "Yield response to water".

FAO 1976. Agro-meteorological field stations. Irrigation and Drainage Paper 27. J. Doorenbos. Rome.

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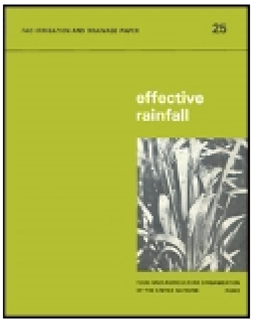

FAO 1979. Effective rainfall in irrigated agriculture, Irrigation and Drainage Paper No. 25, FAO, Rome. http://www.fao.org/docrep/X5560E/X5560E00.htm

This paper presents a number of concepts of effective rainfall currently in use. A distinction is made between effective rainfall and the effectiveness of rainfall. A brief history as well as the criteria for the assessment and factors influencing effective rainfall are presented. In addition, methods of measuring effective rainfall and its different components, as well as merits and limitations of each of these methods are discussed. A number of practices to increase effective rainfall are listed

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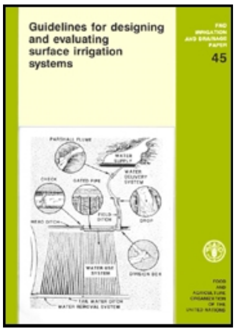
.6 Irrigation

6.1 Irrigation Methods

There are three broad classes of irrigation systems: (1) pressurized distribution; (2) gravity flow distribution; and (3) drainage flow distribution. The pressurized systems include sprinkler, trickle, and the array of similar systems in which water is conveyed to and distributed over the farmland through pressurized pipe networks. There are many individual system configurations identified by unique features (centre-pivot sprinkler systems). There are several sprinkler irrigation systems, which can broadly be divided into set systems and continuous move systems. In localized (drip) irrigation systems, a pipe distribution network is used to distribute and deliver filtered water (and fertilizer) to a predetermined point. The three main categories of localized irrigation methods are drip, spray and bubbler. More recently, drip irrigation systems have been developed whereby the laterals are buried in the root zone of the crop. Gravity flow systems convey and distribute water at the field level by a free surface, overland flow regime. Within this group are the furrow, border strip and basin irrigation systems. These surface irrigation methods are also subdivided according to configuration and operational characteristics.

Irrigation by control of the drainage system, sub irrigation, is not common but is interesting conceptually. Relatively large volumes of applied irrigation water percolate through the root zone and become a drainage or groundwater flow. By controlling the flow at critical points, it is possible to raise the level of the groundwater to within reach of the crop roots.

Irrigation systems are often designed to maximize efficiencies and minimize labour and capital requirements. The most effective management practices are dependent on the type of irrigation system and its design. For example, management can be influenced by the use of automation, the control of or the capture and reuse of runoff, field soil and topographical variations and the existence and location of flow measurement and water control structures. Questions that are common to all irrigation systems are when to irrigate, how much to apply, and can the efficiency be improved. A large number of considerations must be taken into account in the selection of an irrigation system. These will vary from location to location, crop to crop, year to year, and farmer to farmer. In general these considerations will include the compatibility of the system with other farm operations, economic feasibility, topographic and soil properties, crop characteristics, and social constraints.



FAO Irrigation and Drainage Paper 45, W.R. Walker, Professor and Head, Department of Agricultural and Irrigation Engineering, Utah State University, Logan, Utah, USA (Consultant to FAO), FAO, Rome, 1989. http://www.fao.org/docrep/t0231e/t0231e04.htm

6.1.1 Surface irrigation systems

Surface irrigation systems are based on the principle of moving water over the surface of the land in order to wet it, either partially or completely and are well suited for use on both small and large schemes. They can be subdivided into furrow, border strip and basin irrigation. The choice between them depends on the crop, cultivation practices, soils, topography and farmer preferences. The scheme layout up to field level, such as canals and drains, can be similar for each system. Low irrigation efficiencies are usually associated with poor land levelling, wrong stream size and change in soil type along the irrigated area both vertically and horizontally. Surface irrigation methods are often selected because they are considered to be simple methods well suited to farmers with little or no knowledge of irrigation.

According to FAO (1989), 95% of the irrigated area in the world is under surface irrigation. Some of the major advantages of surface irrigation systems over other systems are that they are easy to operate and maintain with skilled labour, they are not affected by windy conditions and, with the exception of furrow irrigation, they are good for the leaching of the salts from the root zone. Generally, they are associated with low energy costs. Surface irrigation systems do have several disadvantages, though. They are less efficient in water application than sprinkler or localized irrigation systems. The spatial and temporal variability of soil characteristics, such as infiltration rate and texture, make water management practices difficult to define and implement. It is also difficult to apply light, frequent irrigation required early and late in the cropping season. Another disadvantage can be the high labour demand, as compared to sprinkler and localized irrigation systems, in situations where labour is not abundant. Below follows a description of the three surface irrigation methods.

Surface irrigation should never be described as **simple** if at the same time there is a need to use water efficiently. The method places too much responsibility for achieving good results in the hands of the farmer and the technology provides little in the way of support. Good control over the highly variable nature of the movement of water across a soil surface and its infiltration into the soil over a season is extremely difficult to achieve and this makes surface irrigation one of the most complex methods of applying water to soil. It is thus hardly surprising that the efficiency of surface irrigation in the hands of farmers who have no control over farm discharges and the timing of applications is poor. In contrast to its management the design of surface irrigation layouts for basins, borders and furrows and their construction is relatively simple and no special materials are needed. Maintenance too produces few problems and can be done locally by farmers themselves. Larger schemes may require laser controlled grading.

Potentially surface irrigation can be very efficient if all the factors involved are under the careful control of skilled and experienced farmers. More often, however, the water management skills on the farm are lacking and, in the case of large schemes, water supplies may be uncertain, and so efficiency tends to be low. For this reason realistic application efficiency for surface irrigation design is usually assumed to be 60% but in practice it is well below this. However, it would be unwise to design for a lower value; 60% is realistic and is a figure for the farmers to aim for as their irrigation skills develop.

6.1.2 Basin irrigation

Basin irrigation is the simplest and most widely used of all surface irrigation methods because of its simplicity. Basins can be adapted to suit many crops, soils and farming practices. They are ideal for the small farm where a wide range of crops can be grown in small basins. Larger basins are well suited to large mechanised farms. Row crops can be accommodated by ridging or constructing beds in the basins. (Note this is not furrow irrigation). Basins constructed primarily for flooded rice are now increasingly being used for diversified cropping. Modifications to allow for upland crops need to be allowed for in design.

6.1.3 Furrow irrigation

Furrow irrigation is the most widely used method for row crops and is the most misunderstood of all the surface methods. It is usually practiced on gently sloping land up to 2% in arid climates but restricted to 0.3% in humid areas because of the risk of erosion during intensive rainfall. From a farming point of view furrows should be as long as possible as this reduces the cost of irrigation and drainage and makes it easier to mechanise. The technique is well suited to larger farms and should not be confused with furrowed-basins which are best suited to small farms. Furrow length depends on soil type, steam size, irrigation depth and land slope and ranges from 60m to 300m or more but farm (or field) size and shape put practical limits on furrow length. Efficient furrow irrigation always involves runoff and so a surface drainage system will be needed.

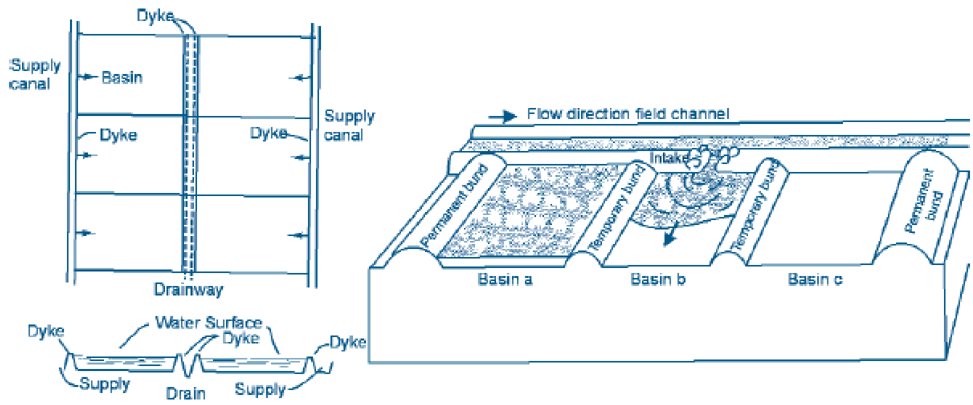
A furrow irrigation system consists of furrows and ridges, of which the shape, spacing and length depend mainly on the crops to be grown and the types of soils. Siphons are mostly used to take water from the field ditch to the furrows. According to Kay (1986), the width of the furrows varies from 250-400 mm, the depth from 150-300 mm and the spacing between the furrows from 0.75-1.0 m, depending on soil type, crops and stream size to be applied to the furrow. Coarse soils require closely-spaced furrows in order to achieve lateral water flow in the root zone. Figure 5.4 shows the general wetting patterns of sand and clay. There is more lateral water flow in clay than in sand. Typical furrow lengths vary from about 60 m on coarse textured soils to 500 m on fine textured soils, depending on the land slope, stream size and irrigation depth. The minimum and maximum slopes for furrows should be 0.05% and 2% respectively in areas of low rainfall intensity. In areas where there is a risk of erosion due to intensive rainfall, the maximum slope should be limited to 0.3%. Most field crops, except very closely spaced crops such as wheat, as well as orchards and vineyards can be irrigated using furrows. However, with this type of irrigation there is a risk of localized salinization in the ridges.

6.1.4 Border strip irrigation

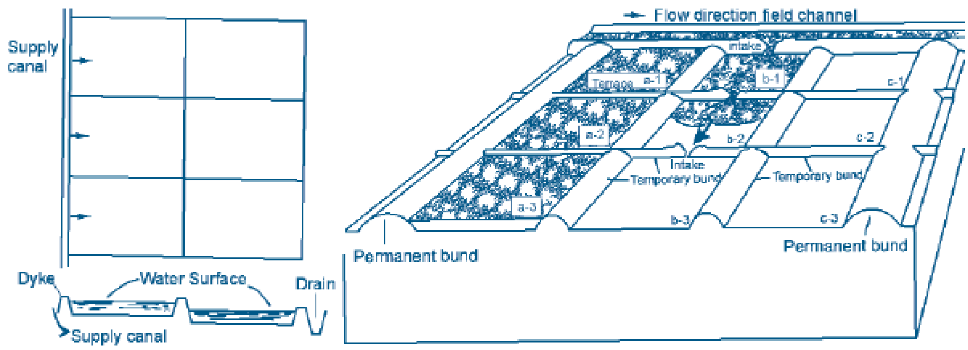
Border strips, border checks or strip checks are strips of land separated by small earth bunds that guide the water as it flows down the field. They can have rectangular or contoured shapes, depending on the field. The border strip slopes uniformly away from the direction from the source of the irrigation water. They should be levelled across, in order to allow for the even wetting of the whole area, covered by a border and allow free drainage at the end. Normally, water is let onto the field from the canals through siphons. The siphoned water spreads across the width of the border when there is no cross slope, thereby facilitating uniform water application. Uneven borders slopes and cross border slopes are some of the most common problems that result in low irrigation efficiencies. Border strips may vary in size from 60-800 m length and 3-30 m width depending on the soil type, stream size, irrigation depth, slope, field size and farming practices. Generally, border width becomes smaller as the soil becomes coarser for the same unit stream size, irrigation depth, and slope, as coarse soils have a higher intake rate than fine soils and consequently less lateral water flow. Border lengths for a width of 12 m vary from 60 m for an irrigation depth of 100 mm, a slope of 2% and a stream size of 15 l/s for sandy soils to 300 m for an irrigation depth of 200 mm, a slope of 0.4% and a stream size of 4 l/s for clay soils. The minimum slope of borders is 1% and the maximum is 2% in humid areas and 5% in arid areas, depending on crop cover. The greater the crop cover, the less the risk of erosion and the steeper the border can be. However, crop cover can only be a determining factor in case a permanent crop, such as pasture, will cover the borderstrip.

6.1.5 Basin irrigation

Basin irrigation is the most common type of surface irrigation and is particularly used in paddy rice irrigation. A basin is a levelled area of land, surrounded by earth bunds, that does not need directed and controlled flow (FAO, 1989) (Figure 6.1). For non-paddy crops basins should be quickly filled with water during irrigation, after which the water infiltrates evenly throughout the basin, in order to achieve high application uniformity. For paddy rice puddling of the soil during land preparation is practised to reduce the percolation rate from ponded fields. Basin irrigation can be a very useful way of leaching harmful salts. However, a good drainage system should also be put in place to dispose of the excess water. Basins can be adapted to suit any crop, soil or farming practices. Crops grown under basin irrigation include rice, alfalfa, row crops and orchard crops. The basins vary in size from 1-2 m^2 to 3-4 ha depending on the irrigation depth, land slope and farming practices. Generally, for the same stream size and irrigation depth, basins should be smaller on light soils than on heavier soils. In cases where the land is considerably steep, terracing may be necessary in order to construct basins. Typically terrace width varies from 1.5 m for 4% land slopes to 150 m for 0.1% land slopes.



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



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

Figure 6.1 Layout of basin irrigation

Source: FAO, 1985

6.1.6 Sprinkler irrigation systems

Sprinkler irrigation is used on approximately 5% of irrigated land throughout the world. It will never seriously replace surface irrigation but it has one distinct advantage; good water management practices are built into the technology thus providing the flexibility and simplicity required for successful operation, independent of the variable soil and topographic conditions. Pumps, pipes and on-farm equipment can all be carefully selected to produce a uniform irrigation at a controlled water application rate and, provided simple operating procedures are followed, the irrigation skills required of the operator are minimal. This puts more of the responsibility for successful irrigation more in the hands of the designer rather than leaving it entirely to the farmer. Thus sprinkle can be much simpler to operate and requires fewer water management skills. However, it requires much more sophisticated design skills and on farm support in terms of maintenance and the supply of spare parts.

Sprinkle is potentially more efficient and uses less labour than surface irrigation and can be adapted more easily to sandy and erodible soils on undulating ground which may be costly to regrade for surface methods. There are many types of sprinkle system available to suit a wide variety of operating conditions but the most common is a system using portable pipes (aluminium or plastic) supplying small rotary impact sprinklers. Because of the portability of sprinkle systems they are ideal for supplementary irrigation. The efficiency of sprinkle irrigation depends as much on the farmer as on the system. For design purposes a figure of 75% is generally used.

Sprinkle irrigation is better suited to large farms rather than the small farms found in many developing countries. Typical spacing for sprinklers is 18m by 18m and this is not very flexible and adaptable to the multitude of small plots usually found on small farms. One option which may fit more closely to the small farm are the smaller sprinklers connected to a main line by flexible hoses - the hose pull system. The sprinklers can then be more easily located around the farm with great flexibility.

Larger schemes can accommodate the requirements of traditional sprinkle irrigation and also take advantage of the recent developments in systems which reduce labour and energy costs through the use of automation. At the forefront of all these developments is the centre pivot machine which can irrigate up to 100 ha from a single machine. These machines are also very adaptable. In UK they have been used on small and irregular shaped fields and they cross field boundaries to irrigate several fields growing different crops at the same time. One machine can also irrigate several farms if the farmers are able to cooperate. Their role in irrigating large areas with minimal inputs should not be underestimated.

A sprinkler irrigation system consists of a pipe network, through which water moves under pressure before being delivered to the crop via sprinkler nozzles. The system basically simulates rainfall in that water is applied through overhead spraying. Therefore, these systems are also known as overhead irrigation systems. As such, the water distribution of certain sprinkler systems is affected to a large extent by the wind patterns and velocity in a particular area. Sprinkler irrigation systems are suitable for most crops, except those whose leaves may be sensitive to prolonged contact with water or crops requiring ponding of water at some stage of their life. They are generally suitable for light, frequent irrigations, unlike most surface irrigation systems. They have a large component of built-in management in that it is easy to apply the exact amount of water that one requires, unlike surface irrigation systems where the depth of irrigation desired at a given time cannot be accurately applied. Sprinkler irrigation systems also require much less labour than surface irrigation systems. In contrast to these advantages, sprinkler irrigation systems are relatively high energy demanding and require fairly good water quality, in terms of sodium and chlorite. These systems are also susceptible to windy conditions. There are several types of sprinkler irrigation systems, which can be broadly sub-divided into two groups: set systems, which operate with sprinklers in a fixed position, for some time at least, and continuous move systems, which operate while moving.

Set systems can be further divided according to whether or not sprinklers should be moved through a series of positions during the course of irrigating a field. Those systems that must be moved are called periodic-move systems and those that do not require any movement are called fixed systems. Periodic-move systems can be further divided according to the method of movement of sprinklers and laterals into hand-move systems, where laterals and sprinklers are moved manually, and mechanically-move systems, where the movement is done by mechanical means. The hand-move lateral systems are comprised of either portable or buried mainlines, sub-mainlines and hydrant valves at intervals for connecting the laterals.

Hand-move lateral systems normally utilize quick-coupling laterals that are moved from one hydrant position to another by hand. Therefore, they are labour-intensive compared to other sprinkler irrigation systems. In fact they are the predecessors of mechanically-move systems, which were developed to reduce labour input. Hand-move systems are adapted to irregular field shapes, fairly steep topographies and are suitable for most field crops. Due to their labour demand, they may be ideal where labour is available and cheap. A brief description of the various periodic hand-move systems (portable, semi-portable and drag-hose) is given below. The differences between the individual systems depend on which components are movable and which are not.

Portable systems: A portable sprinkler irrigation system has portable aluminium or light steel mains, submains, laterals and sometimes even portable pumps. This means that the equipment can be moved from one area to another in order to carry out irrigation events as required. It is, therefore, designed to irrigate different fields with different crops using the same equipment. It suits areas that border perennial streams or that have a number of sources of water in their vicinity or where supplementary irrigation is required. They are extensively used in tobacco because of the 3-4 year rotation followed for this crop. The lateral is moving towards the pump in a clockwise direction. When the lateral reaches the last position closest to the pump, it is flipped over to the other side of the mainline and continues moving away from the pump. After having finished this side the mainline can be moved to another position and the next part can be irrigated moving the lateral in the same way as explained above.

Semi-portable systems: The semi-portable or semi-permanent system usually has permanent AC or uPVC mains and submains, which should be buried and portable aluminium or light steel laterals. This means that the mains and sub mains cannot be moved. Both the portable and the semi-portable systems are common in many parts of the world.

Drag-hose systems: Drag-hose or hose-pull systems are composed of buried mains, sub-mains and laterals. The hoses are attached to the hydrants or garden taps of the laterals on one end and to the risers, fixed onto tripod stands, on the other end. The sprinklers are fixed on tripod stands. Usually, one sprinkler is attached to each hose. A prerequisite to the uniform wetting of the system is the systematic manner of movement of the sprinklers from one position to another, so that adequate overlap is achieved. The hose and tripod stand are manually moved from one sprinkler position to the next. These systems were originally used to irrigate citrus trees and orchards. In Southern Africa they are now increasingly used for the irrigation of sugar cane, field crops and vegetable crops. The length of the hose varies with the desired ease of operation and initial capital investment required. A length of 30 m is considered as reasonable. The drag-hose irrigation system has been successfully implemented in Zimbabwe's smallholder irrigation sector since 1988. In 1997 it was estimated that more than 30% of all smallholder schemes in Zimbabwe were under this system. Other countries, such as South Africa, Swaziland, Malawi and Kenya, are using this system.

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

Side-roll and side-move lateral system: These systems are similar to the hand-move system, except that instead of people moving laterals it is done by a machine. The system is a rigidly-coupled lateral supported on a number of wheels, which are mechanically moved by a power source such as an engine at the centre of the line or at the end. The number of wheels varies with the length of the lateral. The lateral is attached to the main line via a flexible hose or a portable aluminium pipe. When the system is operating, the wheels are stationary. When a change of lateral position is needed, an engine moves the wheels to the next position. The side-roll lateral system has the disadvantages of being only suited to short crops and mostly rectangular fields. Due to its long lateral, which extends to about 500 m, it is not suitable for rapidly changing topography or steep slopes. In the side-move lateral system, the lateral is raised to a height of 1.5 m from the ground, making it suitable for higher crops. The general disadvantage of both systems is that when they reach the end of the field they have to be towed back to the beginning of the field, a process that is time consuming. End-tow lateral systems are similar to hand-move systems except that they consist of rigidly coupled laterals, up to 400 m in length, connected to the mainline during operation. They also need to be towed from one side of the mainline to the next. The towing is normally done using machinery such as tractors rather than by hand. This system, by virtue of its long laterals, is not suited to irregular field shapes, rough and rapidly changing topography or row crops grown following the contours.

Gun and boom sprinkler irrigation systems: Gun sprinklers have large nozzles, 16 mm in diameter or larger, that are rotated by a rocker arm. Boom sprinkler irrigation systems have rotating arms on which sprinklers are positioned. The gun and boom sprinklers operate at up to 62 metres (or 6.2 bars) head and discharge approximately 31.5 l/s (Keller and Bliesner, 1990). The systems are used on most crops, mainly for supplementary irrigation. Their use is limited to coarse textured soils because heavier textured soils have low intake rates that are incompatible with the high application rates of these systems. The gun and boom sprinklers are normally mounted on trailers or skids, which have to be towed from one position to the next. In one instance the gun is pulled towards the fixed winding machine by the pipe supplying water, while in the other the gun is self-hauled on the pipe supplying the water. In the latter the winding machine is moving towards the pipe anchorage as the pipe winds onto the drum. Fixed sprinkler irrigation systems can be sub-divided into solid-set systems and permanent systems as described below. These systems are 'on and off' in terms of their operation and therefore require very little labour. However, they do require high capital investment. Fixed systems can be automated, in which case the automatic control system can be programmed for irrigation, cooling and frost protection.

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

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

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

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

Centre pivot. This is one of the most popular irrigation systems. The centre pivot system consists of a pipe lateral mounted on steel towers. The fixed end of the lateral, the pivot, is connected to a water supply. The pipe carries different sizes of impact, spinner or spray sprinklers. The steel towers, also called spans, have wheels that rotate continuously around a centre pivot point. The speed of movement varies from tower to tower. The closer the tower is to the centre of the pivot the slower the wheels move. Centre pivots vary in length depending on the design area and can irrigate up to 120 ha. Centre pivots vary in height; they can be of low, standard or high clearance (from 3-5 m). The laterals can be fitted with end guns to irrigate irregular areas at the periphery of the circle. These systems are suitable for most field crops. They are best suited to soils that can take up high infiltration rates, and areas without obstructions such as power lines and buildings. The use of centre pivots is increasingly gaining popularity among commercial farmers in Eastern and Southern Africa. The low per hectare cost of large centre pivot systems, the limited labour requirements and the low energy requirements of pivot systems using spray nozzles are the main reasons for the popularity of these systems. Centre pivot systems equipped with nozzles and drop pipes, placing the nozzles just above the crop canopy, are very useful under windy conditions.

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

Travelling irrigators: One of the most recent variations of the continuous-move systems is the continuous travel wheel, whereby the lateral, mounted on wheels, moves continuously while irrigating. A long flexible hose provides the lateral with water from the main pipe. The lateral is a gun or a boom with low-pressure sprayers, mounted on a wheeled irrigation machine. Figure 16 illustrates the components of a cable-drawn machine and the typical layout. Gun sprinklers can also be hose-pulled during irrigation. In the latter case, the irrigating machine can be self-hauled or pulled by the pipe supplying the water. In contrast to the gun travelling irrigators, the boom with low-pressure nozzles is comparable to the centre pivot system and has been successfully used for the irrigation of several crops grown on different soils.

Table 6.1 Summary of Sprinkler Irrigation Systems

System			Use
Conventional systems	portable	hand move roll move tow line	Uses small rotary impact sprinklers Widely used on all field and orchard crops Labour intensive
	semi permanent	sprinkler hop pipe grid hose pull	Similar to portable. Lower labour input but higher capital cost
Mobile gun systems	hose pull hose drag		Large gun sprinklers but can be replaced by boom. Good for supplementary irrigation
Mobile lateral systems	centre pivot linear move		Large automatic systems. Ideal for large farms with low labour availability
Spray lines	stationary oscillating rotating		Fixed spray nozzles. Suitable for small gardens and orchards

6.1.7 Drip (Trickle) Irrigation

Drip irrigation is the least used system on a world scale and involves less than 0.1% of irrigated land. Even in Israel where much of the early research and development was done and water is very scarce, trickle has not flourished as much as might be thought. Sprinkle irrigation still provides more than 70% of Israel's irrigation because this is still considered to be a most efficient method of irrigation and one which is financially viable. Drip is not without its technical problems and high cost and on a large scale emitter blockage can cause serious crop losses if the systems are not carefully managed but in some areas with the right characteristics it can be a very useful method. Many claims are made about this method, including increased crop yields, greater efficiency of water use, possible use of saline water, reduced labour requirements and its adaptability to poor soils. An important advantage is the ease with which nutrients can be applied with the irrigation water.

Claims made about water saving need to be judged with care. Crops respond primarily to water and not to the method of application. If the right amount of water is being applied to the crop at the right time it will flourish. It will not depend on whether the water comes from a sprinkler or a trickle emitter. Thus the saving is only in the potential efficiency of the method when compared to other methods. There are also misunderstandings about the efficiency of trickle irrigation. Its potential is 90%, however, actual efficiency, like in surface and sprinkler irrigation will depend to a large extent on the farmer and how the equipment is used in practice. A distinct advantage of trickle is that it is well suited to small and varied plots on small farms. This is how trickle is being used in India where farmers have gone from surface irrigation to trickle and have missed out sprinkle as being an inflexible system for small plots. Simple local manufacture of trickle parts has also encouraged Indian farmers to take up the method and they are assured of spare parts.

A major technical problem with trickle irrigation is emitter and lateral blockage from sand and silt, chemical precipitation from groundwater and algae from surface water. Each of the problems takes the use of trickle into a level of technology and support which is difficult to sustain in a developing country. On a small scale of these problems can simply be overcome by the farmer going around and cleaning the system regularly. However, on a large scale this would not be practicable. Trickle really comes into its own when water is scarce, when it is expensive, when the quality is marginal, when the land is marginal, when labour is expensive or not available and it is being used on high value crops. In such cases there may be no option but to use trickle. It can be an easy system to operate. It is a pipe system and so can be switched on and off easily by the farmer and so there is the potential for high levels of efficiency. But there may be problems in realising that potential.

6.1.8 Micro Irrigation

This is a method of irrigation part way between sprinkle and trickle. It uses small sprinklers (mini sprinklers or spitters 30 to 60 l/hr) to spray water over a limited area of a few metres and is ideally suited to orchards or small plots. Another technique is the bubbler which allows water to bubble from a pipeline at a much faster rate than a trickle emitter and so avoids the problem of blocking. Many farmers now prefer micro irrigation methods to trickle because they will not only do same the job as trickle but are less susceptible to blockage by silt and chemical precipitates. It is also easy to see when an irrigator is partially blocked because the spray pattern is distorted. With a trickle system a partly blocked emitter only comes to light when it is tested or the crop nearby shows sign of stress. At this point it may be too late to take any corrective action.

Localized irrigation systems: Localized irrigation is a system for supplying filtered water (and fertilizer) directly onto or into the soil. The water is distributed under low pressure through a pipe network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. There are three main categories of localized irrigation: (i) drip irrigation, where drip emitters are used to apply water slowly to the soil surface, (ii) spray irrigation, where water is sprayed to the soil near individual trees (iii) bubbler irrigation, where a small stream is applied to flood small basins or the soil adjacent to individual trees

A localized irrigation system consists of the head of the system that filters and controls the supply of water and fertilizers to the network, the plastic buried pipes that supply the water to the laterals, the polyethylene laterals, usually 16-20 mm in diameter, that supply the water to the emitters, and the emitters that discharge the water to the pre-determined points and at pre-determined flows. It is a capital-intensive system with built in management that requires very little but skilled labour. The main advantage of localized irrigation is its potential to reduce water requirements and achieve a very high efficiency, while at the same time increasing crop yield and quality. The system has been successfully used on tree and vegetable crops, and high yields attributed to it. Localized irrigation provides the means for very frequent irrigation, daily if needs be. Hence it is particularly suitable for light shallow soils, irrespective of slope, and for shallow-rooted crops. It has also proved suitable for most row crops. The main disadvantages of localized irrigation systems are their high capital cost, a susceptibility to clogging and a tendency to build up localized salinity, especially in low rainfall areas. As such, this category of system requires careful management for its maintenance..

6.2 Irrigation efficiencies

There is an ever-growing demand on water resources, which emanates from an increasing human population. This means that there is increasing competition for the use of water for agricultural, industrial, domestic and environmental purposes. This calls for more efficient use of finite water resources in order to minimize conflict between the sectors. This section provides some basic information that can be used by planners for the selection of an irrigation system based on levels of their efficiencies. For more precise information the reader is referred to literature dealing more specifically with this subject. In the process of applying irrigation water to crops, water losses occur. These losses have to be taken into account when calculating the gross irrigation requirements of an irrigation project. This can be done through the use of an efficiency factor, which has to be estimated at the planning stage. Different types of irrigation systems have different levels of efficiency. The higher the irrigation efficiency, the larger the area that can be irrigated from a given finite water source. The less the leaching of nutrients and damage to the soil the more environmentally friendly the irrigation system. The water that is saved can be used for other productive purposes.

The overall efficiency, also known as project efficiency (Ep), comprises conveyance efficiency (Ec), field canal efficiency (Eb) and field application efficiency (Ea). According to FAO (1992):

- Conveyance efficiency (Ec) is the ratio of the water received at the inlet of a block of fields to the water released at the headwork
- Field canal efficiency (Eb) is the ratio between water received at the field inlet and that received at the inlet of the block of fields
- Field application efficiency (Ea) is the ratio between water directly available to the crop and that received at the field inlet
- Project efficiency (Ep) is the ratio between water made *directly available to the crop and that released from the headwork, or Ep = Ec x Eb x Ea.*

Conveyance and field canal efficiencies are sometimes combined and called distribution system efficiency, Ed, where Ed = Ec x Eb. Field canal and field application efficiencies are also sometimes combined and called farm efficiency, Ef, where Ef = Eb x Ea.

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

Table 6.2 Conveyance, Field Canal and Field Application Efficiencies (FAO, 1992)

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

6.3 Criteria for Selection of Irrigation Method

The choice between the methods of surface irrigation depends on land slope, soil type (infiltration rate) field shape, crops and labour requirements. Tables 6.3 and 6.4 below, together with Table 4.1 (see section) summarises the key selection characteristics and the relative complexities.

Table 6.3 Selecting Surface Irrigation Methods

Irrigation method	Land slope (%)				Soil infiltration	Field shape	Crops				Labour
	Humid regions		Arid regions		rate (mm/h)		Row crops	Sown, drilled crops	Flooded rice	Orchards	h/ha per irrigation
	Bare soil	Crop cover	Bare soils	Crop cover							
basin	level or <0.1% (steep slopes need terracing)				up to 30	any shape	yes	yes	yes	yes	0.5 - 1.5
border	0.5	2.0	2.0	5.0	up to 30	rectangular	yes	yes	no	yes	1 - 3
furrow	0.3	-	2.0	-	up to 30	rows of equal lenght	yes	no	yes	yes	2 - 4

Table 6.4 Technical Factors Affecting Selection of Irrigation Method

Irrigation Method	Crops	Soils	Labour (h/ha/irrigat.)	Energy Demand	Potential Efficiency (%)	Capital Cost
Surface					60	low
• Basin	all crops	clay, loam	0.5 - 1.5	low		
• Border	all crops except rice	clay, loam	1.0 - 3.0	low		
• Furrow	all crops except rice and sown/drilled	clay, loam	2.0 - 4.0	low		
Sprinkle	all crops except rice	loam, sand	1.5 - 3.0	high	75	medium
Trickle	row crops, orchards	all soils	0.2 - 0.5	medium	90	high

Note that it is difficult to give general indication of the cost of each system, because this depends on the site conditions and the availability of locally manufactured equipment. However, in broad terms an indication of the relative capital cost is given in Table 6.4.

6.4 Design Parameters

A number of parameters need to be considered when determining the design flow of the irrigation system. Available moisture, root zone depth, allowable moisture depletion, irrigation frequency and cycle, irrigation efficiencies and the net peak water requirements all need to be taken into account. The net depth of water application (dnet) is the amount of water (mm) needed to be supplied to the soil to bring it back to field capacity. It is the product of the available soil moisture (FC-PWP), the effective root zone depth (RZD) and the allowable moisture (AM) depletion can be calculated from:

$$\mathbf{d_{net} = (FC - PWP) \times RZD \times P}$$

Where:

d_{net} = net depth of water application per irrigation for the selected crop (mm)
FC = soil moisture at field capacity (mm/m)
PWP = soil moisture at the permanent wilting point (mm/m)
RZD = depth of soil that the roots exploit effectively (m)
P = allowable portion of AM permitted for depletion by the crop before the next irrigation
AW = Actual amount of water to be applied to meet both ET_{crop} and leaching
= d_{net} + LR

6.5 System capacity

Gross depth of water application (d_{gross}) is obtained by dividing the net depth of water (d_{net}) [11] [that includes the leaching requirement – see Section 5.9] by efficiency (see Section 7.1.9):

$$\mathbf{d_{gross} = (d_{net} + LR) / E}$$

Irrigation frequency (IF) is the time it takes a crop to deplete the soil moisture at a given depletion level and can be calculated as follows:

$$\mathbf{IF = d_{net} / ET_{crop}}$$

Where:

IF	=	Irrigation frequency (days)
d_{net}	=	Net depth of water application (mm)
ET_{crop}	=	Crop evapotranspiration (mm/day)

For design purposes, the peak daily amount of water used by the crop is required. The net peak daily irrigation requirement (IRn) is determined by subtracting the rainfall (if any) from the peak daily crop water requirements.

The irrigation cycle is the time it takes to irrigate the entire scheme. At peak, there may be not gap between the first and following irrigation cycles. In general, however, gaps exist and these can be used for repairs and activities that relate to the irrigation and drainage systems and that need the cessation of flows to be affected. For example, an irrigation frequency of 7 days with an irrigation cycle of 5 days, leaves 2 days for other works and practices inside and outside the scheme. The greater the difference between the frequency and the cycle, the greater the flexibility to deal with unforeseen situations such as breakdowns, but this will often impact on the overall cost of the system. It does however permit the later expansion of the scheme, utilizing the same conveyance and distribution system, but needs to be taken into account during planning and design as it will also affect the economics (see Chapter). In general, the difference between the irrigation frequency and the irrigation cycle should not exceed one day.

System capacity (Q) is the discharge that the main system needs to carry in order to meet all irrigation demands and has to be abstracted via the headworks during a given period per day and it is used for the design of the headworks and the conveyance system. It is determined by the following equation:

$$\begin{aligned} \mathbf{Q} &= \mathbf{V/T} \\ &= [10 \times A \times d_{gross}] / T \\ &= [10 \times (At/IC) \times d_{gross}] / T \end{aligned}$$

Where:

Q	=	Discharge (m^3/hr)
T	=	Irrigation duration per day (hr)
V	=	Volume of water abstracted per day (m^3) = 10 x A x d_{gross}
A	=	Area irrigated daily (ha) = At/IC
d_{gross}	=	Gross depth of application at overall scheme level (mm)
At	=	Total area (ha)
IC	=	Irrigation cycle (days)
10	=	Conversion factor to convert mm to m^3/ha

The system capacity can be reduced by incorporating night storage in the system, but this requires suitable topography and a higher level of water management that may not be available in CBSSI without external management support.

[11] The actual amount of water to be applied to supply both crop ET and leaching (long-term salt control).

6.6 Other References

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Explains irrigation methods and their variations, and provides information on what elements to take into consideration before choosing any method. Methods of irrigation outlined include surface irrigation, drip-macro irrigation, sprinkler irrigation, and sub irrigation. Each method is discussed in terms of capabilities and limitations, institutional considerations, and economic factors, taking into account crop, climate, economics, water quality, support infrastructure, and energy availability. Includes b&w photos of sites.

Kay, Melvyn. Surface Irrigation: Systems and Practice. Cranfield University Press; (3 May 1990). # ISBN-10: 0947767266; # ISBN-13: 978-0947767266

Regional Land Management Unit (RELMA), Soil and Water Conservation Manual for Eritrea, Amanuel Negassi, Estifanos Bein, Kifle Ghebru, Bo Tengnäs.

.7 Conveyance Systems

The distribution system conveys water from the source of supply to the fields and may comprise of pipes, open channels or a combination of both. Channel distribution and surface irrigation is usually the least capital cost option when planning a new scheme. However, it will only be the best option if it works as planned. Field experience in many countries has shown that this combination is very difficult to manage properly. Canal systems are very slow to respond to changes in demand. As a result, farmers are restricted in the timing and amount of water they can have, which in turn puts restrictions on the crops they can grow. In contrast, pipe systems are much easier to manage because they respond faster to changes in demand, and they can be turned off when water is no longer needed. This is ideal for farmers who wish to choose their irrigation times and their cropping pattern to suit their needs rather than those of the irrigation system management.

7.1 Design of Canals

The most common method of water distribution for irrigation is with open channels. Although unlined canals are the most common, the choice should be based on: economics of both capital and running costs, expected water seepage, and expectations for suitable maintenance. Lined canals do not just reduce seepage losses in highly permeable ground they can also reduce the need for maintenance later in the life of a scheme. Thus, capital investments made at the beginning of the scheme may reduce costs later. This is particularly important when it is known that maintenance is likely to be under-resourced. Large water losses can easily occur in open channels. This may be seepage but it is more likely to be through mismanagement of the canal system. Therefore, it is most important to ensure a suitable operation as this may save more water than lining of canals.

7.1.1 Canal Capacities

The capacity of the canals will be determined by the system of delivery adopted and the areas commanded. The design discharge adopted for each reach is then taken as the product of the net area for each measured from the topographical maps multiplied by the specific discharge derived. Manning's formula, which is empirical, is the basic flow equation for the design of open channels. In its usual form:

$$\mathbf{Q = (1/n) \times AR^{2/3} S^{1/2}}$$

Where:

R	=	Hydraulic Radius (m) = A/P
A	=	wetted cross section area (m^2)
P	=	Wetted Perimeter (m)
Q	=	canal discharge in m^3/s = v x A
v	=	flow velocity (m/s)
b	=	bottom width (m)
h	=	water depth (m)
S	=	energy gradient (canal slope) (m/m)
n	=	Manning's roughness coefficient
m	=	side slope (vertical : m horizontal)
f	=	freeboard
w	=	width of free water surface = b + 2mh
h_{total}	=	Total water depth = h + f

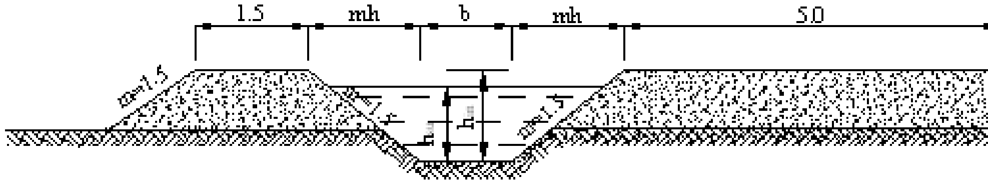


Figure 7.1: Typical cross section of the canals

Most canals to be used on CBSSI in the Nile Basin will have a trapezoidal cross section. On private schemes with high management and greater investment costs, there will be lined canals with circular or U-shaped cross sections. For trapezoidal canals, the following formulas can be used to calculate P, R and A.

$$\mathbf{P = b + \{2(d^2 + (dm)^2\}^{1/2} = b + 2d(1 + m^2)^{1/2}}$$

$$\mathbf{R = [d(b + md) / [(b + 2d (1 + m^2)^{1/2}]}$$

7.1.2 Manning's "n" Roughness

The canal roughness, as depicted by the Manning roughness coefficient, influences the amount of water that passes through a canal. Unlined canals with silt deposits and weed growth, and lined canals with a rough finish tend to slow down the water velocity, thus reducing the discharge compared to that of a clean canal with a smooth finish. Canals that slow down the movement of water have a high roughness or "n" value. The lower this value goes, the greater will be the capacity of the canal for a given cross section. The roughness coefficient depends on the roughness of the material from which the canal bed and sides are built, the shape of the canal, the canal irregularity and alignment, any piers, trees or other type of obstructions.

When designing a canal, the value adopted for roughness must be the value that will result during normal operation and not the value once the canal has been built. The former will be rougher than expected and will reflect the level of maintenance, the quality of the maintenance and any vegetative or algae growth. A value of Manning's "n" of 0.027 should be adopted for earth canals under normal farmer operating conditions. Where concrete lining is used, a value of 0.017 should be adopted and for gravel sections at the start of the canals at the intakes, a value of 0.030 is appropriate.

7.1.3 Canal Section and Side Slopes

To limit excavation and the need to acquire additional land, canal side slopes are designed as steep as possible. Soil material, depth of the canal and the occurrence of seepage will determine the maximum steepness for a stable side slope. The minimum slopes in cut for earth canals for various soil materials are given in Table 7.1 below, and the minimum slopes for earth canals constructed with well compacted cohesive materials are shown in Table 7.2.

In traditional canals, side slopes are in many places steeper than the recommended values, however, the stability is maintained by trees, bushes and vegetation along the canal banks. When canals are to be cleaned, reshaped and realigned, it is necessary to revert to the theoretical design slopes dictated by the depth of excavation and the soil types. For design purposes, the following have been generally used:

$$\mathbf{Q < 1\ m^3/s, m \quad = \quad 1:1}$$

$$\mathbf{1\ m^3/s < Q < 5\ m^3/s, \quad m \quad = \quad 1:1.5}$$

Table 7.1 Minimum Side Slopes for Various Soils

Soil Material	Side Slope Range (1:m)
Rock	< 0.25
Stiff Clay, Loam, Losses	1 - 2
Sandy Clay, Cohesive	1.5 - 2.5
Silty Sand	2 - 3

Table 7.2 Minimum Side Slopes for Canals in Well Compacted Fill

Soil Material	Side Slope Range (1:m)

D < 1.0	1 : 1
1.0 < D < 2.0	1 : 1.5
D > 2.0	1 : 2

For embankments higher than 3 m, a berm of at least 1 m width should be constructed. For the outside slope, a berm, if needed, should be situated midway between top and foot of the embankment.

7.1.4 Water Depth and Bed Width to Depth Ratio

The most efficient hydraulic section is that with the minimum wetted surface area. In practice, other considerations such as cost, command and depth of excavation have to be considered. From experience, generalized values for the ratio of bed width to water depth for irrigation canals can be used. These depend upon discharge, soil type, side slope and canal roughness factor K. The design values that have been recommended are shown in for earthen trapezoidal canals are given in Table 7.3.

Table 7.3 Recommended b/d ratios

Recommended b/d ratios	Water depth b/d ratio
Small (d < 0.75 m)	1 (clay) - 2 (sand)
Medium (d = 0.75-1.50 m)	1.5 (clay) - 3 (sand)
Large (d > 1.50 m)	> 3

The bed width should be wide enough to allow easy cleaning. A bed width of 0.20-0.25 m is considered to be the minimum, as this still allows the cleaning of the canal with small tools such as a shovel. Lined trapezoidal canals could have similar b/d ratios as given above.

7.1.5 Longitudinal Slope

Canal slopes will be first determined to ensure that sufficient command is maintained over the lad to be irrigated. Slope must be then related to cross section shape, allowable velocity (so as not to cause scour) and hence capacity. Where excessive velocities derive, the slopes must be adjusted down.

7.1.6 Freeboard

Freeboard (f) is the vertical distance between the top of the canal bank and the water surface at design discharge. It gives safety against canal overtopping because of poor management and communications, blockages in the canals due to debris, animals falling into the canals or an accidental rising of the water level due to closure of gates.

$$\mathbf{f = C \times h^{1/2}}$$

Where:

C = 0.8 for discharges <0.5 m3/sec up to 1.35 for discharges > 80 m3/sec

h = Water depth (m)

Back water curves, the water surface upstream from any constriction such as a cross structure, culvert etc, should be examined when determining the required freeboard to ensure that the theory meets actual practical needs. In practice, minimum values of f are applied and for Q < 0.5 m^3/sec, 0.25 to 0.40 are recommended. For Q = >0.5 < 1.5, f = 0.50 m and for Q = >1.5 < 5.0, f = 0.60 m.

7.1.7 Canal velocities

The available velocity depends on many factors: soil material, amount of discharge, depth and curvature of canal etc. The acceptable velocities used in the design for earth irrigation canals are presented below. As command is often a problem, in some canals velocities fall below these values.

These are evidenced by excessive siltation. In most cases, however, except in the initial canal reaches, velocities lie in the range 0.25 to 0.50 m/sec. The maximum permissible non-erosive water velocity in earthen canals should be such that on the one hand the canal bed does not erode, and that on the other hand the water flows at a self-cleaning velocity (no deposition). A heavy clay soil will allow higher velocities without eroding than will a light sandy soil. Table 7.4 below suggests suitable design velocities for earth canals in traditional irrigation systems. Consideration should normally be given to the type of material through which the canals pass and this has been taken into account when determining the design velocities.

Table 7.4 Design Velocities for Earth Irrigation Canals

Design Discharge (m3/sec.)	Design Velocities (m/sec.)
0.15 - 0.30	0.30 - 0.32
0.30 - 0.50	0.32 - 0.35
0.50 - 0.75	0.35 - 0.38
0.75 - 1.00	0.38 - 0.40
1.00 - 1.50	0.40 - 0.43
1.50 - 3.00	0.43 - 0.50
3.00 - 4.50	0.50 - 0.58
4.50 - 5.00	0.58 - 0.60

Velocity increases with an increase in gradient or longitudinal slope. A canal with a steeper gradient but with the same cross-section can discharge more water, but this must not be too steep to cause scouring and erosion of the canal bed and banks.

Steeper slopes could result in such high velocities that the flow would be super-critical. It would then be difficult, for example, to siphon water out of the canal, since an obstruction in a canal where super-critical flow occurs tends to cause a lot of turbulence, which could result in the overtopping of the canal. This is due to the change from the super-critical state to the sub-critical state. The state of flow should be checked to determine the Froude Number to make sure the flow is sub-critical ($F_r < 1$)

$$\mathbf{Fr = V / [(g \times d)^{1/2}}$$

Where:

$$d = A / \text{width of free water surface (w)}$$

The canals that are found in the traditional irrigation systems are unlined earth canals. These have been constructed some years ago and have been cleaned annually by removing deposited and weed growth. The quality of this will vary and will generally be one of the reasons that rehabilitation is needed. Canal capacities vary from a few litres a second for the very small schemes, up to several cubic metres per second for the larger CBSSI schemes. Many of the systems will have been originally developed by the farmers themselves with little to no external assistance, solving the problems of shape and slopes through trial and error. Efficiency of canal design has not been as important as head/command. In the flatter lands these considerations are more important, particularly in the larger irrigated areas where land slopes can be considerable less than the river slopes. Considerable care must be exercised when planning changes to traditional canal systems during rehabilitation. It may be possible to make minor adjustments to canal alignment and slope, but experience has shown that farmers may only be prepared to accept minor changes before conflicts arise.

7.1.8 Design Duty

Estimates of design duty are made considering an average value of 1 l/s/ha. This assumes 24 hour irrigation, a situation that is uncommon except during peak demand periods and low flows in the river or streams. This should not be applied directly to the secondary or tertiary canals as capacities will depend upon the period and system of rotation adopted. Where 12 hr or day time irrigation only is practiced, the continuous flow value will need increasing to approximately twice the 24 hour value.

These figures are only to provide initial estimates and actual design figures will need to be determined through determination of all the design factors presented here and considering the proposed cropping patterns.

7.1.9 Canal Efficiency

To account for the losses of water during conveyance from the rivers to the fields, an efficiency factor needs to be included in the calculation of project/ area water requirements. This enables the capacity of the canals at given points to be determined when designing structures. The efficiency is made up of Distribution Efficiency (E_d) and Field Application Efficiency (E_a). The Distribution Efficiency (E_d) itself comprises Conveyance Efficiency (E_c) and Field Canal Efficiency (E_b). Distribution Efficiency is the product of these two and thus:

$$\mathbf{E_d = (E_b) \times (E_c)}$$

The Field Application Efficiency (E_a) is the ratio of the water made directly available to the crop and that is released into the canal system. It will depend upon irrigation methods and the soils to be irrigated. Estimates are provided in Chapter 5 but for surface irrigation, $E_a = 0.60$ is considered to be reasonable. These have thus been adopted here.

The Project Efficiency (E_p) thus becomes:

$$\mathbf{E_p = E_a \times E_b \times E_c}$$

For surface irrigation, project efficiencies of around 0.40 are reasonable with existing schemes requiring rehabilitation falling as low as 0.15 to 0.25.

$$\mathbf{Q = Q_d \times C \quad l/s/ha\ (gross)}$$

where:

Q_d = Design discharge deriving from above.

C = Flexibility factor that allows variation in future cropping patterns and intensities. The value of C normally varies between 1.1 and 1.4 depending upon the size and type of system. A value of 1.15 has is recommended for CBSSI schemes

Bank Top Widths: For the purposes of operation, maintenance and access, embankments along the canals should have a minimum width so that damage and erosion of the canal bank is avoided. Recommended minimum widths are given below.

Table 7.5 Recommended Minimum Embankment Widths

Design Discharge (m3/s)	Minimum Embankment Width (m)	
	w/out Inspection Road	With Inspection Road
Q < 1	1.00	3.00
1 < Q < 5	1.50	4.00

Radius of Curvature: The maximum radius of curvature of the centre lines of the canals should be 3 Ws, where Ws is the surface water width in metres for canal discharges less than 0.6 m^3/sec up to 7 Ws for large canals Q > 10 m^3/sec.

7.1.10 Design Chart

Figure 7.1 can be used to determine the optimum canal parameters for trapezoidal canal sections through trial and error. The steps to be followed for canal design can be summarised:

(a) Design water surface levels in relation to natural ground slope and required head for irrigation of fields or for drainage to outlet, taking into account head losses for turnouts and other structures.
(b) Calculate corresponding hydraulic gradients.
(c) Divide network into sections of uniform slope (S) and discharge (Q).
(d) Determine required design (maximum) discharge per section.
(e) Select roughness coefficient (n) – [side slopes/ preferred minimum velocity and permissible/ maximum velocity/ bottom width/water depth ratio].
(f) Calculate hydraulic section dimensions and corresponding velocity, using nomograph (Figure 7.1).
(g) Check calculated velocities against preferred and maximum velocity values; if V is too high, reduce hydraulic gradient and corresponding bottom slope. The gain in head should preferably be used in upstream and downstream canal sections but, if this is impossible, it must be absorbed by drop structures.

7.2 Balance between Cut and Fill

In order to minimise the costs of earthworks, a balance between the cut and fill should be reached along reaches of canals. Allowance must be made for swell when soils are excavated from the natural condition and also for the losses that result from unsuitable material etc. Most computer programmes that are used to compute earthworks quantities have this option included, but it is important to check results as in many cases the options provided for input are sometimes too restrictive.

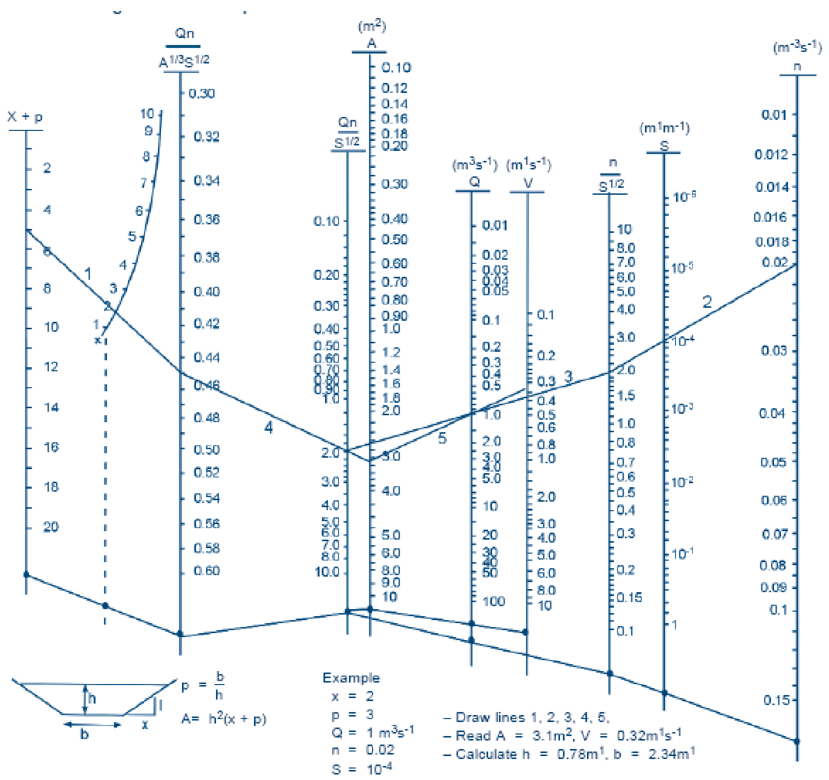


Figure 7.2 Nomograph for Design of Trapezoidal Canal using Manning's Formula

7.3 Field Canals

The required water level at the outlet to the tertiary block is calculated from the level of the land to be commanded with an allowance for head loss, through the structures and canals through which the water has to pass. The field or tertiary canals should have sufficient command over the whole length in order to allow the correct discharge to be supplied to the field. For these canals the ground elevations after land levelling have to be taken into account in deciding the slope of the canal. As normal practice, water depth at the outlet to the field should 10-15 cm above the levelled ground surface. Allowing for head loss across the outlet structure, the minimum command in the canal should be 0.20 to 0.25 m above the maximum ground level in the field to be irrigated.

Field canals (tertiary canals and sometimes secondary canals) usually run at an average land gradient. When the existing land slope exceeds the proposed canal gradient, drop structures should be used to avoid excessive fill which is costly. A common drop in small canals is 0.15 m. Such small drops do not require stilling basins. The drop should be constructed when the bed level of the canal reaches the ground level after land levelling and structures such as a simple rectangular weir or small Cipoletti weir should be built. Other allowances can be generalized as:

Turnouts/ divisions at field level	=	0.05 m
Other Turnouts/ divisions	=	0.10 m
Head loss in culvert	=	0.05 m

These must also be related to the anticipated maximum and minimum water levels in the canals. In practice, smaller heads only may be available, but it is essential to ensure that when canals and structures are modified or provided that land that is intended for irrigation can be adequately commanded.

7.4 Seepage losses and Canal lining

Unlined earthen canals are the most common means of conveying irrigation water to irrigated lands. Farmers prefer them because they can be built cheaply and easily and maintained with farm equipment. Unlined canals are also flexible, as it is easy to change their layout, to increase their capacity or even to eliminate or rebuild them the next season. However, unlined canals have many disadvantages that make them less desirable compared to lined canals:

- Usually lose more water due to seepage, leakage and spillage
- Rodents can burrow into the banks and cause leakage and damage to crops
- Frequent cleaning is needed because of weed growth
- Earth ditches can erode and meander, creating problems in maintaining straight or proper alignments
- Labour costs of maintenance of unlined canals are normally higher than of lined canals:
- They provide an ideal environment for the vector of bilharzia[12]

When designing earthen canals, it is important to ensure that the slope is such that the bed does not erode, and that the water flows at a self-cleaning velocity. In general, apart from the initial canal reaches near to headworks where rocky out crops and permeable materials are often encountered, canals are located onto the types of soils that they are to irrigate, namely on soils with a high percentage of silt and clay that have generally low infiltration rates.

In earthen canals, seepage occurs through the canal bed and sides. Seepage (in m^3/m^2 of wetted surface area of canal/day) can be estimated through measurement of (i) inflow into and outflow from the canal at selected points with the difference representing seepage and evaporation losses and (ii) the rate of fall of the water level in a reach of canal that has been closed and where the water has been allowed to pond. Evaporation should be subtracted from these measurements to obtain seepage losses. Typical average seepage losses for different types of soil are given in Table 7.6.

[12] HR Wallingford. Schistosomiasis host snail control in irrigation night storage reservoirs Ref: ODTN 83. T E Brabben, 1997. http://books.hrwallingford.co.uk

Table 7.6 Typical Seepage losses for Different Soil Types

Type of soil	Seepage (m^3 water/ m^2 wetted surface area per day)
Impervious clay loam	0.07 - 0.10
Clay loam, silty soil	0.15 - 0.23
Sandy loam	0.30 - 0.45
Sandy soil	0.45 - 0.55
Sandy soil with gravel	0.55 - 0.75
Pervious gravelly soil	0.75 - 0.90

7.5 Canal Lining

Loss of water from canals (seepage) occurs in all types of canals. In general those canals passing through clay soils will not require lining, but sandy soils will. In many canals, the materials through which the alignment passes will vary and it may be necessary to selectively line those parts that pass through permeable soils. Unlined canals are the most common, as they are the cheapest and easiest type of canal to construct. However, if water has to be used more efficiently, due to its scarcity or if it has to be pumped, it usually becomes economical to line the canals. Canal lining is generally done in order to reduce seepage losses and thus increase the irrigation efficiencies. It also substantially reduces drainage problems and canal maintenance as well as water ponding, thus reducing the occurrence of vector-borne diseases. Also, smooth surface linings reduce frictional losses, thereby increasing the carrying capacity of the canals.

The selection of a lining method depends mainly on the availability of materials, the availability of equipment, the costs and availability of labour for construction. The most common lining materials include concrete, clay, brick, concrete blocks and sand-cement. Construction of lining is important as poor practice will result in seepage and weed growth as well as early damage.

For a very good description of different types of canal lining see Laycock, 2007.

7.6 Canal Control Systems

Hydraulic control structures are used in canal systems to distribute water and to maintain canal command levels. The choice of structures should include the ease of management of the canal system as well as the hydraulic needs of the system. The main choice is between automatic control, flexible control and fixed control.

Automatic control normally involves the Neyrpic (French) gates which automatically control water levels and/or discharges in canals to pre-set values. These gates were used extensively in N. Africa to manage scarce water resources require very little skill from both the canal operators and the farmers. All the management decisions about command level and discharge can be built into the gate settings during design. Such systems are expensive. Although the gates are very reliable maintenance may be a problem as spares will be specialist parts.

Flexible control systems use gates which can be adjusted to suit the changing water demands of the crops. However, this can only be done from a supply point of view and does imply that there are experienced staff, who know how to set the gates and can make the right adjustments at the right time. Without experienced operators this system can be very difficult to operate effectively and efficiently particularly on a large scale.

Fixed control comprises fixed weirs along each canal to divert the flows into the farms. It is quite inflexible and may lead to wastage, but it can be managed easily both by system managers and by farmers. The water runs through the system and any excess goes into the drainage system. A system similar to this has recently been constructed in N. Nigeria on a scheme covering 2000 ha, and is working well. Remember that the relatively poor efficiency of this type of system may not be important. 'Losses' go back into the river or recharge the groundwater and so will be available elsewhere for someone to use.

7.7 Types of hydraulic structure

There are two types of hydraulic structure for water level and discharge control along canals; the orifice structure (underflow) and the weir structure (overflow). A weir structure makes a very good cross regulator because the head is insensitive to changes in discharge. Conversely, an orifice structure is a good head regulator because the discharge is relatively insensitive to changes in canal water levels. However, the combination of weir cross regulators and orifice head regulators along a canal can result in poor distribution of water along a canal, particularly when it is operating below its design discharge.

The farmers at the head of the system get most of the water while those at the tail get very little. Thus, the choice of irrigation structures along a canal can exacerbate the common top ender tail ender problem. One way of avoiding this problem is to ensure that the type of structure used is the same for both the cross regulator and head regulator.

7.8 Pipelines

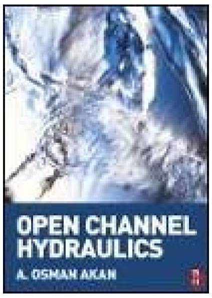
Pipelines are essential for sprinkle and trickle irrigation but are often considered too expensive for surface irrigation when compared with canals. However, expensive is a relative word and when both capital and operating costs are considered low pressure concrete or plastic pipes can be an attractive option and are well suited to tertiary distribution. Low pressure pipes have several advantages:

- very low distribution losses - can be less than lined channels. It is much easier to close off the flow in a pipe than in an open channel and so avoid wastage
- reduced distribution losses means that a larger area of land can be irrigated whose returns may offset the additional capital cost of the pipes
- less land area is taken up by buried pipes again increasing the cropped area within the scheme. Channels can take up 0.5 to 2% of the command area.
- pipes can often be installed at lower cost than lined canals • pipe systems can provide a more flexible, responsive and reliable system of supply
- because of the improved flexibility irrigation efficiency is likely to improve
- reduced contact with water has potential health benefits

7.9 Other References

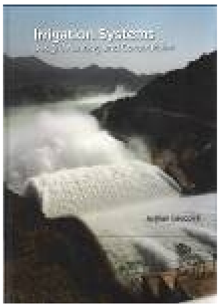
Key Reference: *Chapter 7, Irrigation Manual, Module 7, Surface Irrigation Systems, Planning, Design,Operation and Maintenance, Developed by Andreas P. SAVVA and Karen FRENKEN, Water Resources Development and Management Officers, FAO Sub-Regional Office for East and Southern Africa, Harare, 2002.*

The Water Team of FAO's Sub-regional Office for East and Southern Africa in Harare, Zimbabwe, has developed an Irrigational Manual for irrigation practitioners, resulting from several years of field work and training of irrigation engineers in the sub-region. It deals with the planning, development, monitoring and evaluation of irrigated agriculture with farmer participation. It consist of 14 Modules, regrouped in five volumes (Volume 1: Modules 1-6; Volume 2: Module 7; Volume 3: Module 8; Volume 4: Module 9; Volume 5: Modules 10-14), with an emphasis on engineering, agronomic and economic aspects of smallholder irrigation, but it also introduces the irrigation engineers to social, health and environmental aspects of irrigation development, thus providing a bridge between the various disciplines involved in irrigation development. For on-line reading, click one of the following: Cover page, Module 1, 2, 3, 4, 5,



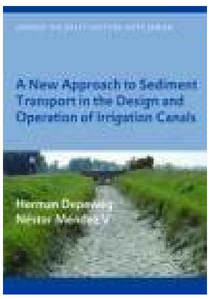
Adrian Laycock, Irrigation Systems, Design, Planning and Construction, CABI, 2007. ISBN: 978 1 84593 263 3.

Drawing on almost 40 years of experience of irrigation in the developing world, Laycock introduces new ideas on the design of irrigation systems and combines important issues from the disciplines of social conflict, management, and political thinking. enquiries@adrianlaycock.com



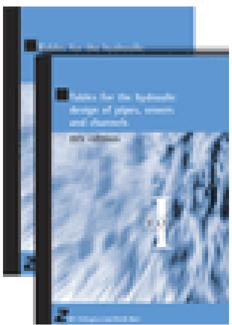
Akan, A. Osman. Open Channel Hydraulics. Butterworth Heinemann. March-2006. ISBN-13: 978-0-7506-6857-6; ISBN-10: 0-7506-6857-1.

Open Channel Hydraulics is written for undergraduate and graduate civil engineering students, and practicing engineers. Written in clear and simple language, it introduces and explains all the main topics required for courses on open channel flows, using numerous worked examples to illustrate the key points. With coverage of both introductions to flows, practical guidance to the design of open channels, and more advanced topics such as bridge hydraulics and the problem of scour, Professor Akan's book offers an unparalleled user-friendly study of this important subject



Depeweg, Herman; Méndez V Néstor. New Approch to Sediment Transport in the Design and Operation of Irrigation Canals. UNESCO-IHE Lecture Note Series. Taylor and Francis. 30/10/2006. ISBN: 978-0-415-42693-0

The transport of sediment greatly influences the sustainability of an irrigation system. Erosion and deposition not only increase maintenance costs, but may result in an inequitable and inadequate distribution of irrigation water. Understanding the behaviour and transport of sediment allows efficient planning and reliable water delivery schedules, and ensures the controlled deposition of sediments, making maintenance activities more manageable. These lecture notes present a detailed analysis of sediment transport in irrigation canals, together with physical and mathematical descriptions of the behaviour. A mathematical model predicts the sediment transport, deposition and entrainment rate for various flow conditions and sediment inputs. The model is particularly suitable for the simulation of sediment transport in irrigation canals where flow and sediment transport are largely determined by the operation of flow control structures.



HR Wallingford. Tables for the hydraulic design of pipes, sewers and channels: 8th edition (2 volume set) Ref: ISBN 0727733850, 2006.

For over 30 years, HR Wallingford's publication Tables for the hydraulic design of pipes, sewers and channels has been an essential reference for civil engineers working in the field of hydraulics. For this new edition the system of increments of gradient have been modified to reduce the need for interpolation. Includes the results of new work on the assessment of roughness size in commercial pipes manufactured from materials currently utilised to give a smooth finish and on the assessment of additional losses at bends in such pipes.

Kay, Melvyn. Surface Irrigation. Batsford (27 Sep 1984). # ISBN-10: 0713416939; # ISBN-13: 978-0713416930.

Explains irrigation methods and their variations, and provides information on what elements to take into consideration before choosing any method. Methods of irrigation outlined include surface irrigation, drip-macro irrigation, sprinkler irrigation, and sub irrigation. Each method is discussed in terms of capabilities and limitations, institutional considerations, and economic factors, taking into account crop, climate, economics, water quality, support infrastructure, and energy availability. Includes b&w photos of sites.

.8 Drainage System

Drainage of agricultural land is one of the most critical water management tools for the sustainability of productive cropping systems, as sustainability is very dependent on the control of waterlogging and soil salinization in the root zone of most crops. On some agricultural lands, the natural drainage is sufficient to maintain high productivity. However, many others require improvements in surface and subsurface drainage to optimize land productivity, while maintaining the quality of soil resources. Over time, drainage requirements may change due to socio-economic conditions, such as input and output prices, and more intensive crop rotations. In the irrigated lands of the arid and semi-arid regions (where salinity problems dominate), in addition to the benefits described above, subsurface drainage has been essential for controlling soil salinity and reducing the incidence of erratic crop yields. In the semi-humid and humid tropical regions, drainage has been less developed than elsewhere. However, salinity control is required during the irrigation season in the semi-humid tropics, and waterlogging control during the rainfall season where monsoon rainfall is prevalent. Flood control is also a necessary component of many irrigation and drainage projects.

The general goal in all agro-climate zones is to obtain a proper water table control necessary at the given time and under the given circumstances. Sometimes, special water control methods are required, e.g. in acid-sulphate soils and in peat soils, and in areas where rice is grown in rotation with dry-foot crops. These and the other main aspects of drainage in I&D developments are discussed in this Chapter.

8.1 Factors affecting drainage

8.1.1 Design Requirements and Criteria

Water level requirements. The capacity requirement of the main drainage outlet system is that it maintains sufficiently low water levels under unfavourable conditions. This means that in wet periods occurring with a frequency of once in 5–10 years, it must provide an adequate outlet for the field drainage systems to ensure free discharge into the main system, or if this is not always possible partial submergence for periods of short duration. Water levels are governed by the following:

- specific discharge (drainage coefficient)
- design discharges of channels
- hydraulic gradients and geometry of channels
- head differences for culverts, bridges, weirs, sluices and pumps.

The drainage system is divided into small enough sections for design purposes to ensure more or less homogeneous conditions for discharge and gradient, with each section having the same bottom width and water depth. Bridges, culverts, weirs, sluices and pumps are treated as separate structures.

Specific discharge is the rate at which excess water must be removed by the system without difficulty. It is the runoff that occurs on average from rainfall with a frequency of 1 in 5–10 years, increased with water from other sources (e.g. seepage). It is usually expressed in mm/day (comparable with rainfall) and is converted into a drainage coefficient expressed in l/sec/ha. A less probable precipitation event is sometimes taken (1 in 25, 50 or 100 years) to check the safety of the system and duration of the flooding under more extreme circumstances. More extreme probabilities are used in places where rainfall data are limited and to take account of the impact that climate change has on precipitation events.

Main drainage system discharges are generated by various field drainage processes, of which the surface drainage processes are usually the most critical. Under arid conditions, not more than 1.5–2 mm/d is usually required for salt control and irrigation losses. Where monsoon and heavy rainy seasons occur, much higher coefficients are needed. In principle, expected seepage should be added.

In arid regions, the drainage coefficient is low and seepage can be of comparable magnitude or even higher. Where seepage is saline, then the soil salt balance of the root zone may be affected significantly. Impermeable surfaces where infiltration into the soil is impossible such as areas with bare rocks, asphalt road, buildings and horticulture under glass or plastic, have a large specific discharge. Agricultural areas permit much higher infiltration and the influence of these areas on the design is usually of minor importance. However, built-up and covered areas tend to become more extensive over time, especially where large cities come into existence or where covered horticulture or orchards with intensive surface drainage systems become widespread. Problems often arise during periods with exceptionally intense rainfall and areas of open water storage (wetlands, or retention basins) are often used as a safety measure to permit flooding during extreme events.

Design discharge for drainage channels are derived considering accumulation of all design discharges from upstream sources and drainage branches, including extreme rainfall events. The transport capacity at the end section must be considered in relation to maximum permissible water levels for optimum agricultural production and any back water effects that may result from control structures or lower order drains entering higher order drains. Channel retention and different travelling times in the sub drainage catchments need also to be taken into account. The design flow for the determined return periods (such as 1 in 5 to 10 years) is determined at representative places:

- at the outlet of contributing smaller channels;
- at the beginning and end of each of channel section;
- at other constructions;
- at the final outlet.

At these places and intermediate channel sections, control points are located where characteristics such as surface elevation and other data are measured. Flow rate will change with time and storage in the channels will cause the discharge process to be non-steady. In many cases, channel storage is relatively small in comparison with storage in a pre-wetted soil (low percentage and 10–20% respectively). Thus the storage leading to non-steady effects results mainly from in-field drainage system rather than the main system (provided most outflows are via the groundwater). Moreover, the channels are often short enough to ignore outflow retardation by travelling discharge waves, so that steady-state calculation is often a good approximation. However, in cases where surface runoff is important, storage in the fields will be much smaller and the design discharges for the main system become far higher. Non-steady-state calculations for runoff normally begin at the upper end of open drains and proceed downstream. Determination of the timing of the runoff peak, its shape and duration are used to calculate the size of outlet drains. Generally, the unit hydrograph empirical method is used with the shape of each contributing area and the slope of the watersheds enter into the channel-sizing equation.

For steady-state calculations in a short channel sections, the flow is taken as flow from upstream sections plus the inflow into that section. Both flows are calculated as the product of the specific discharge (q in l/sec/ha) multiplied by the contributing area (A in ha) in order to obtain the flow (Q in m^3/sec). This gives a slight overestimation, but the difference is on the safe side. A reduction in the form of an exponent ($n<1$) is often applied to the upstream flow from large areas (Q). Where the rainfall is localised, the area considered for reduction is >1000 ha. Where the local rainfall is widespread, reductions will be introduced for areas larger than 50,000 ha. Recommended area reduction factors (n) can be consulted in Smedema, Vlotman and Rycroft (2004). In irrigated areas of arid regions where rainfall is negligible, the accumulation of discharges from different parts of the system is not necessary unless flooded rice is grown. In this case, a high drainage discharge capacity is required at the end of the growing season. This is because all farmers want to evacuate the remnants of the standing water layer in a relatively short time. As not all fields are irrigated at the same time in non-rice areas, the peak discharges from the different sections do not occur at the same time. Thus, the peak discharge from the entire system is less than the accumulated peak discharges from the sections. FAO (1980) has provided values for the multiplying factors to determine the design discharge for collector drains as related to the fraction of the area that is irrigated simultaneously.

Exceptional discharge. In order to check the safety of the system during discharges with return periods of 50–100 years (which may occur at any time), the calculations are sometimes repeated with a value of q of 1.5–2 times higher than the design coefficient. For such rare occasions, the water levels may become much higher than normally allowed, but disasters such as serious floods or severe damage must be avoided.

The hydraulic gradient of a channel section is the slope of the hydraulic energy line along the channel. At low velocities (< 0.5 m/s), this line is almost equal to the slope of the channel water surface. It must be more or less parallel to the slope of the land along the channel. Initially, the average hydraulic gradient available for gravity discharge can be chosen to be approximately the same as the surface gradient. Where the terrain is completely flat, it is necessary to choose a small hydraulic gradient that must be enough to allow sufficient water flow. However, considering the need to avoid erosion, the flow velocity should not exceed 0.5 m/s. In silty soils, it may be as low as 0.20 m/s. The bottom slope of an open-channel section should normally be equal to the average hydraulic gradient. Values of 0.05–0.1 per thousand are common in flat areas (even lower where the area is extremely flat). To create a higher gradient in these cases, discharge by pumping from one section into another could be considered. However, the capitalized operation costs may easily exceed the saving on channel dimensions.

In a longitudinal profile of a channel, the level of the strip of land along the top of the banks and the water levels to be tolerated at design discharge should be indicated, together with the location of buildings and confluences. Sudden changes in the gradients should be avoided and, where necessary, occur only at the limits of a section. Where sudden water level changes are required by the topography (to avoid deep excavations or excessive flow velocities), weirs are needed. Their location follows from land surface measurements. Head losses caused by weirs and other structures must be shown in the channel hydraulic profiles. Weirs and culverts cause differences in head between their upstream and downstream ends, and weirs in particular lead to backwater effects that may be noticeable far upstream in flat country.

8.2 Surface drainage

In flat lands, the approaches to cope with excess surface water depend on the circumstances. Where high groundwater is not a problem, surface systems, such as furrows and raised beds, are sufficient. However, a system of shallow ditches, combined with surface drains where necessary, is often used to cope with high groundwater as well as surface water.

Furrow at the downstream end of a field. Where there is a small slope (either natural or by land grading), surface runoff from an individual field may be discharged into a furrow running parallel to the collector ditch at the downstream end of the field. Bank erosion may be prevented by a small dyke along the ditch. The water collected in the furrow is then discharged safely into the open ditch through a short underground pipe. The same drainage outlet is generally used for removing excess irrigation water, especially in rice fields.

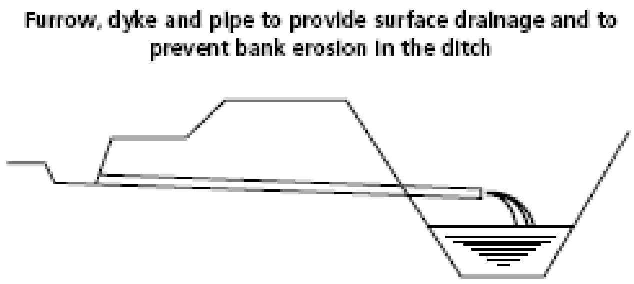


Figure 8.1 Typical Drop Outlet into Drain

Ridges and furrows. Where crops are grown on ridges with furrows in between, their somewhat higher elevation protects plants from inundation. The furrows also serve as conduits for the flow of excess water, which is collected by an additional furrow at the downstream sides of the field and discharged into the ditch in a similar way as described above. The ridged fields may have a small slope towards the sides. Where fields are made highest in the middle (e.g. by land grading), this position can also be used for irrigation supply to the furrow. The length and slope of the furrows depend on the field dimensions and the soil conditions and usually ranges from 150 to 250 m. The slope along the length is usually some 0.5–5 per thousand and this guarantees a non-erosive flow velocity of less than 0.5 m/s.

Layout of a field for irrigation and surface drainage through furrows

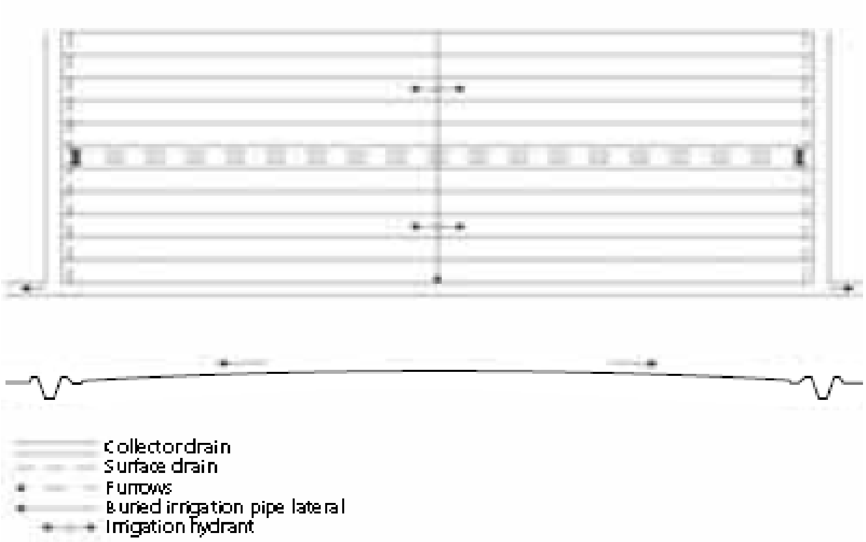


Figure 8.2 Typical Layout for On Farm I & D

Convex raised beds and furrows. In flat lands with low infiltration rates, surface runoff is facilitated by shaping the land into raised beds with a convex form between two furrows. Beds run in the direction of the prevailing slope (Figure 8.3) with the lateral direction slope being 1–2% which is sufficient. Raised beds can be made on-farm by repeated directional ploughing or by land grading. The intervening furrows are shallow enough to be passable for agricultural implements and cattle. These furrows should have a slight longitudinal slope for their discharge, either directly to the collector ditch, as in grassland where the soil is sufficiently protected, or to a system with a downstream furrow acting as a surface drain (described above). While normal ploughing operations must always be carried out in the same way the beds were ploughed originally, all other farming operations can be carried out in either direction. The beds have a length of about 100–300 m. with the bed widths and slopes depending on soil permeability, land use and farm equipment. Some recommendations (Raadsma and Schulze (1974) and Ochs and Bishay (1992)) are:

- 8–12 m for land with very slow internal drainage (K = 0.05 m/d);
- 15–17 m for land with slow internal drainage (K = 0.05–0.10 m/d);
- 20–30 m for land with fair internal drainage (K = 0.1–0.2 m/d).

The elevation of the beds, i.e. the distance between the bottom of a furrow and the top of the bed, can range from about 0.20 m for cropland up to 0.40 m for grassland, where land covering reduces erosion hazard. The furrows between the beds are normally about 0.25 m deep, with gradients of at least 0.1%. The bedding system does not provide satisfactory surface drainage where crops are grown on ridges, as these prevent overland flow to the furrows. Bedding for drainage is recommended for pasture, hay or any crop that allows the surface of the beds to be smoothed. It is less expensive but not as effective as a parallel furrow drainage system. The system cannot be combined with surface irrigation, although sprinkler and drip irrigation remain possible.

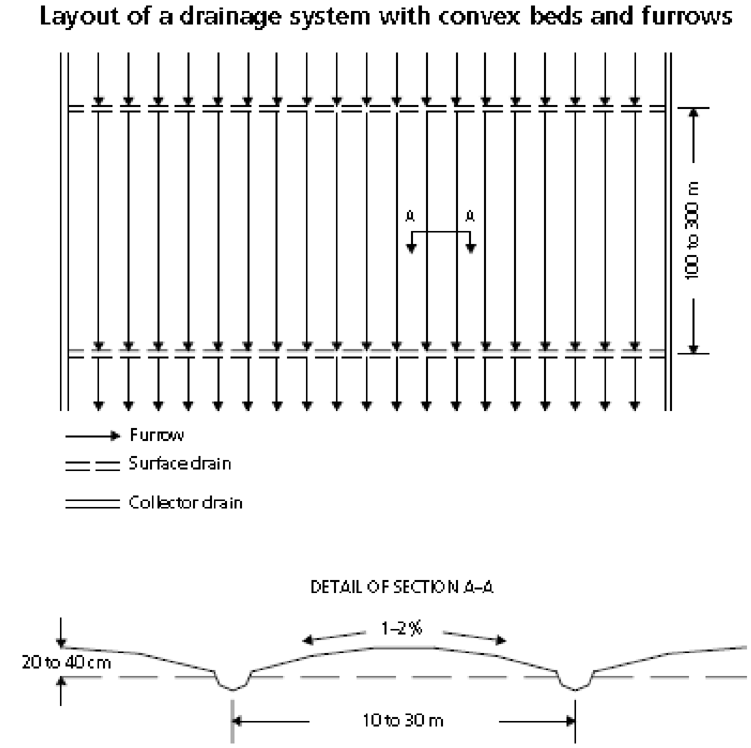


Figure 8.3 Typical Layout for On Farm I & D Using Beds & Furrows

Parallel field drainage systems (Figure 8.4) are the most common and generally the most effective design recommended for surface drainage of flat lands, particularly where field surface gradients are present or constructed. These drainage systems facilitate mechanized farming operations. Shallow field drains are generally parallel but not necessarily equidistant, and spacing can be adjusted to fit farm equipment. The spacing of parallel field drains depends on crops to be grown, soil texture and permeability, topography and land slope. Drain spacing generally ranges from 100 to 200 m on relatively flat land, and it depends on whether the land slopes in one direction or in both directions after grading. Side slopes should not exceed 1: 8 (if equipment will be crossing) and longitudinal grades should range from 0.1 to 0.3% (never less than 0.05%). To enable good surface drainage, crop rows should be planted in a direction that will permit smooth and continuous surface water flow to the field drains. Ploughing is carried out parallel to the drains and all other operations are perpendicular to the drains. The rows lead directly into the drains and should have a slope of 0.1–0.2%. Where soil erosion is not probable, the row slope may be as high as 0.5%. Under some conditions, deeper field drains are also used to provide subsurface drainage. In several places, especially at the outlets, small filled sections with culverts are often needed to provide access to the fields.

Parallel small ditches (Figure 8.5). This system employs small ditches 0.6–1.0 m deep and is used with the dual purpose of removing surface runoff and controlling high water tables. The system is especially useful where the groundwater stagnates on a poorly permeable layer at shallow depth (perched water tables), but also functions to prevent a high rise of the groundwater during wet periods. In this case, all farming operations are carried out parallel to the drains. The distance between the small ditches is usually 50–100 m, with a length up to 500 m. With wider spacing or low-permeability soils, additional shallower ditches can be used instead of the furrows shown in. The length of these ditches depends on the spacing of the ditches receiving the discharge. Longitudinal slopes of 2–5 per thousand are recommended to secure their discharge and prevent their erosion. Where surface runoff is a problem, shaping the land will provide either one- or two-sided discharge to these ditches. Erosion protection for parallel ditches is sometimes needed, especially on arable land. A system with a small parallel furrow that discharges at its lowest points through pipes into field collector ditches, can be used for this purpose. In pastures, the side slopes of the ditches are usually covered with vegetation and protection against surface runoff is seldom needed.

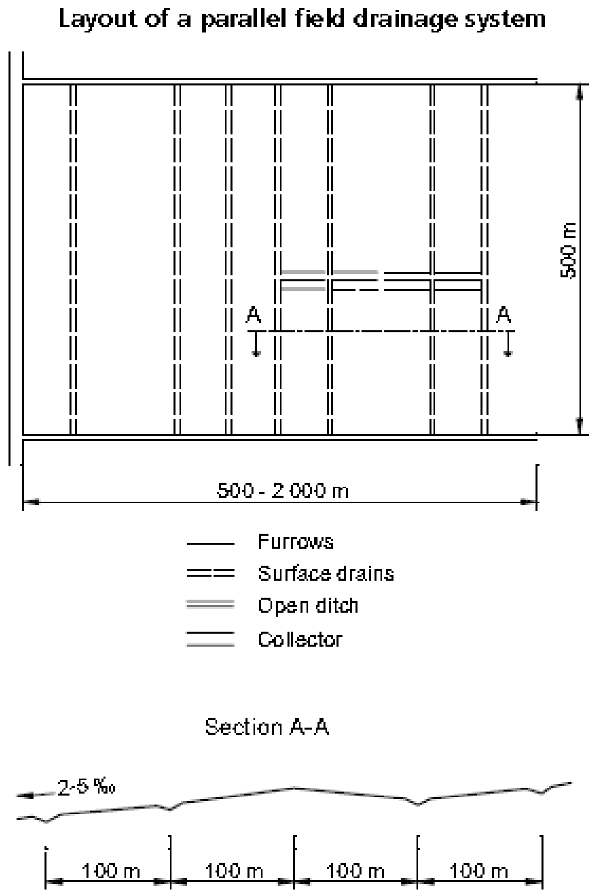


Figure 8.4 Typical Layout for On Farm I & D Using Parallel Drainage

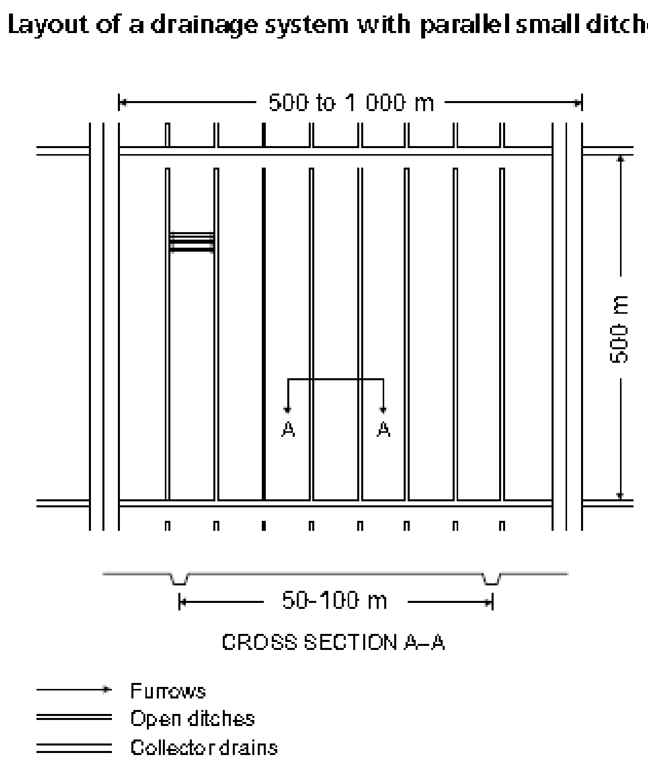


Figure 8.5 Typical Layout for On Farm I & D Using Parallel Small Drainage Ditches

Table 8.1 Summary Guidelines for the Selection of Method to Determine Design Discharges

Type of lands [1]	Aim	Drainage flow conditions	Drainage basin area (ha)	Available data	Recommended method	Remarks
Flat (slope < 0.2%)	To discharge excess surface water in a critical period	Field and canal storage are relevant; overland flow, interflow and subsurface flow	Up to some thousand	Data series of measured flows (m^3/s) (at least 15–20 years)	Statistical analysis of flows	Most reliable method but information not commonly available; need to check land-use changes.
			Up to some thousand	Rainfall distribution (days or hours) Evaporation (mm/d) Soil storage (mm/d) Storage in channels and ponds (mm/d) Maximum time of ponding (days or hours)	Batch method	Suitable to check performance of existing drainage facilities or to determine the design discharge
			< 5 000	24-hour excess rainfall (mm) Area served by the drain (km^2)	Cypress Creek formula	To be used only as a first approximation as this formula was developed for flat lands in the east of the United States of America
Sloping (slope > 0.5 %)	To discharge peak runoff	Free overland flow	Up to some thousand	Data series of measured flows (m^3/s) (at least 15–20 years)	Statistical analysis of flows	Most reliable method but information not commonly available; need to check land-use changes.
			Up to some thousand	Series of rainfall (mm) Some measured flows for 2–6 hours rainfall Unit hydrographs for 10 mm rainfall	Unit hydrograph	Method based on precipitation/surface runoff relationships not always available
			100–200	Rainfall intensity (mm/h) Area of the basin (ha) Slope (%) Soil infiltrability	Rational formula	To be used only as a first approximation as indicative values developed in the United States of America to determine the surface runoff coefficient are used
			Up to some thousand	24-hour rainfall (mm) In each land mapping unit (ha): natural vegetation and land use; agricultural practices; hydrological soil conditions associated to vegetation density; soil infiltrability; and soil moisture content previous to the design storm	Curve Number	To be used only as a first approximation as the original CN numbers were determined in the United States of America and the specific discharge is based on the SCS unit hydrograph

[1] For lands with slope between 0.2 and 0.5%, other factors (rainfall intensity, soil type, vegetation cover, cultivation methods, etc.) should be considered to classify the land as flat or sloping (Smedema, Vlotman and Rycroft, 2004).

8.3 Sub-surface drainage

In flat lands, subsurface drainage systems are installed to control the general groundwater level to achieve water table levels and salt balances favourable for crop growth. Subsurface drainage may be achieved by means of a system of parallel drains or by pumping water from wells. The first method is usually known as horizontal subsurface drainage, although the drains are generally laid with some slope. The second is called vertical drainage. A system of parallel drains sometimes consists of deep open trenches. However, more often, the field drains are buried perforated pipes and, in some cases, subsurface collector drains for further transport of the drain effluent to open water are also buried pipes. The drainage water is further conveyed through the main drains towards the drainage outlet. Less common are vertical drainage systems consisting of pumped wells that penetrate into an underlying aquifer. In sloping lands, the aim of subsurface drainage is usually to intercept seepage flows from higher places where this is easier than correcting the excess water problem at the places where waterlogging occurs from shallow seepage.

8.3.1 Layout of Singular and Composite Drainage Systems

There are several options for the layout of systems of parallel drains:

- singular drainage systems consisting of deep open trenches flowing directly into open outlet drains of the main system;
- singular drainage systems consisting of perforated pipe field drains (laterals) flowing directly into open drains of the main outlet system;
- composite drainage systems in which perforated pipes are used as laterals and closed or sometimes perforated pipes as collector drains with the latter discharging into the main drain outlet system.

As open trenches hamper agricultural operations and take up valuable land, field drainage systems with buried perforated pipes are often preferred although for many CBSSI they will be too costly. Several factors must be considered to select the appropriate drainage system:

- the need to discharge surface runoff
- slope of the land to be drained
- depth of the lateral outlets
- maintenance requirements and possibilities;
- design depth of the water table.

Singular subsurface drainage systems, with pipe laterals only, are appropriate:

- where, in addition to the subsurface flow, it is necessary to discharge excess rainfall through a shallow surface drainage system
- where a certain amount of water must be stored in the open drains to reduce the peak flow in the outlet system
- in very flat lands where the drainage flow is high and available slope is low.

Composite subsurface drainage systems, with pipe lateral and collector drains, are generally recommended in the irrigated lands of arid regions because:

- The depth of field drains is usually greater than in the temperate zones and large excavations depths would result if open ditches were used as field or collector drains
- Excess rainfall is generally negligible and thus drainage rates are low (although often very salty). The discharge of a considerable number of parallel pipe drains can thus be readily collected and transported by a subsurface collector system
- Weed proliferation increases the maintenance costs of open ditches.

This type of system is common in the Nile Delta, Egypt, where subsurface drainage systems discharge only the necessary leaching to control soil salinity and keep the groundwater level sufficiently deep to prevent salinization caused by capillary rise of saline groundwater. Composite systems are also recommended in sloping areas where i) soil erosion must be controlled and/ or drainage problems occur in depressions, ii) areas where the land is very valuable, iii) where subsoils are unstable leading to bank collapse of open drains. In some areas, especially where the maintenance or availability of deep open drains is difficult, groups of pipe collector drains discharge into tanks (sumps) from where the water is pumped into a shallow main outlet system (where the external water level is above the field groundwater level). This is the case for arable crops and mango orchards in some parts of the Lower Indus Plain, Pakistan, and in some areas of the Ebro Delta, Spain, where horticultural crops are grown. In the latter case, subsurface drainage systems have been installed to control the saline groundwater table.

Controlled drainage is sometimes used to slow drainage during dry periods and increasingly to control water requirements of rice in rotation with dry-foot crops. The level of water tables are thus controlled at by technical means, such as temporary plugs in subsurface drainage systems, raising seasonally the open drain water levels, or rising lateral/collector pipe outlets. Thus, a certain amount of water is saved from flowing away during droughts, or when fields are flooded during a rice crop. In Egypt, during rice cultivation in otherwise dry-foot crop cultivated land, such plugs are used to close the orifice in the bottom part of a specially constructed overflow wall inside inspection maintenance hatches of composite drainage systems. Water tables can also be controlled by sub-irrigation where water from outside sources flows into the drain if the outside water level in the whole area is kept high for a considerable period. Apart from these uses, it is effective for preventing clogging with iron compounds and the outflow of nitrates from the drainage system may be reduced by denitrification. However, great care should be taken with such systems in arid areas subject to salinization.

Although no physical restrictions exist in relation to the length of subsurface field drains, it is usually governed by size of the agricultural fields and the drain maintenance requirements. In composite systems, the same applies to the length of collectors. Where cleaning is required, the maximum length of pipes is usually limited by the maximum length of the cleaning equipment (<300 m). Where sufficient slope exists and no constraints due to field dimensions, extended systems can be designed. However, they still require suitable access at about every 300 m for cleaning devices. As longer drains require larger diameter pipes, maintenance hatches should be installed to facilitate the connection between pipes of different diameters, as well as for inspection and cleaning, notably in the case of collector drains. Accessible junction boxes should be placed at the junctions between laterals and collectors.

8.4 Structural Elements

Where the position and hydraulic characteristics of the outlet are known, the following need to be considered in the layout and design of the various structures of the main drainage system:

- channels and ditches require inspection and maintenance facilities alongside (tracks, agreements with adjacent land users / landowners)
- bridges and aqueducts
- culverts and siphons
- weirs and drop structures
- sluices, gates and main pumping stations at the outlet, or any intermediate pumping stations may be considered to belong to this category because they form part of the outlet works
- Erosion prevention structures at points where surface runoff collects or field drainage systems are connected with the open channels of the main system.

8.4.1 Layout

The projected main drainage system usually has a branching-tree configuration in which drainage water has only one way to reach the outlet. However, more complicated network structures are sometimes found, usually remnants from former natural drainage systems. The network depends greatly on the size of the area, its topography, the existing watercourses and the form of its borders. In a system composed of buried field drains, collector pipe drains, ditches and larger waterways, the length of each successive order determines the distances of the next. Thus, the distances of the first open channels (usually ditches) depend on the lengths spanned by the subsurface drainage system. There is a tendency to replace the first open ditches with buried pipes, thus reducing the density of open waterways and consequently saving on maintenance (a costly operation). Another element for the choice of layout is the future maintenance of the main system and its organization. The smaller elements can be maintained usually by hand by farmer or local farmer groups. The larger elements can be maintained mechanically by the overall organization in which the stakeholders participate and can have indirect influence (see sections 12.2 & 13). Within the project area, there may be protected natural reserves. These should be left untouched by the main drainage elements with the channels keep sufficiently far from these areas to avoid any influence.

Opportunities for improving ecological values sometimes exist in important areas not protected as reserves. Some special drainage with water table management may improve the habitat or ecological values considerably. These potential options should be discussed with stakeholders. Villages and towns and agriculture-based industrial zones in the project area are best provided with a dedicated connection to the public main drainage system, to facilitate controlled disposal of polluted water and minimize the risk of improper reuse. Where possible, such urban waters should be treated. The location of the drainage channel network depends on the topography. In undulating terrain, the watercourses follow the valleys and, thus, the pattern is irregular. However, in flat land, a rectangular layout is usually designed, with exceptions due to the shape of the project boundary and natural watercourses, or slight differences in elevation. Existing waterways are often enlarged and sometimes replaced by a new and wider spaced network of larger channels. These should follow the natural drainage paths where possible.

8.4.2 Channels and ditches

Open waterways or channels form the principal part of a system that conveys the outflow from the fields to the outlet. Two types of layout exist: a tree structure, where this path is fully determined (e.g. from ditch via a small watercourse into an ever larger one, until the outlet is reached); a network structure in which more than one route is available and where the path depends on the local gradients. Special calculation methods for flows through networks are available, but they are complicated. In most projects, the tree structure is chosen with its straightforward method of calculation. The cross-section of open channels (Figure 8.6) is usually trapezoidal with intermittent berms for larger channels.

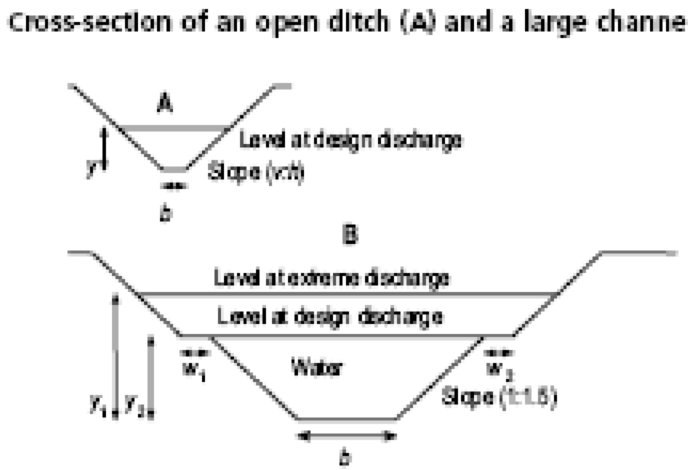


Figure 8.6 Cross-section of Open Channel

Side slopes (ratio of vertical to horizontal (v:h)) depend mostly on soil type:

- Steep slopes reduce excavation costs and occupy less agricultural land but can result in bank failures if due consideration is not given to soil stability.
- Local experience is the best guide for safe channel side slopes.
- Any slope failures usually occur shortly after construction – later, the bank vegetation has a stabilizing effect.
- Vegetation (especially submerged plants) obstruct water flow and regular maintenance is required with woody vegetation removed from banks.

- Lateral groundwater seepage promotes slumping of channel banks and allowance must be provided where high seepage rates are anticipated. Flatter slopes are required in these cases or artificial bank protection such as the use of geotextiles.
- Trapezoidal profiles are designed and built but develop in time into parabolic forms, often with steeper slopes above normal water level.

The calculation of the expected flow rates for dimensioning channels is based on Manning's formula, and thus the ratio of water depth (v:h) to bottom width (y:b) needs to be kept within certain limits. Where flow rates are high, milder gradients should be adopted and/or a different y:b ratio. As with open canals, flow velocities must be limited to avoid erosion in watercourses but they must also avoid meandering at low flows. Both can be achieved by either placing weirs as control sections at appropriate points or by limiting the bottom width of the channel. Parabolic drain sections or small base flow sections in the drains are also successfully in some cases. Whatever is chosen, it is important that the bed widths of the channels are compatible with the machinery that will construct and clean them and minimum standard bed widths of 0.50 m are indicated.

Attention needs to be given at outflow points from field drainage systems into open waterways. Adequate "drop in" allowances are needed so that free outflow is maintained, but that erosion is avoided. Where larger flows are involved, head loss structures are required. Depth of water in the channels is important, for if a minimum depth can be maintained, it will act as an energy dissipater at the drop in points. However, stagnant water encourages weed growth and vectors and the growth of vegetation in the channels will encourage silt deposits. Larger water depths (>1 m) hamper the growth of reeds, although submerged and floating plant species may still thrive. Where channels can dry up for certain periods, this can again reduce weed growth. However, experience has shown that at periods when this happens, optimum growing conditions for weeds occur that utilise residual available moisture in the banks and beds of drains.

Although these measures assist in reducing maintenance needs, they cannot be avoided. Designs must therefore aim to reduce the amount needed and facilitate annual maintenance by both WUA groups and project organisations. Special equipment is available for mechanical cleaning (desilting and de-weeding) and the requirements for the use of this machinery must be taken into account when designing the systems.

8.4.3 Bridges and aqueducts

Where roads and railways cross main waterways, bridges are needed. Irrigation canals usually cross by means of aqueducts. Those that leave the cross-section of the waterway intact have no influence upon the flow in the channel. However, if they are narrower, notably in flat areas, special formulae for flow through openings are used to limit backwater effects. Erosion of the channel under the bridge should then be avoided by not allowing high flow velocities. Piers provide restriction to flow and allow accumulation of debris and should be avoided or minimised.

8.4.4 Culverts

Culverts provide useful crossing structures for small drains under farm roads and tracks (Q< 0.5 m^3/s). Calculations for culverts are based on the hydraulics of flow through openings and friction in pipes. Culverts are usually over dimensioned because they are less able to cope with extraordinary large discharges, and to avoid floating debris that may clog them. For larger crossings and channels, multiple pipe culverts can be used for flows up to 1 m^3/s. The diameter depends on flow and slope but a minimum diameter of 0.3 m is recommended, to avoid blocking by weeds and debris and to facilitate cleaning. Where the flow is higher, large-diameter pipes, box-type culverts or bridges using simply supported slabs resting on pillars at each bank provide the best solutions. Whatever structure is chosen, it is essential that flow cross sections are not easily blocked and that they are self cleaning where possible. Although drains are planned for regular inspection, this rarely happens in practice due to poor access and vegetative growth.

8.4.5 Weirs and drop structures

Weirs are used to separate different water levels that would otherwise lead to deep excavations upstream, or to an excessive flow velocity and erosion. They can be adjustable or have a fixed crest level. This crest can be sharp or broad, in which case a different coefficient is used for design. There are various kinds of weir, belonging to two groups:

- Fixed weirs. These are the simplest type, but their width may not be ample enough to handle heavy discharges. In this case, "long nose" ("duck bill") weirs may be a solution.
- Movable weirs. These are of different types varying from planks or stop logs resting in grove side-walls to self-adjusting valves acting on upstream water levels or forming part of a remotely controlled system.

Drop structures are used in sloping lands where the bottom gradient must be smaller than the ground slope to prevent erosion. They are necessary to maintain the permissible flow velocity and to dissipate excess head. Where the energy drop exceeds 1.5 m, inclined drops or chutes should be constructed; and where it is less, straight drop structures are preferred. For further information on structural designs, the following Chapter 9 should be consulted.

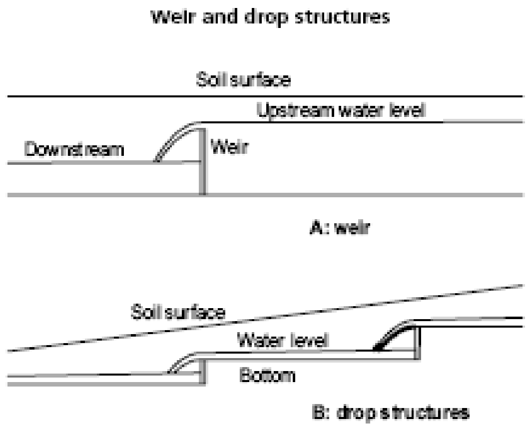


Figure 8.7 Typical Drop Arrangements

8.5 Salinity

Soil salinity control is a key environmental factor for land development and the requirements to ensure adequate leaching to avoid salinity build up were discussed in Section 5.9. Where reuse of drainage water is considered, crop tolerances need to be taken into account (Table 8.2).

Table 8.2 Relative crop salinity tolerance rating for use in irrigation

Relative crop salinity tolerance rating	Soil salinity (ECe) at which yield loss begins
Sensitive	< 1.3 ds/m
Moderately sensitive	1.3 – 3.0 ds/m
Moderately tolerant	3.0 – 6.0 ds/m
Tolerant	6.0 – 10.0 ds/m
Unsuitable for most crops (unless reduced yield is acceptable)	> 10.0 ds/m

If there are few crops in an area, it may be desirable to prepare separate guidelines for each specific crop or group of crops rather than use the broad guidelines given above. Such guidelines can be more specific and are better aids to managers and cultivators for evaluating the suitability of the available water supply.

Key Reference: *FAO. 1994. Irrigation and Drainage Paper 29 Rev. 1. Water quality for Agriculture. R.S. Ayers; D.W.Westcot.*

This document is very useful and provides details on various tolerance levels for different salts by crop.

8.5.1 Drainage water reuse

In the tail ends and fringes of an increasing number of irrigated areas in arid and semi-arid regions, where freshwater supplies are also required for other socio-economic developments, medium-quality water from open drainage channels can potentially be used for irrigation. In many places, drainage water is necessarily used for irrigation, either directly or after mixing with irrigation water of better quality, in order to compensate for decreasing freshwater flows. The suitability of drainage waters for reuse depends greatly on the salts and pollutants carried by the water, on the crops to be grown and on irrigation practices (see Table 8.7 and FAO. 1994). Waters with a low salinity can be reused for irrigation by pumping directly from the open drains. Where N compounds are present, they can be beneficial for crops as they form a valuable nutrient input resource and can reduce artificial fertilizer requirements. However, excess nitrates prevent the reuse for drinking-water for humans or livestock. This occurs where water is polluted with agrochemicals such as pesticides and/or raw sewage water and process water spills of urban and industrial areas.

Another option where water supplies are inadequate and freshwater and drainage water are available, is to use freshwater in periods when crops are salt sensitive, and the more saline drainage water when they are tolerant. It is imperative to keep salinity in the seed bed low at early stages of plant growth, as plants are relatively sensitive during germination and emergence. Crops become more tolerant during later stages of growth.. However, problems of soil structure stability can occur if freshwater is applied after irrigation with drainage water with high sodium content. The cycling option requires special infrastructure and considerable public water management efforts in order to realize it on a practical scale. As the drainage water quality is reduced owing to increased salinity, more salt tolerant crops must be used. FAO (2002b). To verify whether water of a certain salinity can be used safely for a particular crop, an annual salt balance can be made to check that the salt in the soil profile does not accumulate or rise periodically above the acceptable salt level chosen for the crop.

Saline (not polluted) drainage waters can also be used to:

- irrigate halophytes where a proper system for salinity control is provided
- maintain water levels in commercial fish ponds
- temporarily secure minimum water levels in environmentally valuable brackish coastal lakes
- provide leaching for reclamation of salt-affected soils during the initial stage of the reclamation process.

Large volumes of drainage water, which are not suitable for the irrigation of dry foot crops, may be used successfully for continuous refreshment of the standing water layer of rice grown on non-subsurface drained clay soils in the tail ends of the irrigation system of the Nile Delta, Egypt. Rice yields on lands with topsoil salinity in the growing season of 3–5 dS/m, increased by about 1 tonne/ha if frequent flushing of the standing water layer decreased the average salinity of the standing water layer with 1 dS/m (Egyptian–Dutch Panel for Land Drainage, 1977–79).

Reuse of drainage water inside a project area reduces the volume to be disposed of, but tends to concentrate salinity and pollutants, although the total load of discharged pollutants may be slightly reduced. Ultimately, disposal of this reduced volume of drainage water outside the project area is inevitable. In the case of domestic or industrial wastewater polluting agricultural drainage water, degradable and notably persistent organic pollution is a major problem and water treatment is needed in order to achieve safe reuse. For irrigation of crops not used for direct consumption, treated wastewater can be used directly. For this purpose, treatment by conveying the water through constructed wetlands with reeds or rushes, or through stabilization ponds, is often sufficient. However, for most other purposes, especially for irrigation of vegetables, more sophisticated methods of treatment are required. This subject has been covered by FAO (1992a and 1997) and more details can be found in FAO (1985, 2002b) and FAO/ ICID (1997).

8.5.2 Disposal of drainage waters

In many development schemes, drainage water is disposed back into a natural river system directly or via wetlands. In this case, the drainage water discharged from the project area is part of the water resource supply for downstream water users and will form a potential source of pollution of the river downstream of the discharge point. A drainage outlet into a river alters its outflow regime (especially in small rivers). Salinity may affect downstream interests and plant nutrients or pollutants may also exert their influence on ecosystems. Attention must be given to changes in river morphology caused by erosion and siltation. Large-scale constructions are sometimes undertaken in order to avoid pollution of a river with drainage outflow from very large projects (e.g. Right Bank and Left Bank Outflow Drain, Indus Plain, Pakistan) or urban and industrial developments (Bahr el Baqr Main Drain, Nile Delta, Egypt). Most rivers flood whether seasonally or irregularly. Peaks are often of a shorter duration, but will still cause back flows into the drainage systems if outlets are left open or reverse flow restrictions are not provided. Where outlets are protected by a sluice or flap gate, the normal upstream discharge may have the same effect. For simple cases, a computer program may provide some indication about these backwater effects. One solution is an extended outlet channel with an outlet further downstream. In other cases, a pumping station is preferred. Much depends on the local circumstances, especially on the river gradient and the duration of high water levels blocking the drainage outflow.

Evaporation ponds are sometimes used in arid climates for disposal of saline water in inland drainage projects where no other possibilities exist. Natural depressions are sometimes used, but artificial ponds are frequently constructed. Where possible, a number of cascading ponds are used to maintain a constant water level to achieve suitable environments for water birds. To design such evaporation ponds, the composition of the inflowing drainage water needs to be known and the impact on a planned inundated area must be calculated on the basis of the water balance needed to control the salt concentration in the pond. In this way, part of the cascading ponds can eventually be used to store water temporarily for reuse during dry periods.

8.5.3 Life expectancy of drainage systems

The economic life of a land drainage system is an important factor in the economic evaluation and for large drainage schemes built predominately for salinity control, a 100- year life expectancy is planned. Drainage systems in tropical and humid areas are built with a shorter economic life (25–30 years) that reflects the lower investment of primarily surface drainage systems. The anticipated actual technical life of a well-maintained pipe drainage system is usually 50–100 years. However, the economic life of a project is more a consideration of the time at which a project will be renewed. The value of a project is greatest soon after construction and reduces steadily with time until the end of the economic life. The terminal value is generally considered zero. A project could have an economic life that coincides with its actual or expected design life, but future costs that occur after about 15 years are insignificant in economic terms. Thus, the economic life is generally taken to be 20–30 years.

8.5.4 Cost recovery

Cost recovery considerations regarding investments in new drainage systems should not always be thought of in the same manner as for irrigation system installation. Major drainage facilities for a project area are normally considered a public good. This is because they benefit entire communities or regions and normally provide secondary jobs, resulting in poverty reduction in areas much larger than the actual project areas. Investment costs of public drainage facilities that protect numerous landholdings, infrastructure and housing provide a public good not only controlling salinization and waterlogging but also flooding. Main drains are considered to provide a regional benefit similar to public works such as roads, bridges, utilities and other infrastructure that provide incidental protection and secondary benefits. However, recurrent O&M costs of the public drainage system should be recovered as much as possible and in accordance with the level of benefit that accrues to individual project stakeholders.

Drainage facilities on private land and facilities for small groups of farmers are usually considered as private investments. The costs for constructing, operating and maintaining these smaller facilities should be recovered from the direct beneficiaries. The larger collector drains that serve much larger areas should not be included. In areas with mature drainage systems that need to be repaired or rehabilitated, organizations of drainage boards or drainage districts become common. Drainage improvements in these areas are normally carried out using the normal cost-recovery procedures used for local irrigation project areas. Thus, the beneficiaries pay for improvements to their own systems and even the larger civil works that involve numerous landholdings and provide some incidental public good. In irrigated areas, where the irrigation district is normally the user organization responsible for drainage facilities, cost recovery is carried out for the drainage work and assessments are made for the beneficiaries that benefit directly.

8.5.5 Operation and maintenance costs

Annual O&M costs must be planned prior to construction and discussed in detail with the users to ensure that affordable costs derive (see Section 13.4 for more details). Planning and design should not be restricted to defining the technology of the systems. System designs and institutional design of O&M arrangements should be fully compatible. An organization with the authority to perform the O&M when it is needed with the financial capacity to carry the involved costs and with the skills necessary to recognize the needs, should be in place when the construction is complete. The earlier this organization is established, the greater the chance for it to become fully familiar with construction requirements and the impact on O&M.

8.6 Other References

Burt, C.M.; Isabell, Brett; Burt, Lisa. 2003. Long-Term Salinity Build up on Drip/Micro Irrigated Trees in California. Paper presented at the IA Technical Conference in San Diego, California.

FAO. 1980. Drainage design factors. FAO Irrigation and Drainage Paper No. 38. Rome. 52 pp.

FAO 1999. Soil salinity assessment. Irrigation and Drainage Paper 57. J.D.Rhoades, F. Chanduvi, S. Lesch.. Rome.
The technology described in this report for measuring soil salinity has been extensively and successfully field-tested. It is concluded to be sound, reliable, accurate and applicable to a wide variety of useful applications. It is

based on proven theory of soil electrical conductivity. The required equipment is commercially available. The advocated instrumental methodology is practical, cost effective and well developed for essentially all general applications. It is cheaper, faster and more informative than traditional methods of salinity measurement based on soil sampling and laboratory analyses.

FAO. 2002. Agricultural drainage water management in arid and semi-arid areas. Irrigation and Drainage Paper 61. Kenneth K. Tanji, Neeltje C. Kielen. Rome.
Irrigated agriculture has made a significant contribution towards world food security. However, water resources for agriculture are often overused and misused. The result has been large-scale waterlogging and salinity. In addition, downstream users have found themselves deprived of sufficient water, and there has been much pollution of freshwater resources with contaminated irrigation return flows and deep percolation losses. Irrigated agriculture needs to expand in order to produce sufficient food for the world's growing population. The productivity of water use in agriculture needs to increase in order both to avoid exacerbating the water crisis and to prevent considerable food shortages. As irrigated agriculture requires drainage, a major challenge is to manage agricultural drainage water in a sustainable manner. This publication consists of two parts. Part I deals with the underlying concepts relating to drainage water management. It discusses the adequate identification and definition of the problem for the selection and application of a combination of management options. It then presents technical considerations and details on the four groups of drainage management options. Part II contains the summaries of the case studies from the United States of America, Central Asia, Egypt, India and Pakistan. These case studies represent a cross-section of approaches to agricultural drainage water management. The factors affecting drainage water management include geomorphology, hydrology, climate conditions and the socio-economic and institutional environment.

FAO. 2003. Data Sets, Indicators and Methods to Assess Land Degradation in Drylands. Report of the LADA e-mail Conference 9 October _ 4 November 2002. FAO. Rome.
The LADA E-mail conference responded to several of LADA's objectives by providing a forum to: exchange ideas on potential land degradation indicators and integrated methods; disseminate documents reviewing data and information on land degradation in drylands; and initiate the development of a network among national, regional and international teams involved and interested in land degradation assessment of drylands. Specific goals of the E-mail conference were to raise awareness on LADA, exchange expert views on land degradation assessment, and start identifying at relevant scales.

FAO. 2005a. Materials for subsurface land drainage systems. Irrigation and Drainage Paper 60 Rev 1. L.C.P.M. Stuyt, W. Dierickx, J. Martínez Beltrán. Rome.
Reliable subsurface drainage systems for groundwater table and salinity control are needed to maintain or enhance the productivity of irrigated lands and to contribute to the rural development of lowlands in the humid tropics. In addition, they continue to be important as a means of groundwater table control in some areas of the temperate zones. The selection of appropriate materials (i.e. pipes and envelopes) and their adequate installation and maintenance are essential for the proper and lasting performance of subsurface drainage systems. This was acknowledged in FAO Irrigation and Drainage Paper 9, Drainage Materials, published in 1972. At that time, the expertise concerning drainage materials came mainly from projects located in the temperate zones of northwestern Europe and the United States. Since then, valuable experience has also been gained in tropical countries that may be useful and, as such, should be made available to the professional communities.

FAO. 2005b. Drought-resistant soils. Optimization of soil moisture for sustainable plant production. FAO Land and Water Bulletin No. 11. Proceedings of the electronic conference. FAO. Rome.
The present volume contains: an analytical summary of the conference discussions; the abstracts of papers submitted during the conference; and the discussion papers prepared to introduce the different topics. In keeping with the electronic character of the workshop, the complete materials are included on the CD-ROM that accompanies this document. It is hoped that the wealth of information supplied here will shed some light on the issues surrounding the optimization of soil moisture management.

FAO. 2007. Land evaluation, Towards a revised framework. Land and Water Discussion Paper No. 6. Rome, 2007
As the purpose and scope of land evaluations shifted to a wider range of concerns, it is now felt necessary to include additional concepts, definitions, principles and procedures in the Framework so as to address them more systematically. In particular, the new concerns about the sustainability of land use should be addressed and their implications fully examined. The requirements for the protection of the environment, the economic viability of

the land use over a longer term and the social acceptability of land use conditions necessitate more complex studies of the land resources, of the land uses, of their interactions and of their environment. Above all, they call for the involvement, not only of more specialists and of all the land users, actual or potential, but also of all the other stakeholders in the land use, and this in the whole process of land evaluation.

International Institute of Land Reclamation and Improvement 1972-74. Drainage principles and applications. Vol. I-IV. Wageningen, The Netherlands.

IPTRID. 2001. Drainage and sustainability. Issues Paper No. 3. FAO. Rome.
The purpose of this paper is to promote recognition of the crucial contribution that land drainage can make towards sustainable agriculture by reducing the negative effects of human activities on the environment and improving rural health conditions, and to emphasize the need for higher investment in land drainage projects. It aims to provide a logical argument for ensuring that drainage is considered in plans for new agricultural development projects or rehabilitation of existing projects. The long-term sustainability of many agricultural projects is threatened by neglect of land degradation that may occur after some years of cultivation and that could be wholly or partly compensated for by drainage. With regard to the environment, drainage must be seen as contributing to equilibrium between productive agriculture and nature conservation. Drainage plays an important role in improving the health and well-being of the rural population by reducing the incidence of water-borne diseases.

Smedema, L.K. & Rycroft, D.W. 1988. Land drainage: planning and design of agricultural drainage systems. London, B.T. Batsford Ltd.

Smedema & Rycroft, 1993. Land Drainage. Cornell U. Press,

Skaggs, R.W.; Van Schilfgaarde J. (eds.). 1999. Agricultural Drainage. Agronomy No. 38, ASA CSSA SSSA, Madison Wisconsin.

U.S. Dept. of Interior. 1993. Drainage manual. 2nd Edition. Denver, CO, USA.

.9 Hydraulic Structures

Small structures used at the farm level in fields and in networks with small discharges at the intakes, having capacities of less than 1 m^3/sec, account for more than 70% of all hydraulic structures installed in many irrigation networks. These small structures have not always received the attention they deserve from planners and designers. Irrigation headworks and other irrigation engineering works would have little value without an efficient distribution system (requiring small structures) extending right down to the farmers' fields. This Chapter discusses the main types of structures involved in CBSSI. It is not exhaustive, but provides an overview and links to other publications to enable the designers to provide good and user friendly designs for what often comprises the largest investments in the irrigation and drainage systems. Many of the Nile Basin countries already have detailed design manuals covering all types of structure and CD ROM #3 should be consulted further as much useful material is provided on the disk.

9.1 River diversions

River diversions are normally designed for a 25 year operational life span, but operate for much shorter periods, as diversion weirs have been silted up or damaged by seasonal peak floods requiring major rehabilitation works even within ten years of operation. Lack of, or inadequate watershed rehabilitation, inadequate community skill training during the construction phase, poor scheme management and design errors are the major causes for the reduced lifetime of irrigation structures. Where rivers are heavily silted during the rainy season, watershed rehabilitation work should precede the construction of irrigation schemes. A more community-based approach (see Section 12) will assure close involvement of community members during the planning and construction phase, and facilitate on-the-job-training of local masons. This enables communities to carry out timely repairs to damage to intake structures and water distribution systems. Repair of major damages on structures requires experts and external materials. The possibility of insurance coverage (engineering insurance) for damage on structures caused by design errors should be considered. This is more likely to be possible in schemes that have been constructed by private contractors. Premature damage occurring on structures that have been built by the public sector need to be referred to a regional or central Civil Engineering Authority/Committee.

9.2 Types of Structures

Hydraulic structures are provided to control and measure discharge, control water levels for command requirements, divide flows between different canals, dissipate unwanted energy, pass drainage and runoff water through access roads, canals and other scheme infrastructure, deliver the right volume of water to meet crop water requirements, incorporate recycled tail water, if available.

The most common structures are:

- Headworks for river water offtake
- Night storage reservoirs
- Head regulators
- Cross regulators
- Drop structures
- Tail-end structures
- Canal outlets
- Discharge measurement structures
- Crossings, like bridges, culverts, inverted siphons

These structures are discussed briefly below. It is important that the designed understands basic hydraulic design and it is assumed that the designer has either civil or irrigation/agricultural engineering basic training. The basics of hydraulics are thus not repeated in this report.

9.3 Headworks and Appurtenant Structures

The function of a headwork is to divert the required amount of water at the correct head from the source into the conveyance system. It consists of one or more of the following

- Offtake at the side of the river
- Regulating structure across the river or part of it
- Sediment flushing arrangement

This section does not include storage dams as these are dealt with in the Water Harvesting Volume (**Part II_Guidelines in WH_Final.doc**). This report concentrates on headworks for direct river offtake and offtakes using a weir.

9.3.1 Diversion Weirs

A diversion weir should be located in a stable part of the river where it is unlikely to change its course. The weir should be built high enough to fulfil command requirements and not to be over topped during flood flows. A location with firm, well defined banks is required and bank protection works will also be needed. Where possible, the site should have good foundation conditions, such as rock outcrops. In any case, the structure will need to be designed by an experienced engineer to ensure that seepage and stability calculations are correctly calculated in addition to the hydraulic calculations. To reduce costs, the crest of the weir should be kept as low as possible.

Water levels of rivers vary considerably from high floods during relatively short rainy season to low stages during the much longer dry season. Diversion weirs thus need to be designed for wide variations in river stage to resist high flood flows, but also to provide sufficient head to ensure adequate irrigation of all of the planned command area. Such structures often account for over 50% of the total construction cost of an irrigation system.

The weir crest is determined in relation to the design water level in the conveyance canal. The weir length is designed to pass the design flood over the weir with an adequate freeboard. The design flood is obtained through analysis of streamflow data, using the assistance of a hydrologist to determine the maximum discharge in relation to the probability of occurrence. The return period will relate to the reliability of flow data, the cost of the structure and the impact on the scheme if it should fail. If sufficient data are not available, flood marks should be checked and local knowledge obtained from people living near to the proposed weir site. Combining these data with longitudinal slope of the river enables an estimate of the maximum flood flows to be obtained to cross check with those estimates obtained from the streamflow data.

Discharge over the weir can be obtained form the general weir formula:

$$\mathbf{Q = C1 \times C2 \times B \times H^{3/2}}$$

Where:

Q	=	Discharge (m^3/sec)
C_1	=	Coefficient related to condition of submergence and crest shape (Figure 9.1)
C_2	=	Coefficient related to crest shape (Figure 9.2)
B	=	Weir length, (m)
H	=	Head over the weir crest (m)

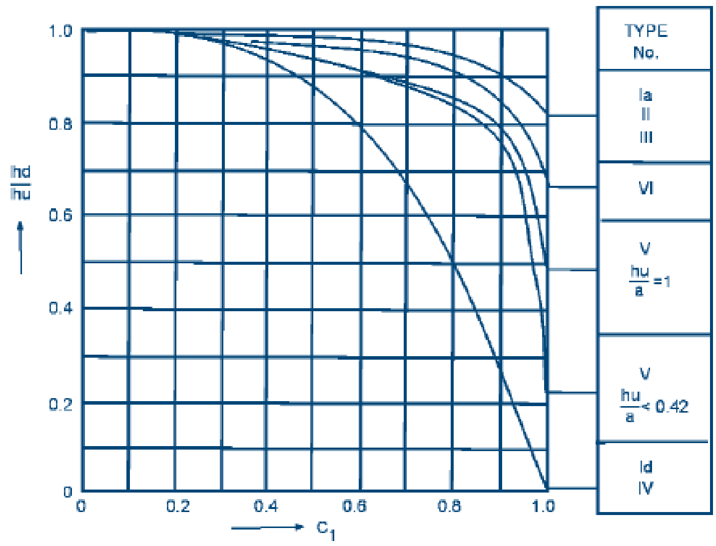
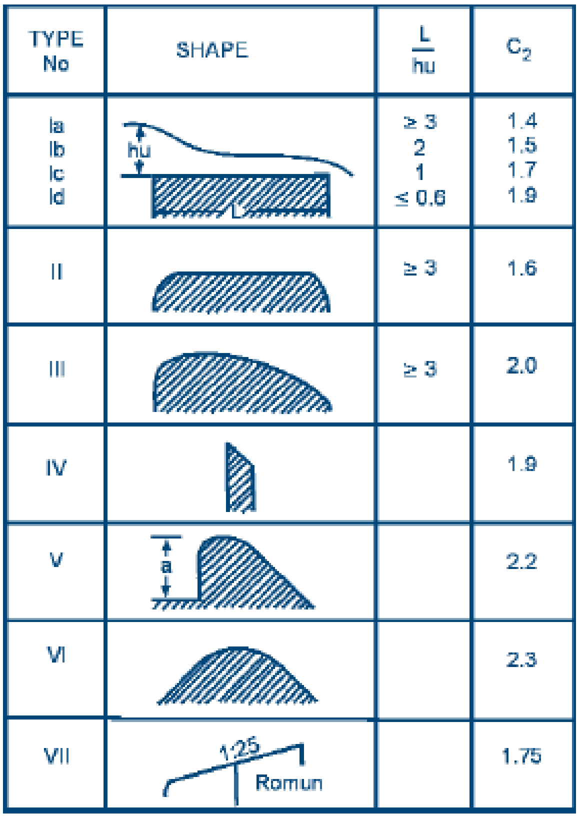


Figure 9.1 C1 coefficient for different types of weirs based on crest shape



TYPE No	SHAPE	L/hu	C_2
Ia Ib Ic Id	hu, L	≥ 3 2 1 ≤ 0.6	1.4 1.5 1.7 1.9
II		≥ 3	1.6
III		≥ 3	2.0
IV			1.9
V	a		2.2
VI			2.3
VII	1:25 Romun		1.75

Figure 9.2 C2 coefficient for different types of weirs based on crest shape

Gabions are used for the design of weirs in many cases, and are good low cost solutions provided that suitable material are available for filling the gabion baskets and that the river or stream water does not contain excessive amounts of silt. There are good detailed design guidelines and manuals available for the design of such weirs produced by the suppliers of the gabions and available on the internet. These should be consulted for further information. Useful reference: http://www.maccaferri.co.uk/index.html.

For all weirs it is essential that the stilling basin is correctly designed using empirical formulae. The failure to provide adequate stilling area to dissipate energy is the cause of failure of many structures. Apron floors should have sufficient thickness to counterbalance the uplift hydrostatic pressure and should be long enough to prevent piping action. By applying Lane's weighted-creep theory, which is an empirical, but simple and proven method, the length can be determined.

Key Reference: *Part 6, Manual for Senior Staff on gravity irrigation schemes operated by farmers, December 1986, Republic of Kenya, AED/Irrigation and Drainage Branch, Ministry of Agriculture..*

Part 1	:	Structures to prevent excess flow in canals
Part 2	:	Concrete and Concrete Products
Part 3	:	Culverts
Part 4	:	Drop/Check Structures
Part 5	:	Division Structures
Part 6	:	Weir Design
Part 7	:	Surveying with a Level Instrument

9.4 Night storage reservoirs

Night storage reservoirs (NSR) store water during times when there is abstraction from the headwork but no irrigation. Depending on the size of the scheme, this can involve the construction of a reservoir located at the top of the scheme at the head of the main canal, or more than one reservoir at the head of secondary canals to command sections of the scheme they are serving. Night storage reservoirs could be incorporated in the design of a scheme when (i) the distance from the water source to the field is very long, resulting in a long time lag between releasing water from the source and receiving it in the field (ii) when the main canal is relatively steep and long and thus water and time can be lost when irrigation finishes and irrigation starts again (iii) the costs of constructing the conveyance canal (or pipeline) are very high due to distance and discharge (iv) the discharge of the source of the water is smaller than would be required for the area without storing the water during times of no irrigation. The need and suitability for a night storage reservoir should be carefully considered examining cost saving in water delivery works against cost of reservoirs, maintenance, seepage, evaporation losses, disease vector control and also the higher levels of management that such a system requires.

9.5 Head regulators

Head regulators comprise of the main offtake structures to the irrigation system. They are located on the river or stream at the entrance to the main canal or at the head of branch and secondary canals. They are designed to pass the computed peak discharge into the canal (or pipeline) and to prevent excessive water from entering during floods. Easy to operate control arrangements are important and these may include radial or vertical lift gates, stop logs or a combination of the two. For smaller canals, orifice intakes are used to throttle high floods to prevent entry. All structures need to be designed so that if a gate is left open, the flow that can enter the canal does not exceed the downstream capacity with the structure operating as a submerged orifice in this case. The main offtake structure will be designed as a weir:

$$\mathbf{Q = C \times B\,(h + hd)^{3/2}}$$

Where:

Q	=	Discharge in intake (m^3/sec)
C	=	Weir coefficient
B	=	Width of the intake (m)
h	=	Difference between upstream and downstream water levels (m)
hd	=	Difference between d/s water level and intake sill level (m)

Sites for offtakes need to ensure that they can divert water to the intake in the required amounts throughout the year, including times of base flow in the river or stream. In these cases, the offtake may need to be sited some distance upstream. Site conditions such as the increased length of the conveyance canal, land ownership, access to the site for construction and subsequent O&M will all need to be considered. Where river sections are wide, it may be necessary to construct a permanent weir downstream of the proposed intake site to ensure that sufficient water can enter the offtake (see 9.3.1 above).

Head regulators are also used to measure flow into the system or parts of the system and this must be taken into account when designing the structure. In many cases, a separate weir structure is located downstream from the head regulator to measure the flows as this provides more accurate measurement than is possible through gates or orifice controls. The Replogle Weir (see Section 11.3) is a very suitable structure for measuring as it has minimal head loss across the structure and therefore can be used even where available command is a constraint. Orifices, such as gates and short pipes, provide restrictions to the incursion of excessive flood flows with the discharge being proportional to the head of water above the crest raised to the power 1/2. As such they are less sensitive to small fluctuations of the upstream water level. Under submerged conditions both the upstream and downstream water depths need to be considered. Under free flow conditions, the discharge is a function of the upstream water depth alone.

$$\mathbf{Q = C \times A \times \sqrt{2gh}}$$

Where:

Q	=	Discharge (m^3 /sec)
C	=	Discharge coefficient, approximately 0.5
A	=	Cross-sectional area of opening (m^2)
g	=	Gravitational force (9.81 m/sec^2)
h	=	Available head (m)

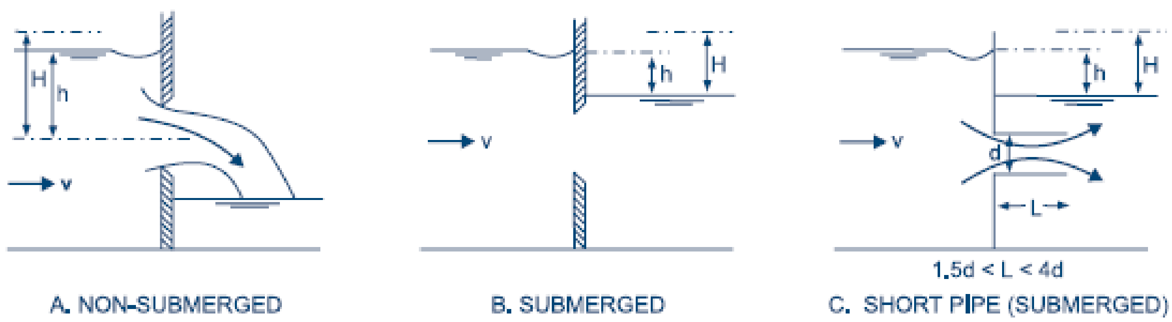


Figure 9.3 Examples of orifice Flow

9.6 Cross Regulators and Division Structures

A division structure (made from in-situ concrete, pre-cast concrete, masonry and in a very simple form from timber) regulates the flow from one canal into one or more other canals. It consists of a box with vertical walls in which controllable openings are provided. The minimum dimensions of the structure depend on its performance in the fully open position. The width of each outlet is usually proportional to the division of water flow to be made. Structures are placed to provide a minimum resistance to flow and where backwater effects that would result in overtopping of the upstream canal are avoided. More care is needed in the case of lined canals due to the higher velocities of flow. Sudden gate closures should be avoided but the structure and associated canal banks and works need to be designed for this eventuality.

A cross regulator structure is built across the canal to maintain the water level at the command level required to irrigate the fields. They can comprise of simple structures with timber stop logs, check plates, weirs or expensive automatic structures that provide constant water levels either upstream or downstream. Common weirs comprise duckbill and diagonal weirs that control the water level at a given height, (Figure 9.4 and 9.5).

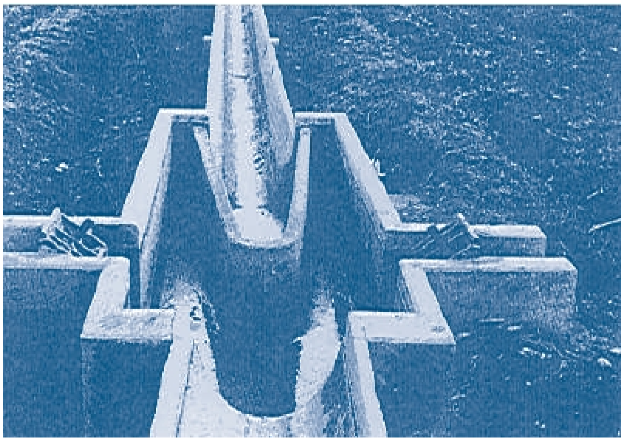
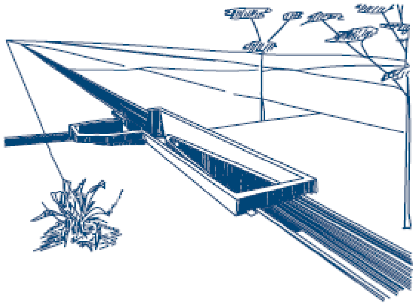


Figure 9.4 Duckbill weir

Basic characteristics

Canal capacity upstream of weir l/s	Dimensions in cm					
	a	b	c	d	e	f
110	7	150	300	13	10	0,08
160	7	220	370	12	9	0,08
210	7	290	440	12	9	0,10
270	8	310	460	11	9	0,10
320	8	370	520	11	9	0,12
370	8	430	580	11	9	0,12



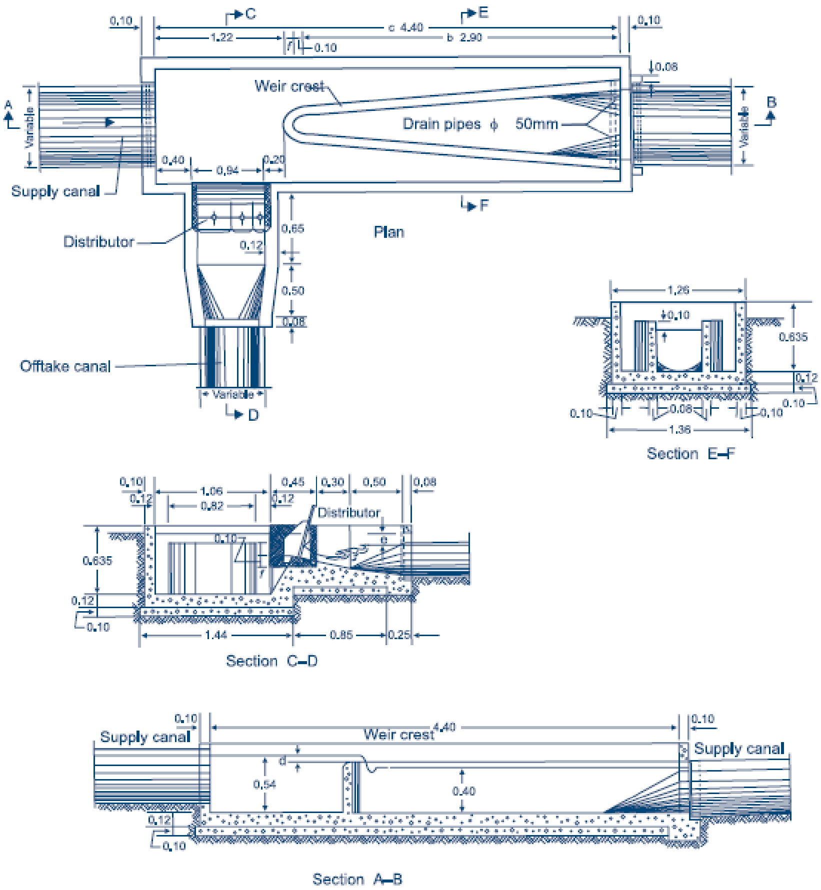


Figure 9.5 Design of Duckbill weir

9.7 Drop structures and tail-end structures

Drop structures and chutes are flow control structures that are installed in canals when the natural land slope is too steep, compared to the design canal gradient to convey water down steep slopes without erosive velocities. If a canal were allowed to follow a steep natural gradient, the velocities would be too high. This in turn would cause erosion and make water management difficult. For this, the canal is divided into different reaches over its length. Each reach follows the design canal gradient. When the bottom level of the canal becomes too high compared to the natural ground level, drop structures are installed. Vertical drops are normally used for the dissipation of up to 1 m head for unlined canals and up to 2 m head for lined canals. For larger drops, chutes are usually used. For canals that do not require command, the position of drops is determined by considering the cost of canal construction, including balancing the cuts and fills and the cost of the structure. Where there is need for command, the drops should be located in such a way that the canal banks are not too high, but still keeping enough command at the same time. An important aspect of a Vertical drop structure is the stilling basin, required to avoid downstream erosion. The floor of the stilling basin should be set at such a level that the hydraulic jump occurs at the upstream end of the basin floor in order to avoid erosion at the unprotected canal bed downstream (Figure 9.6).

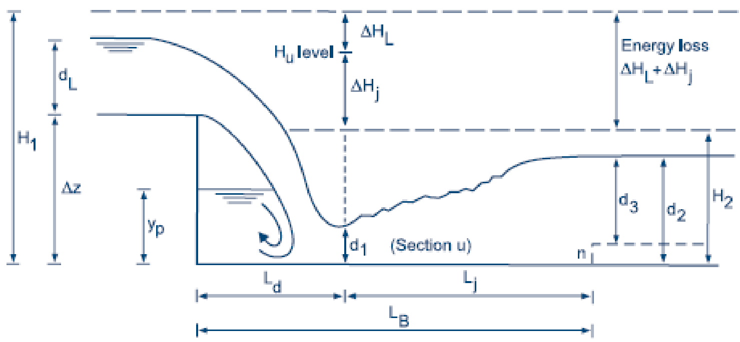


Figure 9.6 Design of Vertical Drop Structure

The empirical formulae to use for the design of a stilling basin (apron) are:

$$D = q^2 / (g \times z^3)$$
$$Ld / z = 4.30 \times D^{0.27}$$
$$d_1/z = 0.54 \times D^{0.425}$$
$$d_2 / z = 1.66 \times D^{0.27}$$
$$Lj = 6.9 \times (d_2 - d_1)$$

Where:

D	=	Drop number (no limit)
q	=	Discharge per metre length of the weir (m^2/sec)
g	=	Gravitational force (9.81 m/sec^2)
z	=	Drop (m)
Ld	= level	Length of apron from the drop to the point where the lowest water d_1 will occur (hydraulic jump) (m)
d_1	=	Lowest water level after the drop (m) - critical depth
d_2	=	Design water level after the apron (m)
L_j	=	Length of apron from the point of lowest water level to the end of the apron (m)

Due to the impact of the water flow on the basin floor and the turbulent circulation, an amount of energy (ΔHL) is lost. Further energy is lost in the hydraulic jump downstream of the section. The energy head (H_2) is equal to about 2.5 x d_1 and this provides a satisfactory basis for design. The basin floor us usually depressed to ensure that the hydraulic jump occurs immediately below the drop, and within the length of the stilling basin.

9.8 Culverts and Cross Drainage Structures

Crossing structures are used to pass over or under obstacles in the field. There are three types of crossing structure to transport irrigation water, namely: aqueducts, culverts, and inverted siphons, and there also are crossing structures not meant for water conveyance bridges. Aqueducts are self-supporting canal sections used to carry water across drainage canals, gullies or depressions. They can be constructed from wood, metal or concrete. Culverts and inverted siphons are buried pipes used to carry irrigation water underneath roadways, drainage canals, natural streams or depressions. Flow through a culvert may have a free water surface or may be submerged. Flow through an inverted siphon does not have a free water surface, and the water is under pressure.

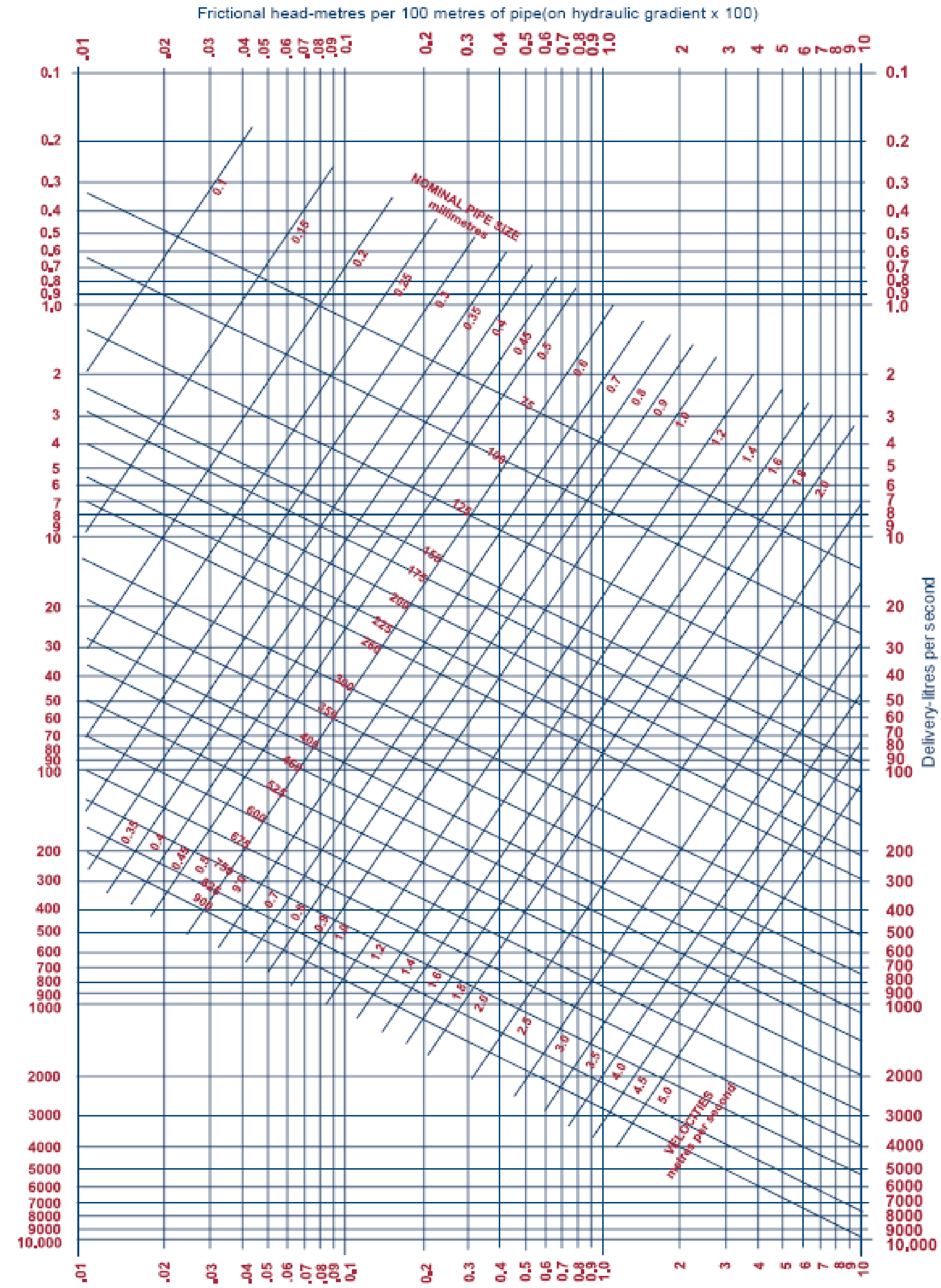


Figure 9.7 Friction loss chart for AC pipes (Class 18)

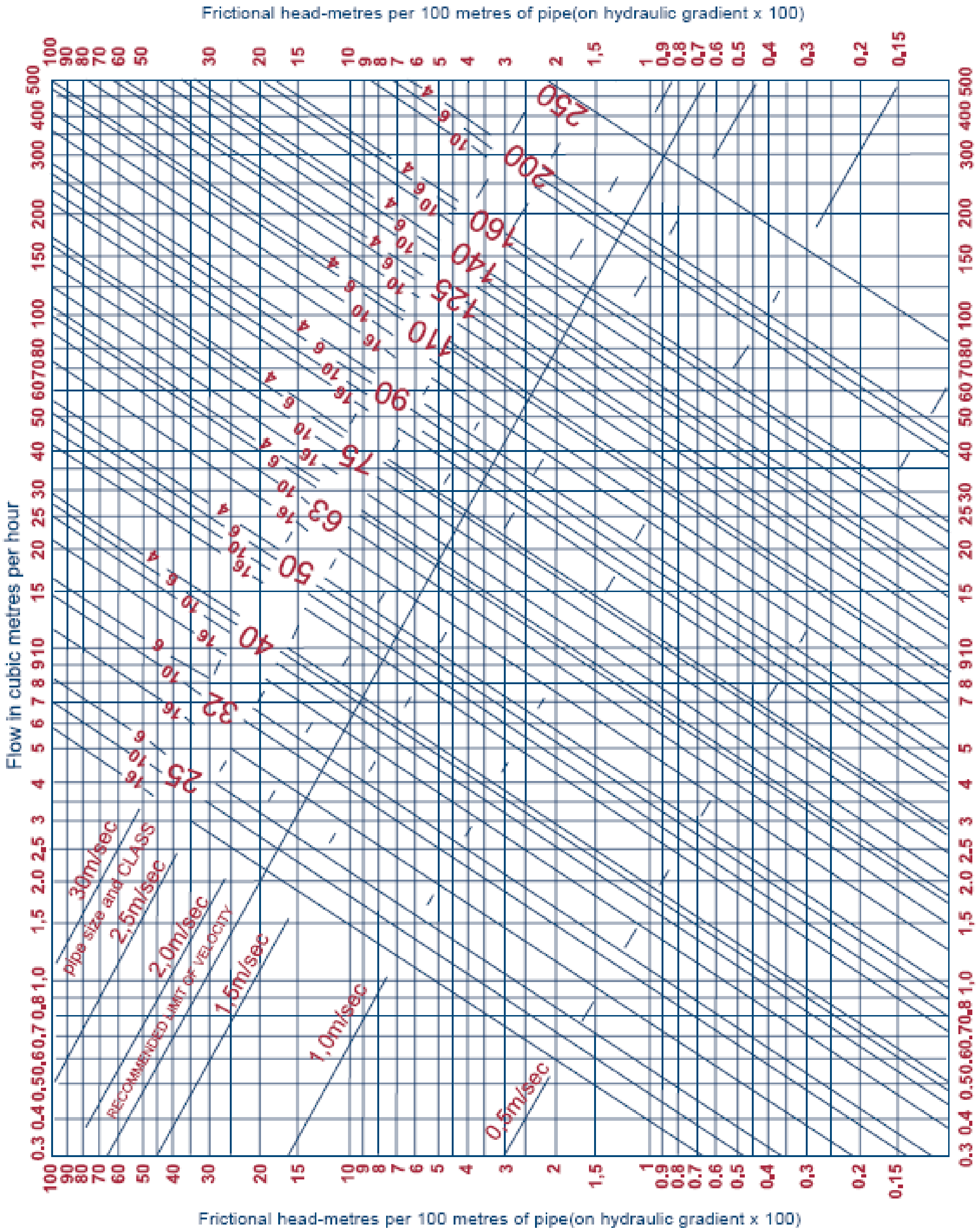


Figure 9.8 Friction loss chart for uPVC pipes

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.10 Pumping

10.1 Irrigation Pumping

Most irrigation pumps fall within the category of pumps that use kinetic principles (centrifugal force or momentum) in transferring energy. This category includes pumps such as centrifugal pumps, vertical turbine pumps, submersible pumps and jet pumps. Most of these pumps operate within a range of discharge and head where the discharge will vary as the head fluctuates. The second category of pumps is that of positive displacement pumps, whereby the fluid is displaced by mechanical devices such as pistons, plungers and screws. Mono pumps, treadle pumps and most of the manual pumps fall into this category.

10.2 Types of Pumps

Depending on the type of discharge, pumps can be divided into:

- Propeller or axial flow pumps
- Vertical turbine and centrifugal pumps
- Mixed flow pumps
- Positive displacement pumps

The most common types used are axial flow; centrifugal and mixed flow pumps.

Axial flow pumps, efficient for lifting large volumes of water at low pressure, and are ideal for lifting water from a river or lake into open channel distribution systems. However, axial flow pumps are normally only available for the larger discharges, and hence only for the larger irrigation schemes. Such pumps would be well suited to small scale irrigation also but unfortunately small axial flow pumps are not easily obtained. While the radial flow type of pump discharges the water at right angles to the axis of rotation, in the axial flow type water is propelled upwards and discharged nearly axially. The blades of the propeller are shaped like a ship's propeller. Axial flow type pumps are used for large discharges and low heads.,

Centrifugal pumps are well suited to sprinkle and trickle irrigation in terms of discharge and pressure, and are the most common type of pump used in irrigation. Although not well suited to low head surface irrigation schemes, it is often the only type of pump available in many countries. Thus, it is widely used for this purpose, despite its poor efficiency in such situations. Additionally, they are much cheaper to buy and maintain than axial flow pumps. Moreover, small pump sets are often readily available and easy to maintain, particularly for small farmers in most developing countries.

Radial flow pumps are based on the principles of centrifugal force, and are subdivided into volute pumps and diffuser (turbine) pumps. The well-known horizontal centrifugal pump is a volute pump. The pump consists of two main parts, the propeller that rotates on a shaft and gives the water a spiral motion, and the pump casing that directs the water to the impeller through the volute and eventually to the outlet. The suction entrance of the casing is positioned such that the water enters the eye of the impeller. The water is then pushed outwards because of the centrifugal force caused by the rotating impeller. The centrifugal force, converted to velocity head and thus pressure, pushes the water to the outlet of the volute casing. Closed impellers develop higher efficiencies in high-pressure pumps. The other two types are more able to pass solids that may be present in the water. Volute pumps are classified under three major categories:

- Low head, where the impeller eye diameter is relatively large, compared with the impeller rim diameter
- Medium head, where the impeller eye diameter is a small proportion of the impeller rim diameter

- High head, where the impeller rim diameter is relatively much larger than the impeller eye diameter

The major difference between the volute centrifugal pumps (Figure 10.1) and the turbine pumps is the device used to receive the water after it leaves the impeller. In the case of the turbine pumps, the receiving devices are diffuser vanes that surround the impeller and provide diverging passages to direct the water and change the velocity energy to pressure energy. Deep well turbine pumps and submersible pumps use this principle. Depending on the required head, these pumps have a number of impellers, each of which is enclosed with its diffuser vanes in a bowl. Several bowls form the bowl assembly that must always be submerged in water. A vertical shaft rotates the impellers. In the case of turbine pumps the shaft is located in the centre of the discharge pipe. At intervals of usually 2-3 m, the shaft is supported by rubber lined water lubricated bearings. Electro-submersible pumps are turbine pumps with an electric motor attached in the suction part of the pump, providing the drive to the shaft that rotates the impellers. Therefore, there is no shaft in the discharge pipe. Both the motor and pump are submerged in the water. They are especially suitable for installation in deep boreholes. Submersible electrically driven pumps depend on cooling via the water being pumped, and a failure of the water supply can result in serious damage to the unit. For this reason, submersible pumps are protected with water level cut-off switches.

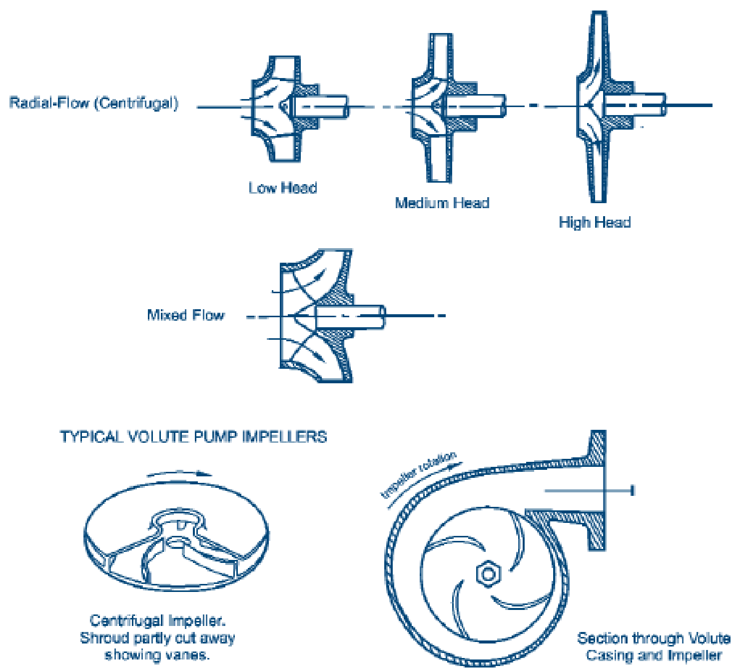


Figure 10.1 Classification of volute pumps based on the impeller proportions

Mixed flow pumps are a mixture of axial flow and centrifugal pumps, and combine the best features of both pump types. Price considerations and local availability may have an overriding impact in the selection. This category includes pumps whereby the pressure head is developed partially through the centrifugal force, as well as the lift of the vanes on the water. The flow is discharged both axially and radially. These pumps are suitable for large discharges and medium head.

Figure 10.2 shows this classification as a function of the total operating head and discharge. Positive displacement pumps are as a rule suitable for small discharges, and high heads and the head is independent of the pump speed. Some types of these pumps should only be used with water which is free of sediments. The vertical turbine and the centrifugal pumps fit the conditions of moderately small to high discharges, and moderately low to high heads. These are the most commonly used pumps in irrigation. They can operate with reasonable amounts of sediments, but periodic replacement of impellers and volute casing should be anticipated. Turbine pumps are more susceptible to sediments than centrifugal pumps. Mixed flow pumps cover a good range, from moderately large to large discharges, and moderately high heads. They have the same susceptibility to sediments as do centrifugal pumps. Axial flow pumps are suitable for low heads and large discharges

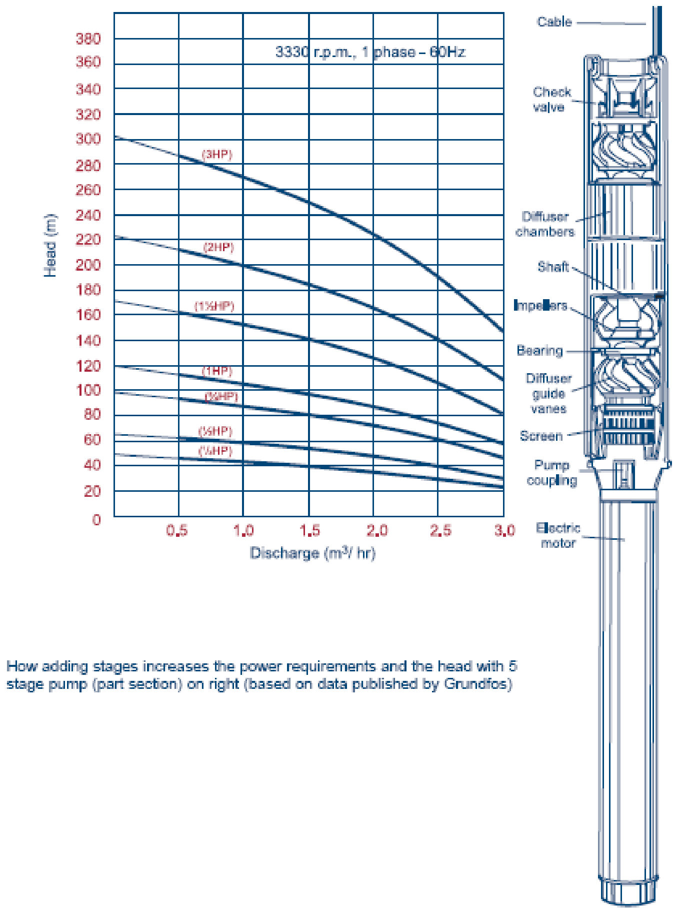


Figure 10.2 Cross-section through a submersible pump and submersible motor (Source: FAO, 1986)

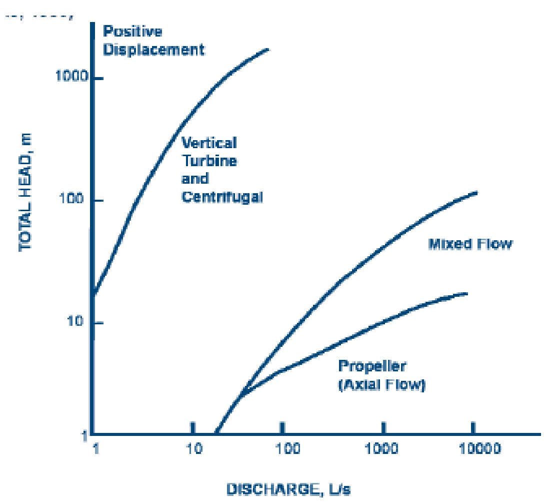


Figure 10.3 Classification of Pump Types as Function of Operating Head and Discharge

10.3 Pumping Head and Losses

Head is the expression of the potential energy imparted to a liquid to move it from one level to another. Total dynamic head or total pumping head is the head that the pump is required to impart to a fluid, in order to meet the head requirement of a particular system, whether it is a town water supply system or an irrigation system. The total dynamic head is made up of static suction lift or static suction head, static discharge head, total static head, required pressure head, friction head and velocity head. Figure 10.3 shows the various components making up the total dynamic head.

Static suction head or static suction lift: When a pump is installed such that the level of the water source is above the eye of the impeller (flooded suction), then the system is said to have a positive suction head at the eye of the impeller. However, when the pump is installed above the water source, the vertical distance from the water surface to the eye of the impeller is called the static suction lift.

Static discharge head: This is the vertical distance or difference in elevation between the point at which water leaves the impeller, and the point at which water leaves the system, for example the outlet of the highest sprinkler in an overhead irrigation system.

Total static head: When no water is flowing (static conditions), the head required to move water from water source to the highest sprinkler or outlet point is equal to the total static head. This is simply the difference in elevation between where we want the water and where it is now. For systems with the water level above the pump, the total static head is the difference between the elevations of the water and the sprinkler (Figure 10.4 (a)).

Total Static Head = Static Discharge Head – Static Suction Head

For systems where the water level is below the pump, the total static head is the static discharge head plus the static suction lift (Figure 10.4 (b).

Total Static Head = Static Discharge Head + Static Suction Lift

Friction head: When water flows through a pipe, the pressure decreases because of the friction against the walls of the pipe. Therefore, the pump needs to provide the necessary energy to the water to overcome the friction losses. The losses must be considered both for the suction part and the discharge part of the pump. The magnitude of the friction head can be calculated using either hydraulic formulae or tables and graphs.

Pressure head: Except for the cases where water is discharged to a reservoir, or a canal, a certain head to operate an irrigation system is required. For example, in order for a sprinkler system to operate, a certain head is required.

Velocity head: This energy component is not shown in Figure 10.4. It is very small and is normally not included in practical pressure calculations. Most of the energy that a pump adds to flowing water is converted to pressure in the water. Some of the energy is added to the water to give the velocity it requires to move through the pipeline. The faster the water is moving the larger the velocity head. The amount of energy that is needed to move water with a certain velocity is given by the formula:

$$\textbf{Velocity Head} = V^2/2g$$

Where:

V = velocity of the water (m/s)

g = gravitational force which is equal to 9.81 (m/s^2)

For centrifugal pumps, to assure good pump performance, the diameter of the suction pipe should be selected with the water velocity V < 3.3 m/s. The resulting velocity head corresponding to the minimum diameter of the suction pipe is 0.56 m/sec (3.32/(2 x 9.81)).

Drawdown: Usually, the level of the water in a well or even a reservoir behind a dam does not remain constant. In the case of a well, after pumping starts with a certain discharge, the water level lowers. This lowering of the water level is called drawdown. In the case of a dam or reservoir, fluctuation of the water level is common and depends on water inflow, evaporation and water withdrawal. The water level increases during the rainy season, followed by a decrease during the dry season because of evaporation and withdrawal of the stored water. This variation in water level will affect the static suction lift or the static suction head and, correspondingly, the total static head.

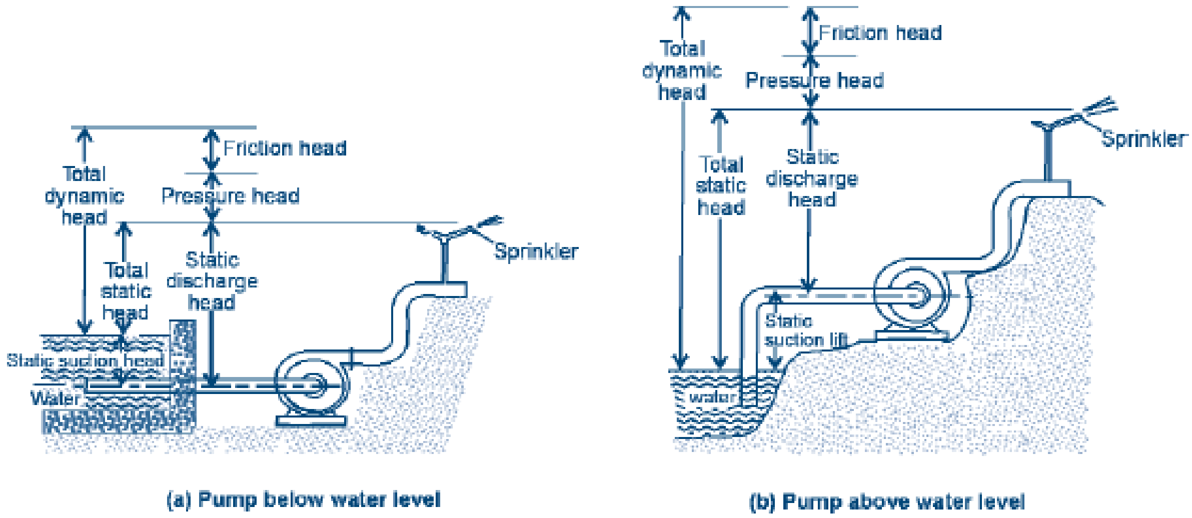


Figure 10.4 Components of total dynamic head (Source: Australia Irrigation Association, 1998)

10.4 Power Units

Pumps can be driven by a diesel or petrol engine or an electric motor. In some special cases solar or wind power or even hand or animal power may be used, but they are not so common and are generally limited to very small irrigated plots. There are four types of transmission usually applied to irrigation pumps: direct coupling, flat belt, V-belt and gear. Direct coupling generally implies negligible or no loss of power. The loss of power through flat belt varies from 3-20%. Transmission losses for V-belt and gear drive, as a rule, do not exceed 5%.

Electric motors: For most centrifugal pumps the motors are directly coupled to the pump. This results in the elimination of belt drives and energy loss due to belt slippage, and safety hazards. Most centrifugal pumps used in Eastern Africa are coupled to the motor shaft through a flexible coupling. In the past it was common practice to overload motors by 10-15% above the rated output without encountering problems. However, because of the materials currently used, motors can no longer stand this overloading. Therefore, they should be sized to the needed and projected future output. For sustained use of a motor at more than 1,100 m altitude or at temperatures above 37°C derating may be necessary. Manufacturer's literature should be consulted for the necessary derating.

Diesel engines: As a rule, petrol engines drive very small pumps. For most irrigation conditions, the diesel engine has gained popularity. It is more robust, requires less maintenance and has lower overall operation and maintenance costs. Most literature on engines uses the English units of measurement. To convert kilowatts to horsepower, a conversion factor of 1.34 can be applied. Horsepower versus speed curves (Figure 10.5) illustrate how output power increases with engine speed. However, there is a particular speed at which the engine efficiency is highest. This is the point at which the selected engine should operate. The continuous rated curve indicates the safest continuous duty at which the engine can be operated. Care should be taken to use the continuous rated output curve and not the intermittent output curve. Manufacturer's curves are calculated for operating conditions at sea level and below 30°C. It is therefore necessary to derate the engines for different altitudes and temperatures where the operating conditions are different. Approximately 1% derating is needed per 100 m increase in altitude and 1% per 5.6°C increase in air temperature from the published maximum output horsepower curve. An additional 5-10% should be deducted for reserve. If continuous output curves are used, only 5-10% deduction is applied. As a rule of thumb, an engine can be derated by 20% to give the total derating needed.

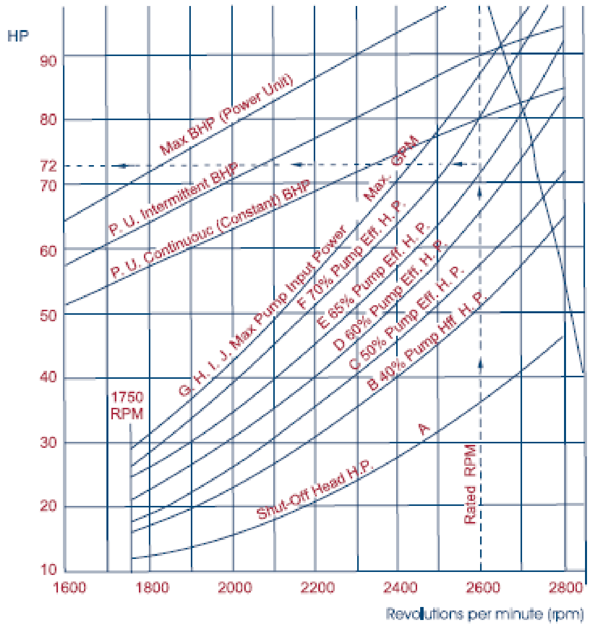


Figure 10.5 Typical Rating Curves for Engines

Internal combustion engines have a good weight to power output ratio, and are compact in size and relatively cheap due to mass production techniques. Petrol engines tend to be the cheaper overall for small schemes (1 to 2 ha), but diesels become more cost effective on schemes over 4 ha. Diesel engines are more efficient to run, and if operated and maintained properly, they have a longer working life (10 years) and are more reliable than petrol (4 years). In some countries, petrol driven pumps have needed replacing after only 2 or 3 years operation. Diesel pumps operating in similar conditions could be expected to last at least 6 years. However, the lifespan of an engine is best measured in hours of operation, and this depends on how well it is operated and serviced. There are cases in developing countries where diesel pumps have been in continual use for 30 years and more. The annual maintenance of petrol engines can be as much as 10% of capital cost whereas diesel maintenance is only 5%.

Table 10.1 Pump Selection for Irrigation Schemes

Irrigation System	Pressure (bar)	Discharge	Pump Type
Surface Irrigation			
• open channel distribution	0.5	high discharge	axial[1]/mixed
• pipe distribution	1.0	high discharge	axial[1]/mixed
• deep tube well	>2.0	low discharge	mixed/centrifugal
Sprinkle System	2-5	medium discharge	centrifugal
Trickle System	1-2	low discharge	centrifugal

Electric motors are very efficient in energy use and can be used to drive all sizes and types of pumps. They can also last much longer than other power units (up to 10 years), with low maintenance costs (approx. 1% of capital costs). The main draw back is the reliance on a power supply which is beyond the control of the farmer and in many places it is unreliable. Electrically driven pumps are much cheaper to operate than diesel pumps. For larger schemes, the energy costs become a much more significant part of the overall cost of the scheme and so any savings in energy could result in significant cost savings. A stand by generator is also essential to cover power failures. **Animal powered water wheels** have been extensively used in countries with a long tradition in irrigation, but they are gradually disappearing from the irrigation scene. Small centrifugal pump units are very competitive in price and easy to operate. It will be difficult to justify the introduction of such pumping devices nowadays, with an exception of remote places. When dealing with small farms, pumping costs are not important. It is the capital cost of the system, equipment availability and its useful life expectancy which dominates the decision making.

General comments

In conclusion, it is local conditions such as the availability of equipment and spares, together with good maintenance facilities which ultimately decide on the type of technology to choose, and not just the most desirable from a financial and technical point of view. For the simplest of shallow wells, small centrifugal pumps located at ground level (or hand lifting devices in some areas) are used to lift the water into the distribution system. Deeper water will require submersible pumps. Diesel driven submersibles can be more expensive to buy and maintain as compared to surface pumps. Electric submersible pumps are a much cheaper option, but are at the mercy of the local power supply.

10.5 Pump Characteristics

Most manufacturers provide four different characteristic curves for every pump: the Total Dynamic Head versus Discharge or TDH-Q curve, the Efficiency versus Discharge or EFF-Q curve, the Brake Power versus Discharge or BPQ curve and Net Positive Suction Head Required versus Discharge or NPSHR-Q curve. All four curves are discharge related. Figure 10.6 presents the four typical characteristic curves for a pump, with one stage or impeller.

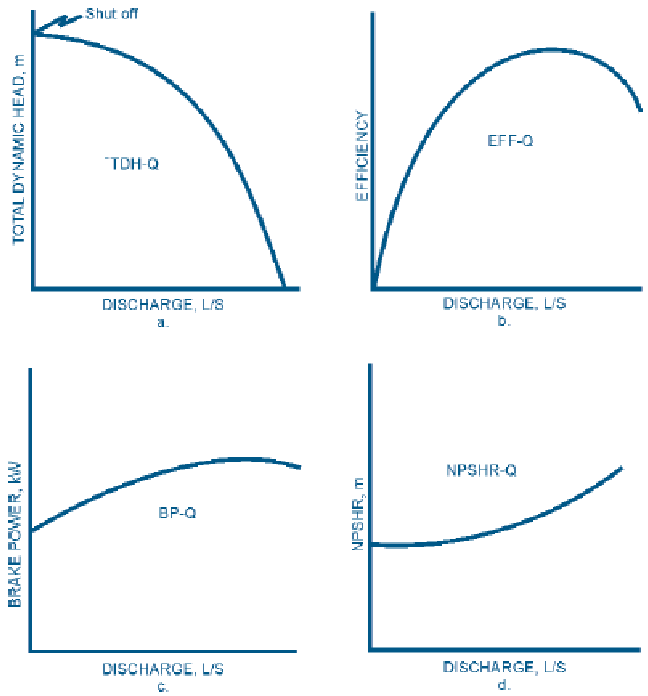


Figure 10.6 Typical Pump characteristic curves

Total dynamic head versus discharge (TDH-Q): This is a curve that relates the head to the discharge of the pump. It shows that the same pump can provide different combinations of discharge and head. Additionally, it is also noticeable that as the head increases the discharge decreases and vice versa. The point at which the discharge is zero and the head at maximum is called shut off head. This happens when a pump is operating with a closed valve outlet. As this may happen in the practice, knowledge of the shut off head (or pressure) of a particular pump would allow the engineer to provide for a pipe that can sustain the pressure at shut off point if necessary.

Efficiency versus discharge (EFF-Q): This curve relates the pump efficiency to the discharge. The materials used for the construction and the finish of the impellers, the finish of the casting and the number and the type of bearings used affect the efficiency. As a rule larger pumps have higher efficiencies. Efficiency is defined as the output work over the input work.

E pump = Output work/ Input work = WP/ BP = Q x TDH/(C x BP)

Where:

E pump	=	Pump efficiency
BP	=	Brake power (kW or HP = 1.34 x kW): energy imparted by the prime mover to the pump
WP	=	Water power (kW): energy imparted by the pump to the water
Q	=	Discharge (l/s or m^3/hr)
TDH	=	Total Dynamic Head (m)
C	=	Coefficient to convert work to energy units – equals 102 if Q is measured in l/s and 360 if Q is measured in m^3/hr

Brake or input power versus discharge (BP-Q): This curve relates the input power required to drive the pump to the discharge. It is interesting to note that even at zero flow an input of energy is still required by the pump to operate against the shut-off head. The vertical scale of this curve is usually small and difficult to read accurately. BP should be calculated as follows:

BP = Q x TDH/(C x E pump)

Net positive suction head required versus discharge (NPSHR-Q): At sea level, atmospheric pressure is 100 kPa or 10.33 m of water. This means that if a pipe was to be installed vertically in a water source at sea level and a perfect vacuum created, the water would rise vertically in the pipe to a distance of 10.33 m. Since atmospheric pressure decreases with elevation, water would rise less than 10.33 m at higher altitudes. A suction pipe acts in the manner of the pipe mentioned above, and the pump creates the vacuum that causes water to rise in the suction pipe. Of the atmospheric pressure at water level, some is lost in the vertical distance to the eye of the impeller, some to frictional losses in the suction pipe and some to the velocity head. The total energy that is left at the eye of the impeller is termed the Net Positive Suction Head. The amount of pressure (absolute) or energy required to move the water into the eye of the impeller is called the Net Positive Suction Head Requirement (NPSHR). It is a pump characteristic and a function of the pump speed; the shape of the impeller and the discharge. Manufacturers establish the NPSHR-Q curves for the different models after testing. If the energy available at the intake side is not sufficient to move the water to the eye of the impeller, the water will vaporize and the pump will cavitate (see below). In order to avoid cavitation, the NPSHA should be higher than the NPSHR required by the pump under consideration.

Cavitation: At sea level water boils at about 100°C and its vapour pressure is equal to 100 kPa. When water boils, air molecules dissolved in water are released back into air. The vapour pressure increases rapidly with temperature increase, while atmospheric pressure decreases with altitude increase. In the eye of the impeller of a pump, pressure may be reduced to such a point that the water will boil. As the water is carried to areas of higher pressure in the pump, the vapour bubbles will collapse or explode at the surface of the impeller blades or other parts of the pump, resulting in the material erosion. The phenomenon described here is known as cavitation. Cavitation makes itself noticeable by an increase in noise level (rattling sound), irregular flow, and the drop in pump efficiency and sometimes in head. Heavy cavitation, especially in larger pumps, sounds like the roar of thunder. In order to determine the possibilities of the occurrence of cavitation, the water pressure at the pump's entrance is determined and compared with the vapour pressure at the temperature of the water to be pumped. For this purpose the NPSHA is calculated as follows:

NPSHA = atmospheric pressure at the given altitude – static suction lift – friction losses in pipe – vapour pressure of the liquids at the operating temperature

Where:

- Atmospheric pressure at the given altitude, Pb = 10.33 – 0.00108 Z (Barometric pressure); Z = elevation (m) can be measured
- Static suction lift (m) can be measured,
- Friction losses hl, in metres, can be calculated from graphs, tables or formulae
- Vapour pressure e (m) estimated
- Gauge pressure (Figure 10.7) = static suction lift + friction losses in pipe + vapour pressure

Table 10.2 Variation of vapour pressure with temperature

Temperature (°C)	0	5	10	15	20	25	30	35	40	45	50
Vapour pressure of water, e (m)	0.06	0.09	0.13	0.17	0.24	0.32	0.43	0.58	0.76	0.99	1.28

If the NPSHA is less than the NPSHR, the NPSHA will have to be increased. This can be achieved by reducing the friction losses in the pipe by using a wider suction pipe, although this is not very effective. Generally, decreasing the static suction lift increases the NPSHA, which can be obtained by positioning the pump nearer to the water level.

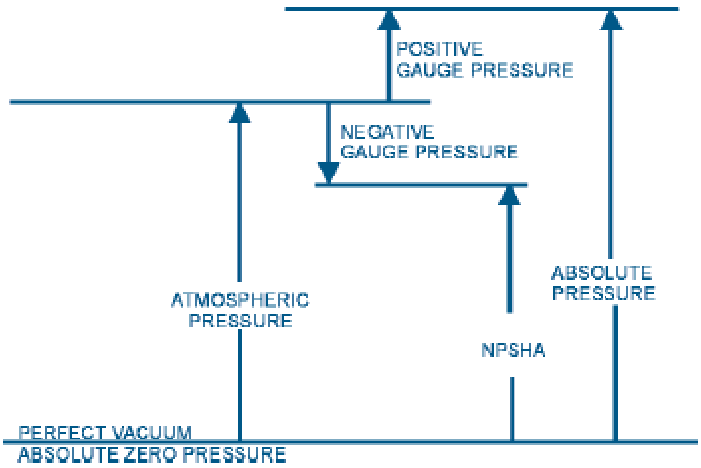


Figure 10.7 Schematic presentation of Net Positive Suction Head Available (NPSHA)

10.6 Combination of Pumps

Connecting centrifugal pumps in series is often required to take water from one source and then supply it either to a pressurised system for a sprinkler, for example or to a series of gravity canals at different elevations. In general, connecting pumps in series applies to the cases where the same discharge is required, but more head is needed than that which one pump can produce. For two pumps operating in series, the combined head equals the sum of the individual heads at a certain discharge. Figure 10.8 shows how the combined TDH-Q curve can be derived. If pumps placed in series are to operate well, the discharge of these pumps must be either the same or there must be sufficient storage and automatic controls to ensure that water levels are always maintained at the required head for the suction pipe of the pumps. The following equation from can be used to calculate the combined efficiency at a particular discharge.

E series = [Q x (TDHa + TDHb)]/ [C x (BPa + BPb)]

Where:

E	=	Efficiency
Q	=	Discharge (l/s)
TDH	=	Total Dynamic Head (m)
C	=	102 (coefficient to convert work to energy units)
BP	=	Brake power (kW)

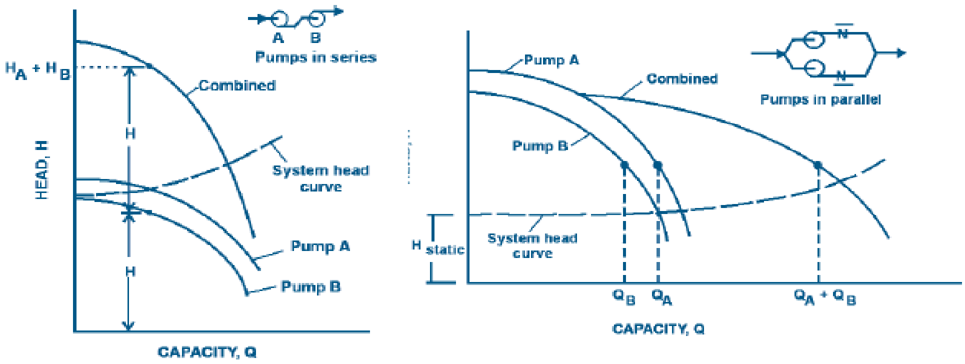
Pumps are operated in parallel where wide ranges of discharge are needed for approximately the same head, as is the case in many perennial irrigations schemes. Several smaller pumps are used instead of a few larger pumps. This provides a certain degree of flexibility when a number of farmers cannot be present, pumps need maintenance and repair or standby pumps are provided. When selecting the pumps used in parallel it must be remembered that they should deliver the same head. Where pumping is required from a number of different sources at different elevations, each pump should deliver into a common reservoir and not a common pipe to avoid backflow of water from one pump to another. The equation for the calculation of the combined efficiency is as follows:

E parallel = [(Qa + Qb)) x TDH] /[C x (BPa + BPb)]

Where:

E	=	Efficiency
Q	=	Discharge (l/s)
TDH	=	Total Dynamic Head (m)

C	=	102 (coefficient to convert work to energy units)
BP	=	Brake power (kW)



(a) (b)

Figure 10.8 TDH-Q curve for two pumps operating in series (a) and in Parallel (b)

10.7 Pump Selection

The selection of pumps requires the use of manufacturers' pump curves. It is possible to identify a pump that can provide the discharge and head required at the highest possible efficiency from various pump curves. Following the identification of the pump, the NPHSR-Q curve is checked and evaluations are made to ensure that its NHPSA is higher than the NPHSR. When the required Q and H combination falls outside the performance curve, or when it falls at the fringes of the performance curve, that type of pump should not be selected. The size of the pump impeller is important when selecting a pump. If the required Q and H combination falls between two impeller sizes, then the larger impeller will have to be used, but only after it is trimmed down by the manufacturers so that it matches the requested Q and H.

10.8 Energy Requirements

Energy requirements are proportional to the discharge, head and efficiency of the pumping system as demonstrated earlier by the formula used to calculate the kW power requirements:

$$BP = (Q \times TDH)/(C \times E\ pump)$$

Where:

Q	=	discharge in l/s with C = 102 or in m^3/hr with C = 360
TDH	=	Total Dynamic Head (m)
Epump	=	pump efficiency

The annual or seasonal energy requirements increase with the total volume of water pumped, and is therefore affected by the overall irrigation efficiency. Motor efficiency also has a bearing on energy requirement calculations with efficiencies normally from 0.88 - 0.92. Small motors (~7.5 kW or less) have motor efficiencies usually below 0.88. For motors of 75 kW or larger the efficiency is 0.9 -0.92. An average motor efficiency for small size irrigation schemes would be 0.88. Drip or localized irrigation will have the lowest energy requirements, followed by surface and sprinkler. These result from higher irrigation efficiency combined with low operating pressure.

When static lift increases, surface irrigation is the most energy inefficient, because of the combined low irrigation efficiency and high static head. As the static lift increases (>25 m), the difference in the energy requirements between surface and sprinkler irrigation increases substantially. The higher efficiency of sprinkler irrigation, will compensate for the higher pressure required for its operation.

When electricity is not available and diesel engines are used for pumping, fuel requirements should be based on the manufacturer's catalogues, as they vary according to the speed at which an engine operates. A consumption of 0.25 litres/kWh, for a diesel engine can be used as a rule of thumb.

10.9 Operation and Maintenance

There are several types of pumps available on the market. All pump manufacturers provide users' operation and maintenance manuals specific to their pumps. These have to be closely adhered to in order to ensure the most efficient operation of the pump, and avoid unnecessary pump breakdowns. In view of the wide variety of operational instructions, which can be expected for different pumps, only general guidelines can be provided. Manual pumps are operated by people or animals, whereas motorized pumps are operated by prime movers, engines and electric motors. In general, the principles of operation of pumps are the same. The discharge and pumping head relationship of all pumps is dependent on pump type, and the amount of energy that the manual operator or prime mover can transfer to the pump, among other factors. This section deals with the general aspects of pump operation, with specific reference to motorized pumps.

Pump start-up and shut-down: There are certain procedures that are recommended by pump manufactures before any pump start-up. Some of the pre-start-up inspections recommended immediately after pump installation are checking for correct pump-motor wiring connections, valve connections, shaft and gland clearance. It has to be remembered that starting a pump dry will cause seizing or destructive wear between the pump components. Pumps that are not self priming or those with a positive suction lift should be primed before they are started. Different manufacturers also have specific instructions for pump shut down after operation. These have to be adhered to strictly.

Priming: While deep well pumps, such as submersible pumps, are submerged into the water and have no need for priming, the well-known horizontal centrifugal pump usually needs priming. Priming is the process of removing sufficient air from the pump and the suction pipe, so that the atmospheric pressure can cause the flow of water inside the pump. The simplest way of doing this is to displace the air in the system by filling the pump and suction pipe with water. For this purpose, a tank is connected to the pump and a foot valve to the suction pipe. The tank is filled with water when the system is operating. Before the system is switched on, the water from the tank is diverted to the pump and suction pipe via a valve. However, the most popular priming method is the use of a manually operated vacuum pump. Other means are also available for priming, such as mechanically operated vacuum pumps and exhaust primers. At times, horizontal centrifugal pumps are installed at a dam outlet. In this case, no priming is required since the water level inside the dam is higher than the level of the impeller, which forces the water to remove all air from the suction pipe and the volute of the pump.

The pump must not be run unless it is completely filled with liquid; otherwise there is the danger of damaging some of the pump components. Wearing rings, bushings, seals or packing and internal sleeve bearings all need liquid for lubrication and may seize if the pump is run dry.

Starting the pump: The pump is started with the gate valve closed. This is because the pump operates at only 30-50% of the full load when the discharge gate valve is closed. In cases where the pump is below the water source, the pump can be started with an open gate valve. To avoid water hammer, the gate valve has to be opened gradually until it is fully open.

Stopping the pump: The first step is to close the gate valve. This eliminates surges that may occur in case of an abrupt closure. When this has been done, the prime mover is then closed or shut down. If the pump remains idle for a long time after it is stopped, it gradually looses its priming. Thus the operator should re-prime the pump every time before start-up. Pump malfunctions, causes and remedies (troubleshooting) Following are some general causes of pump malfunctioning and their remedies that can be used for on-spot trouble-shooting when pump problems are encountered.

Table 10.3 Pump problems, causes and corrections

SYMPTOMS	CAUSES	CORRECTIONS
Failure to pump	1. Pump not properly primed	1. Prime pump correctly
	2. Speed too low or high	2. Check speed, check calculations, consult with manufacturer
	3. Not enough head to open check valve	3. Check speed, check calculations, consult with manufacture
	4. Air leak	4. Check and rework suction line
	5. Plugged section	5. Unplug section
	6. Excessive suction lift	6. Check NPSH and consult manufacturer
Rapid wear of coupling cushion	7. Misalignment	7. Align
	8. Bent shaft	8. Replace
Reduced performance	9. Air pockets or small air leaks in suction line	9. Locate and correct
	10. Obstruction in suction line or impeller	10. Remove obstruction
	11. Insufficient submergence of suction pipe	11. Extend suction line to deeper water to the extent that NPSH allows you or excavate and deepen the area where the suction basket is located
	12. Excessively worn impeller or wear ring	12. Replace impeller and/or wear ring
	13. Excessive suction lift	13. Calculate NPSH, consult with manufacturer
	14. Wrong direction of rotation	14. Ask contractor to rectify
Driver overloaded	15. Speed higher than planned	15. Reduce speed
	16. Water too muddy	16. Raise suction
	17. Too large an impeller diameter	17. Trim impeller
	18. Low voltage	18. Consult power authority
	19. Stress in pipe connection to pump	19. Support piping properly
	20. Packing too tight	20. Loosen packing gland nuts
Excessive noise	21. Misalignment	21. Align all rotating parts
	22. Excessive suction lift	22. Check NPSH, consult with manufacturer
	23. Material lodged in impeller	23. Dislodge obstruction
	24. Worn bearings	24. Replace bearings
	25. Impeller screw loose or broken	25. Replace
	26. Cavitation	26. Check NPSH, correct suction piping
	27. Wrong direction of rotation	27. Ask contractor to rectify
Premature bearings failure	28. Worn wear ring	28. Replace
	29. Misalignment	29. Align all rotating parts
	30. Suction or discharge pipe not properly supported	30. Correct support
	31. Bent shaft	31. Replace shaft
Electric motor failure	32. High or low voltage	32. Check voltage and consult power authority
	33. High electric surge	33. Monitor voltage and consult power authority
	34. Poor electric connection	34. Turn power off, clean and check connections
	35. Overloads	35. Check amperage, do not exceed full load amperage
	36. Bearing failure	36. Change motor bearing
	37. Cooling vent plugged (rodent, dirt, leaves)	37. Install proper screen
	38. Moisture or water in motor	38. Send for blow-dry and protect from environment

10.10 References

Key Reference: *Irrigation Manual, Module 5, Irrigation Pumping Plant, Developed by Andreas P. SAVVA and Karen FRENKEN, Water Resources Development and Management Officers, FAO Sub-Regional Office for East and Southern Africa, Harare, 2002.*

The Water Team of FAO's Sub-regional Office for East and Southern Africa in Harare, Zimbabwe, has developed an Irrigational Manual for irrigation practitioners, resulting from several years of field work and training of irrigation engineers in the sub-region. It deals with the planning, development, monitoring and evaluation of irrigated agriculture with farmer participation. It consist of 14 Modules, regrouped in five volumes (Volume 1: Modules 1-6; Volume 2: Module 7; Volume 3: Module 8; Volume 4: Module 9; Volume 5: Modules 10-14), with an emphasis on engineering, agronomic and economic aspects of smallholder irrigation, but it also introduces the irrigation engineers to social, health and environmental aspects of irrigation development, thus providing a bridge between the various disciplines involved in irrigation development. For on-line reading, click one of the following:

Module: 5,

http://www.fao.org/landandwater/training.stm#irrigman

FAO. 1986. Water Lifting Devices. FAO Irrigation and Drainage Paper 43. Prepared by: Fraenkel, P.L. Rome, Italy.

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Seipt, W.R. 1974. Water hammer considerations for PVC pipeline in irrigation systems.

T -Tape. 1994. Irrigation Training Seminar. Australia.

.11 Measurement

11.1 Overview

In many irrigation and drainage systems, measurement of discharge is an essential component of the operation process. Discharge measurements need to be made in rivers, canals, drains and pipelines and can be made in a variety of ways using:

- velocity-area methods
- dilution techniques
- hydraulic structures
- slope-hydraulic radius-area method
- flow meters

The most commonly used techniques are the velocity-area method, hydraulic structures and flow meters.

11.2 Velocity-area methods

Velocity-area discharge measurement involves the measurement of the channel cross sectional area and the average velocity of flow. The cross sectional area is measured using a tape and level staff or depth gauge, the average flow velocity is determined with a current meter or a float. When measurements have been taken at a given location for a variety of flow conditions, a stage-discharge curve can be constructed to enable discharge to be determined from the depth alone (Figure 11.1). The stage-discharge curve must periodically be checked and if necessary re-calibrated. When establishing the stage-discharge station, it is important to ensure that the channel flows at normal depth, and that flow is not impeded by downstream obstructions (Figure 11.2).

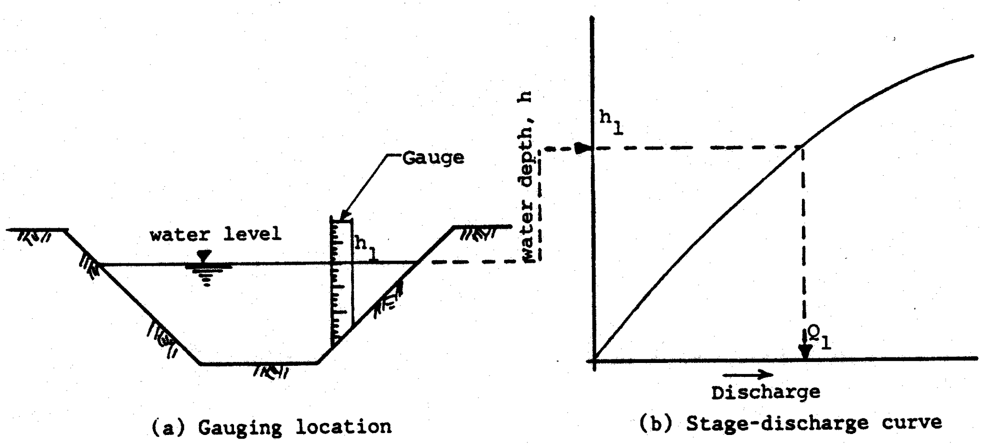

Figure 11.1 Use of a calibrated gauging site for discharge measurement

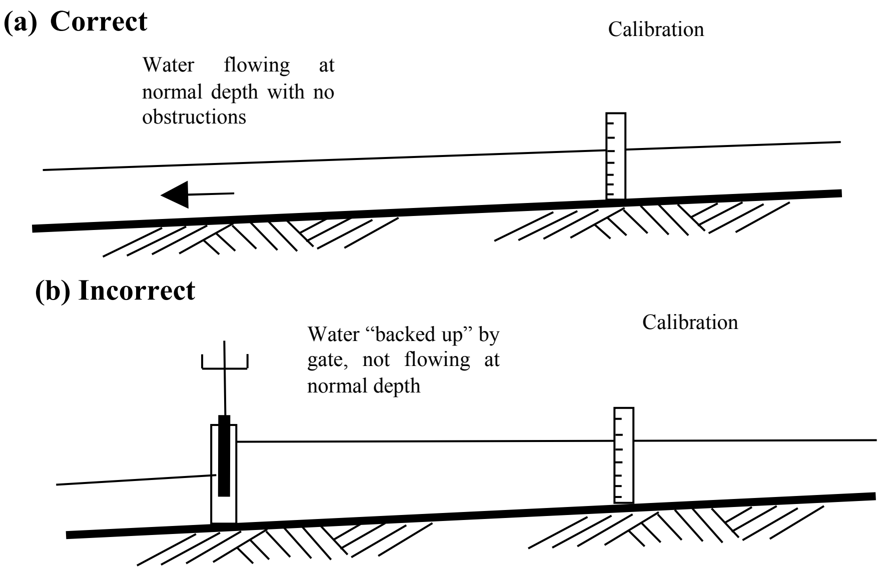

Figure 11.2 Correct and incorrect positions to establish a stage discharge curve

11.2.1 Measurement technique - float method

The float method is a simple, yet effective, way to determine the discharge of a flow stream. It is well suited to smaller channels, less so to larger channels where the variation in velocity across the channel will vary significantly. It will still, however, give a better estimate of the flow than can be obtained by visual estimation and guesswork. The procedures for simple float measurement are outlined below:

(h) Select a fairly straight, uniform and clear (of weeds) reach of channel 20-30m in length, away from areas of turbulence (such as immediately downstream of a gate or drop structure). The length of the measured section should be 10-20 times the water surface width.
(i) Place pegs in the bank to mark the start, middle and end of the section.
(j) Select a float. An orange or a small plastic container or bottle weighted with sand or stones are suitable as they float just below the surface and are not influenced by wind.
(k) Release the float in the centre of the channel about 2-3 m upstream of the start peg to allow the float time to adjust to the flow rate. Measure the time it takes the float to travel over the measured section, and repeat the exercise at least three times to obtain an average surface flow velocity in metres per second.
(l) Measure the cross sectional areas at the start, middle and end of the section using a level staff or graduated rod and tape. Calculate the average cross sectional area of the measured section.
(m) The float measures the surface velocity, which is higher than the mean velocity of flow (Figure 11.3). The mean velocity is given by multiplying the surface (float) velocity by a reduction factor; a value of 0.7 is typically used. The discharge is then obtained by multiplying this mean velocity by the average cross sectional area (Figure 11.4).

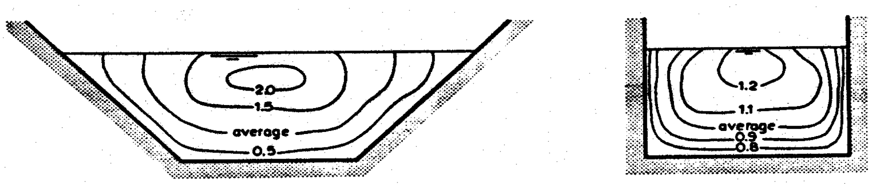

Figure 11.3 Typical velocity distribution within a channel

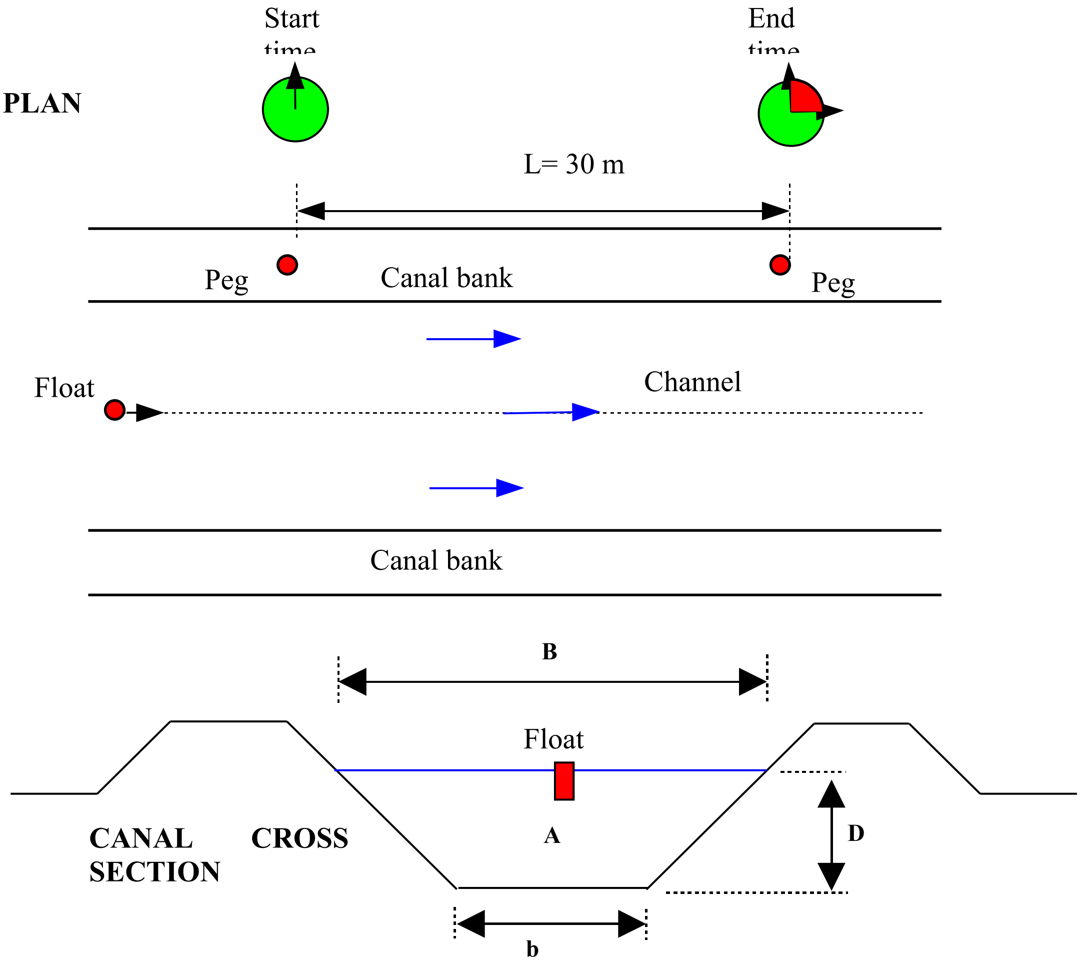

Figure 11.4 Example of calculations for discharge measurement using a float

Description	Data	Formula	Calculation	Result
Canal bed width – b (m)	0.60	b		
Flow top width – B (m)	2.00	B		
Flow depth – D (m)	0.70	D		
Area – A (m^2)		$D \times \frac{(b+B)}{2}$	$0.70 \times \frac{(0.60+2.00)}{2}$	0.91
Float time –T (secs)	70, 74 and 72 secs	$\frac{T_1 + T_2 + T_3}{3}$	$\frac{70+74+72}{3}$	Average = 72 secs
Distance between pegs - L (m)	30	L		
Float velocity – V (m/s)		$\frac{L}{T_{av}}$	$\frac{30}{72}$	0.42
Float coefficient	0.7			
Average flow velocity (m/s)			0.7 x 0.42	0.29
Discharge (l/s)			0.29 x 0.91 x 1000	264

11.2.2 Current metering

Current metering when carried out correctly can be a very accurate method of determining discharge. Using the two point method measurements can be accurate to within ± 5 % of the true discharge, using the single point method measurements can be within ±10 % of the true discharge. The procedures for current metering are outlined below:

(a) Select a fairly straight, uniform and clear (of weeds) reach of channel, away from areas of turbulence (such as immediately downstream of a gate or drop structure). The length of the measured section should be 10-20 times the water surface width.
(b) Stretch a guide rope or tape across the water surface, perpendicular to the streamflow.
(c) Measure the total surface width and divide it up into equally spaced sections such that no section occupies more than 10% of the flow area. If using a rope place tags on the rope to mark the boundaries of each section (Figure 11.5).
(d) For the two point method measure the flow velocity using a current meter at 0.2 and 0.8 of the stream depth (measured form the surface). For the one point method measure the flow velocity at 0.6 of the stream depth (measured from the surface). Take measurements at the (horizontal) centre point of each section, taking at least two measurements at each point. If the measurements differ by more than + 10% take a third. Ensure that the current meter is parallel to the streamflow, and is clear of any weeds.
(e) Calculate the flow velocities at each point using the current meter calibration tables. For the two point method calculate the mean velocity by taking the average of the 0.2 depth and 0.8 depth readings.
(f) Measure the depth and horizontal position at each vertical division of the sections. Multiply each section's area by its average velocity to obtain the section discharge and summate all to obtain the total discharge.
(g) It is a wise precaution to always carry out the calculations before leaving the site and to check the value obtained against a rough estimate made by a simple float measurement.
(h) Monitor water levels at the start and end of the flow measurement period by taking a reading of a nearby gauge board, or by placing a peg at the water's edge at the start. Note any changes in level. Significant variation in water level during the flow measurement period will obviously adversely affect the accuracy of the discharge value obtained.

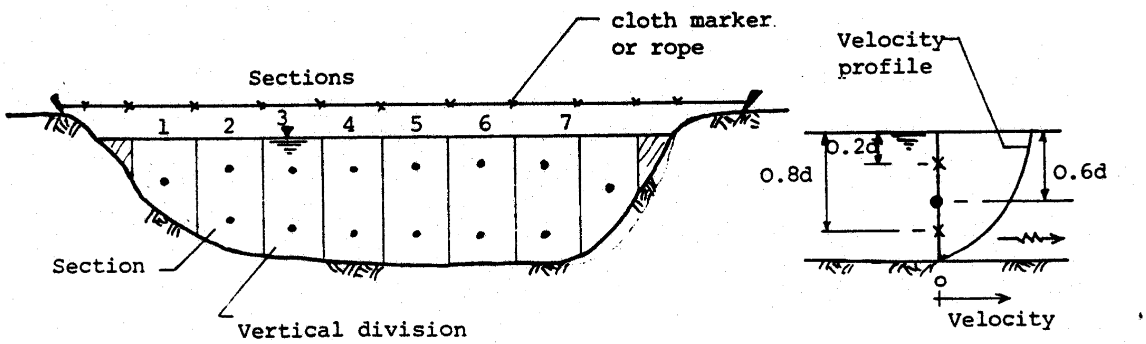

Figure11.5 Sectioning of a channel for flow measurement.

11.3 Hydraulic structures

Hydraulic structures are commonly used to measure discharge at control points. If constructed to the standard designs, they provide an easy to use and accurate method of discharge measurement. Whilst standard measuring structures are often installed for flow measurement, many structures can be used if they are calibrated (using a current meter). Such structures include gates, drop structures and division structures.

There are four main categories of hydraulic structures used for measurement:

- broad crested weirs
- short crested weirs
- flumes
- orifices
- sharp crested weirs

It is important to note that the discharge measuring structure does not reduce the flow entering the canal; this is often a cause of concern amongst farmers who may sometimes damage measuring structures as they think it is impeding the flow. The structure raises the water level upstream by 5-10 centimetres and increases the velocity of flow in the canal section over the weir crest. The discharge is the same as in the canal without the measuring structure.

Where the canal is on a slope, the measuring structure will create a higher water level for a short distance upstream after which the flow depth will return to the normal depth for the canal (Figure 11.6). At some distance from the measuring structure the flow depths upstream and downstream of the measuring structure will be the same, with no interference from the measuring structure.

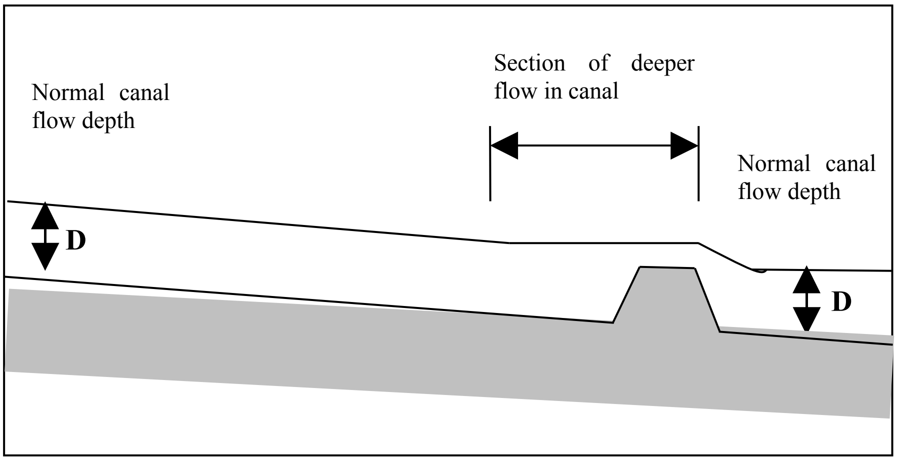

Figure 11.6 Zone of interference from discharge measuring structure

11.3.1 Theory for hydraulic structures

The theory behind hydraulic structures is complex and lengthy, and is well described elsewhere (Bos, 1989). A brief summary of some of the key points are, however, of value in understanding the practical functioning of such structures. For practical purposes with discharge measuring structures we are interested in relating a single measurement of water depth to the discharge flowing over the structure. For some measuring structures the relationship between depth and discharge can be derived mathematically, in others it must be determined empirically through measurements in a laboratory where standard depth-discharge tables can be derived.

For broad-crested weirs, flumes, orifices and short-crested weirs the head-discharge relationship can be derived mathematically, for short-crested weirs hydraulic model tests are required. Analysis of broad-crested weirs and flumes is similar, whilst sharp-crested weirs can be considered to behave as orifices with a free water surface.

For broad-crested weirs and flumes flow is contracted such that the flow passes from sub-critical through critical depth and back to sub-critical. In the weir the base of the channel is constricted, in the flume the sides and possibly the channel base is constricted (Figure 11.7). The key features are that the approach velocity approximates to zero, and the control section (the weir crest/ flume throat) is long enough to enable the critical depth to be achieved.

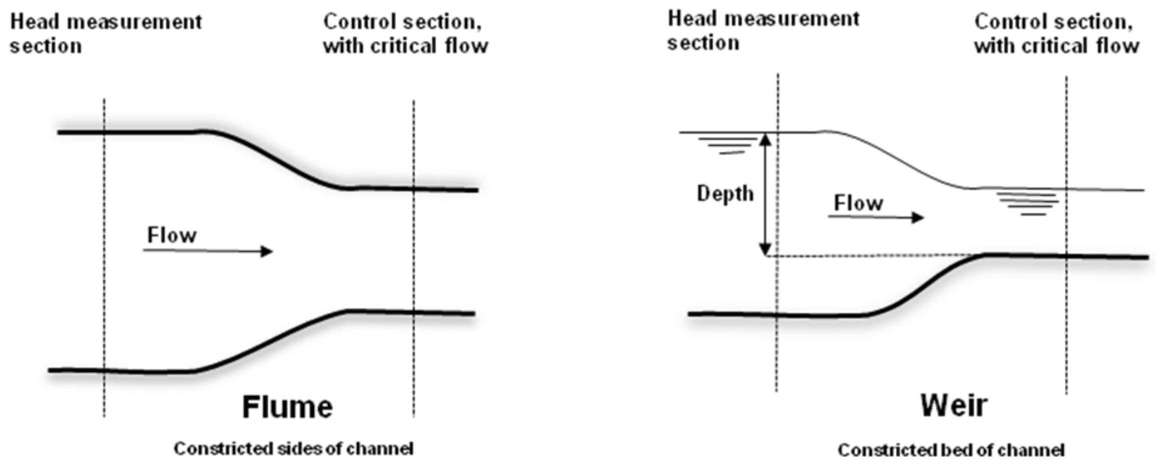

Figure 11.7 Constriction of Channel to Form Control Section for Discharge Measurement

From an analysis of specific energy[13] in an open channel, it is apparent that the specific energy is a function of water depth alone. A plot of water depth against specific energy gives a curve as shown in Figure 11.8. This shows that for a given specific energy level, except the minimum, there are two alternate depths of flow. These correspond to "subcritical" and "supercritical" flow conditions. In the subcritical state the flow is slow and deep, in the supercritical state it is fast and shallow. It can be seen from Figure 11.8 that at the minimum specific energy level there is only one value of depth, referred to as the *critical depth.* By the nature of the characteristics of critical flow, a change in downstream water level cannot influence the upstream water level if critical flow conditions exist between the two sections considered. In a measuring structure, the channel cross section is constricted such that the specific energy level is reduced from subcritical through the minimum to supercritical. The transition from supercritical back to subcritical occurs downstream of the control section in the form of an hydraulic jump.

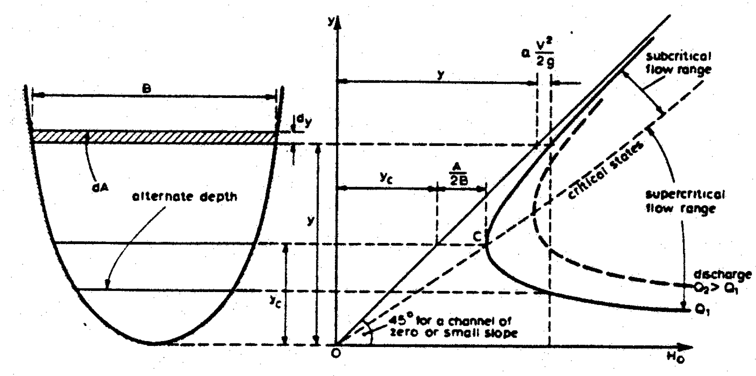

Figure 11.8 Specific energy curve

[13] Defined as the average energy per unit of water at a channel section with respect to the channel bottom

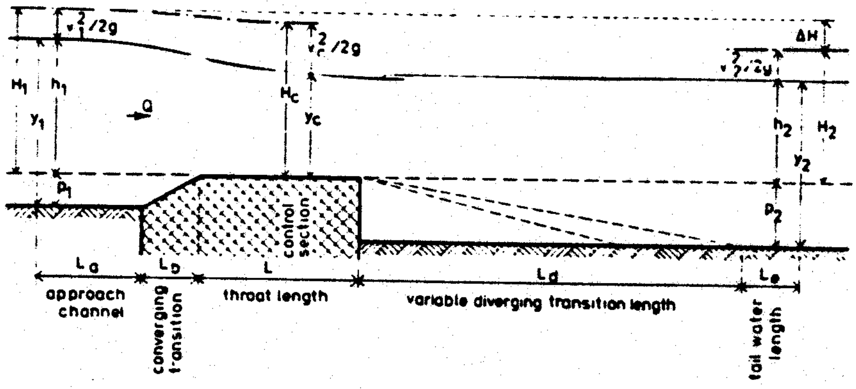

Figure 11.9 Terminology for broad-crested weir

Thus for a broad-crested weir (Figure 11.9), the relationship between the velocity at the critical depth, Bernoulli's equation and the continuity equation the general head-discharge equation for a broad-crested weir with a rectangular control section can be determined:

$$Q = Cd\ Cv\ \frac{2}{3} \left(\frac{2}{3}g\right)^{0.50} bc\ H1^{1.50}$$

Where the discharge coefficient C_d depends on the shape and type of the measuring structure, and C_v is a correction coefficient for neglecting the velocity head in the approach channel. The relationship between the value of C_v and the ratio of the upstream approach area to the control section area is shown in Figure 11.10. The importance of this figure for practical purposes is that it demonstrates the influence that the upstream channel dimensions have on the discharge through the control section. These dimensions are decided and fixed at the design stage, and, for accurate measurement, must be maintained throughout the working life of the structure. Sediment removal upstream of the structure is thus required periodically to maintain the designed section.

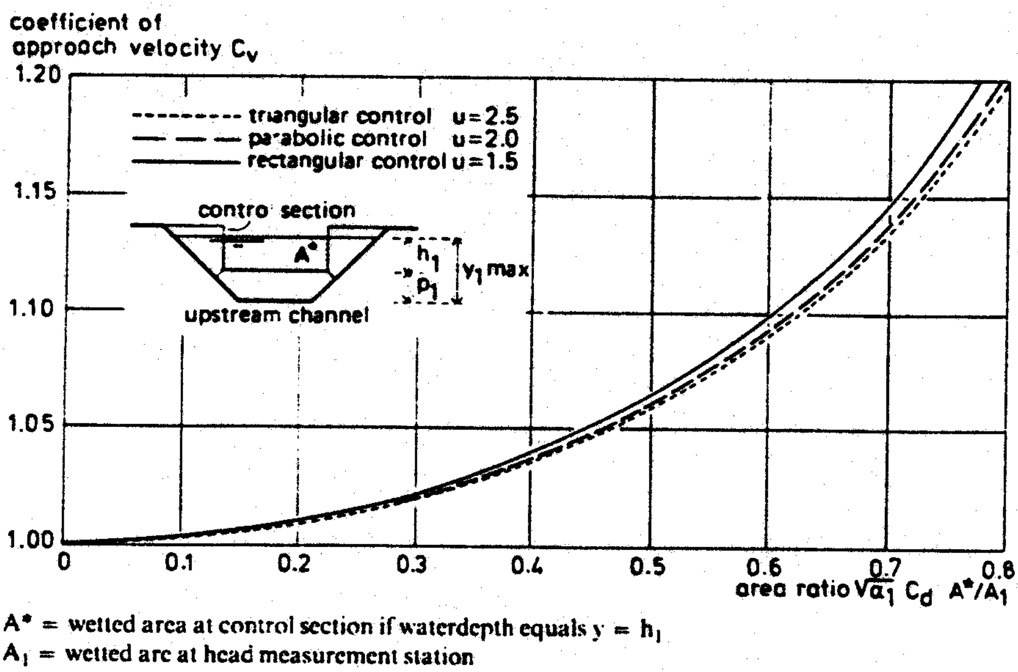

Figure 11.10 C_v values as a function of upstream and control section area ratios

(from Bos, 1989)

The rather complicated equation given above reduces to the more usable formula:

$$\mathbf{Q = 1.71\ bh^{1.5} \quad or \quad Q = 1.71\ bh^{3/2}}$$

From this equation depth discharge tables can be formulated, as shown in Table 11.1.

For *short-crested weirs* the streamlines are not parallel, thus the mathematical derivation of the head-discharge relationship is more complex, and cannot be resolved by current theory. In this case experimental data can be made to fit the head-discharge relationship for broad-crested weirs, with the discharge coefficient expressing the influence of streamline curvature in addition to the factors it accounts for with broad-crested weirs.

For *orifices* the velocity of flow through the orifice is directly related to the head (Figure 11.11). Thus:

$$\mathbf{v = \{2gH_1\}^{0.5}}$$

Introducing Cv and Cd to correct for assumptions regarding the velocity head and the location (relative to the channel sides) and condition of the orifice, then the above equation becomes:

$$\mathbf{v = C_v\ C_d\ \{2gh_1\}^{0.5}}$$

Allowing for the difference in size between the vena contracta and the orifice, the discharge through the orifice can be expressed as:

$$\mathbf{Q = C_v\ C_d\ A\ \{2gh_1\}^{0.5} \quad or \quad Q = C_e\ A\ \{2gh_1\}^{0.5}}$$

where C_e is the effective discharge coefficient.

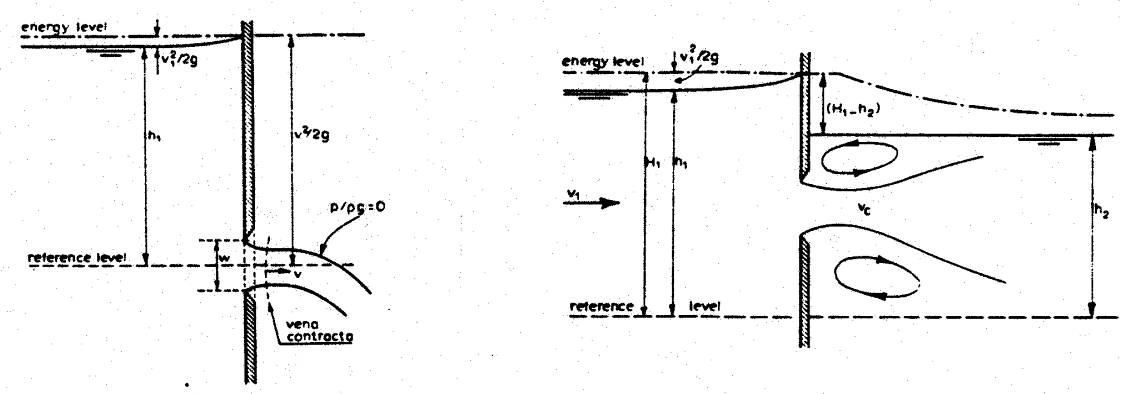

Figure 11.11 Flow patterns through free and submerged orifices

For the derivation of head-discharge relationships sharp-crested weirs can be likened to an orifice with a free water surface. For a rectangular control section this reduces to:

Q = Ce <u>2</u> (2g)0.5 bc h11.5
3

For a Cipoletti weir the formula reduces to:

$$\mathbf{Q = 1.86\ bh^{1.5} \quad or \quad Q = 1.86\ bh^{3/2}}$$

for which depth-discharge tables can be drawn up for field use (Table 11.1)

Table 11.1 Discharge measurement tables for Cipoletti and broad-crested weirs

DISCHARGE MEASUREMENT TABLES

h	Discharge L/S														h
	Cipoletti Weir $Q = 1.86\ b\ h^{3/2}$							Broad Crested Weir $Q = 1.71\ b\ h^{3/2}$							
	b (m)							b (m)							
cm	0.50	0.60	0.80	1.00	1.25	1.50	2.00	0.50	0.60	0.80	1.00	1.25	1.50	2.00	cm
5	10	12	17	21	26	31	42	10	11	15	19	24	29	38	5
6	14	16	22	27	32	41	55	13	15	20	25	31	38	50	6
7	17	21	28	34	43	52	69	16	19	25	32	40	48	63	7
8	21	25	34	42	52	63	84	19	23	31	39	48	85	77	8
9	25	30	40	50	63	75	100	23	28	37	46	58	69	92	9
10	29	35	47	59	73	88	118	27	32	43	54	68	81	108	10
11	34	41	54	68	85	102	136	31	37	50	62	78	94	125	11
12	39	46	62	77	97	116	155	36	43	57	71	89	107	142	12
13	44	52	70	87	109	131	174	40	48	64	80	100	120	159	13
14	49	58	78	97	122	146	195	45	54	72	90	112	134	179	14
15	54	65	86	108	135	162	216	50	60	79	99	124	149	199	15
16	60	71	95	119	149	179	238	55	66	88	109	137	164	219	16
17	65	78	104	130	163	196	261	60	72	96	120	150	180	240	17
18	71	85	114	142	177	213	284	65	78	104	131	163	196	261	18
19	77	92	123	154	192	231	308	71	85	113	142	177	212	283	19
20	83	100	133	166	208	250	333	76	92	122	153	191	229	306	20
21	89	107	143	179	224	268	358	82	99	132	165	206	247	329	21
22	96	115	153	192	240	288	384	88	106	141	176	221	265	353	22
23	103	123	164	205	256	308	410	94	113	151	189	236	283	377	23
24	109	131	175	219	273	328	437	101	121	161	201	251	302	402	24
25	116	139	186	232	291	349	465	107	128	171	214	267	321	428	25
26	123	148	197	247	308	370	493	113	136	181	227	283	340	453	26
27	130	157	209	261	326	391	522	120	144	192	240	300	360	480	27
28	139	165	220	276	344	413	551	127	152	203	253	317	380	507	28
29	145	174	232	290	363	436	581	134	160	214	267	334	401	534	29
30	153	183	244	306	382	458	611	140	169	225	281	351	421	562	30
31	160	193	257	321	401	482	642	147	176	235	294	368	441	588	31
32	168	202	269	337	421	505	673	154	185	246	308	385	462	616	32
33	176	212	282	353	441	529	705	161	194	258	323	404	483	646	33
34	184	221	295	369	461	553	737	168	202	269	337	421	504	674	34
35	193	232	309	385	481	578	770	176	211	281	352	440	528	704	35
36	201	241	321	402	502	603	804	185	222	296	370	462	555	740	36
37	208	251	335	419	523	628	837	191	229	306	382	477	573	764	37
38	218	262	349	436	544	654	871	200	240	320	400	500	600	600	38
39	226	272	362	453	566	680	906	208	250	333	416	520	624	832	39
40	235	283	376	471	588	706	941	216	259	346	432	540	648	864	40
41			390	488	610	732	976			359	449	561	674	898	41
42			405	506	633	759	1012			372	465	581	698	930	42
43			419	524	655	786	1048			386	482	603	723	964	43
44			434	543	679	815	1086			399	499	624	749	998	44
45			449	561	701	842	1122			413	516	645	774	1032	45
46			464	580	725	870	1160			426	533	666	800	1066	46
47			479	599	749	899	1198			440	550	688	825	1100	47
48			495	618	773	927	1236			455	569	711	854	1138	48
49			510	637	796	956	1274			469	586	733	879	1172	49
50			526	657	821	986	1314			483	604	755	906	1208	50
51			542	677	846	1016	1354			498	622	778	933	1244	51
52			558	697	871	1046	1394			513	641	801	962	1282	52
53			574	717	896	1076	1434			528	660	825	990	1320	53
54			590	738	923	1107	1476			542	678	848	1017	1356	54
55			607	759	949	1137	1518			558	697	871	1046	1394	55
56				779	974	1169	1558				716	895	1074	1432	56
57				800	1000	1200	1600				736	920	1104	1472	57
58				822	1028	1233	1644				755	944	1132	1510	58
59				843	1054	1265	1685				774	968	1161	1548	59
60				864	1080	1296	1728				795	994	1193	1590	60
h	0.50	0.60	0.80	1.00	1.25	1.50	2.00	0.50	0.60	0.80	1.00	1.25	1.50	2.00	h

Q = Discharge in litres/sec.
b = Weir crest width (m)
h = Head over weir (cm)

11.3.2 Broad crested weirs

Broad crested or long based weirs are structures that induce the streamlines to flow parallel to each through the control section. To achieve this, the length of the weir must be long enough in relation to the upstream head H. The essential features of such devices are given in Figure 11.12.

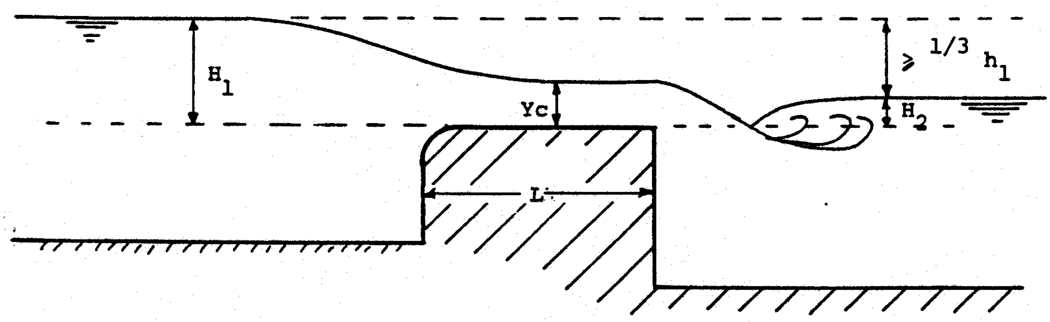

Figure 11.12 Essential features of broad crested weirs

Broad crested weirs are more robust than sharp crested weirs, though they are not as accurate. They have a high modular limit and thus do not require such a high head loss across the structure. For a structure in a channel with an operating discharge range of 30-120 ls^{-1}, a sharp crested weir would require a minimum head loss of 0.15 m and a maximum head loss of 0.31 m (Cipoletti, breadth 0.50 m). A round nosed broad crested weir would require a minimum head loss of 0.03 m and a maximum head loss of only 0.09 m. Their main disadvantage is the difficulty of construction which involves forming parallel faces, a uniform and horizontal crest and smooth, even upstream curves in the case of round nosed weirs.

11.3.3 Short crested weirs

With short crested weirs the streamlines are not parallel over the crest, as is the case with the broad crested weirs. The streamline curvature has a significant influence on the head-discharge relationship. A typical short-crested weir is the Crump weir (Figure 11.13). This weir is suitable for many sizes of canals and rivers, is accurate, relatively cheap and easy to construct and has a high modular limit. With crest tappings to measure the pressure head over the weir crest discharges can be determined beyond the modular limit. An additional important benefit is that the structure passes sediment freely.

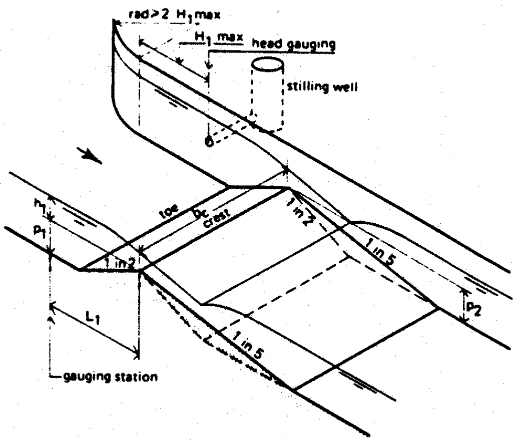

Figure 11.13 Crump weir

11.3.4 Flumes

Flumes are similar in principle to weirs except that the constriction of flow is obtained by narrowing of the vertical walls of the structure, rather than raising the bed level. Flumes are ideal measuring devices where there is a high sediment load, and require a relatively low head loss. They can be difficult and expensive to construct (especially the Parshall flume), and for short throated flumes having to derive the head-discharge relationships empirically means that the range of sizes available is limited. Flumes can be divided into two categories:

- long throated
- short throated.

A long throated flume (Figure 11.14) is a geometrically specified construction built in an open channel, where sufficient fall is available for critical flow to occur in the throat of the flume. The theory for critical depth flumes is the same as for broad crested weirs, as they both constrict the streamlines to parallel flow in the control section. As a result, the design of the structure can be treated analytically.

Short throated flumes produce a large curvature in the water surface and the flow in the throat is not parallel to the flume invert. Their design cannot be treated analytically and it is not possible to predict the stage-discharge relationship, this has to be done through laboratory and field calibration. Examples of short throated flumes are the Parshall flume (Figure 11.15), H-flume and the cut-throat flume (Figure 11.16).

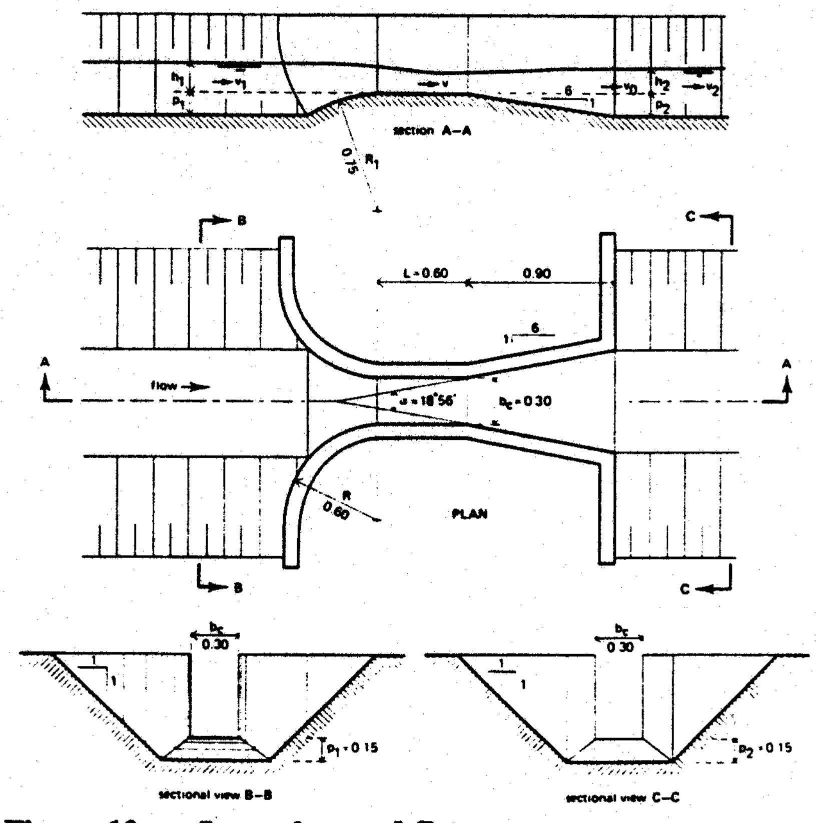

Figure 11.14 Long throated flume

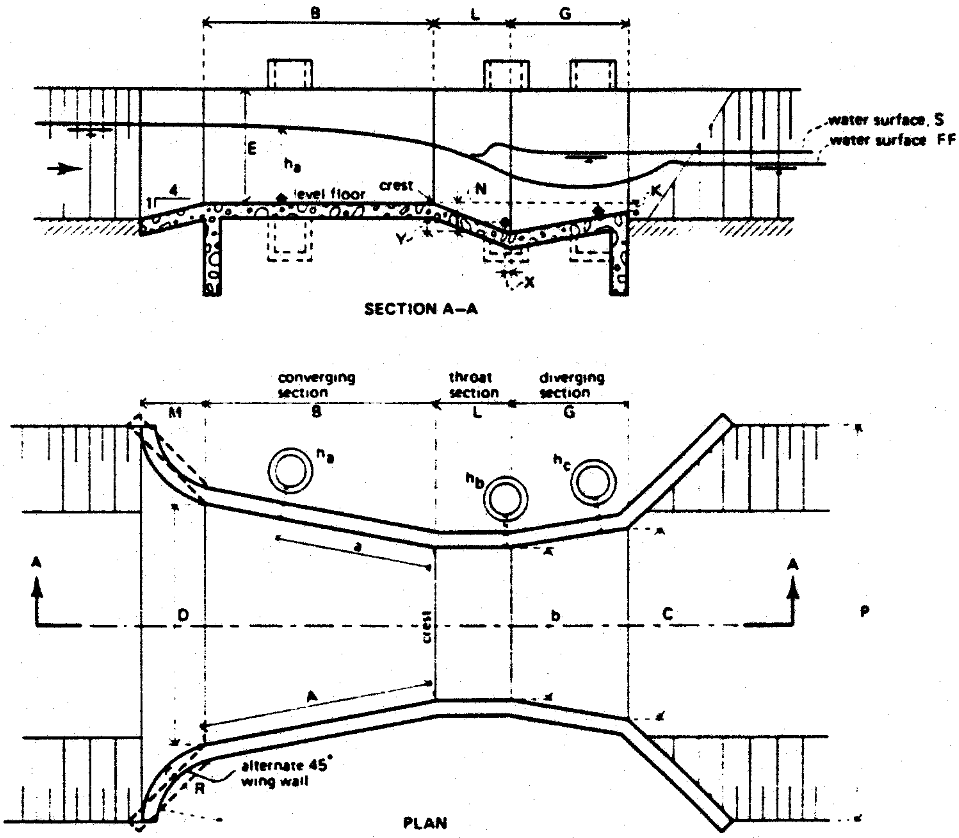

Figure 11.15 Parshall Flume

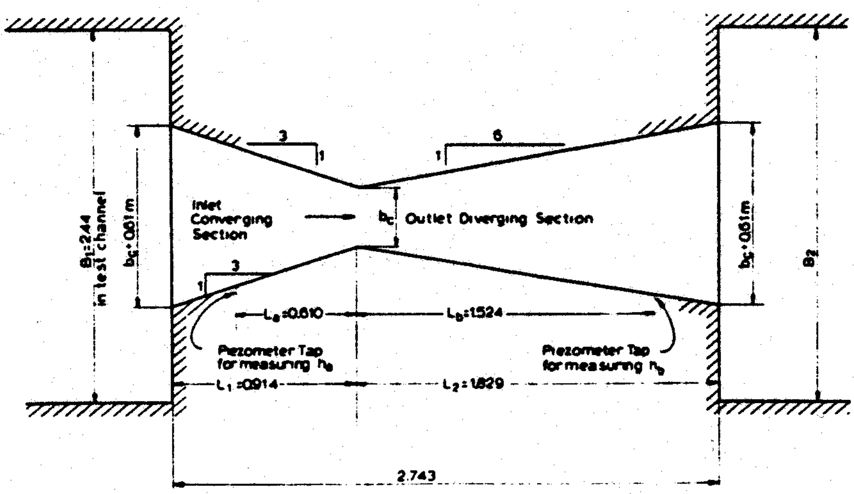

Figure 11.16 Cut throat flume

(a) Measuring the discharge in a primary canal using floats

(b) Measuring the discharge in a primary canal using a current meter

(c) Cipoletti weir

(d) Using a portable Parshall flume to measure the flow in a farmer's furrow

(e) Construction of a Replogle weir in an existing lined canal

(f) Well functioning Replogle weir on a main canal, note the even flow over the weir crest, the head loss and hydraulic jump at the downstream face (Albania)

(g) Neyrtec proportional distribution modules for flow control and measurement

(h) Portable sharp-crested rectangular weir for discharge measurement in small channels

Figure 11.17 Photographs of a range of measuring structures

11.3.5 Orifices

Free flow or submerged orifices can be used for measurement purposes. There are a wide range of orifice structures, some of which are designed specifically for measurement purposes (such as the constant-head orifice and the Metergate) and some which, though not designed specifically for the purpose, can be calibrated and used for measurement (undershot gates are an example).

The constant-head orifice (CHO) is a combined regulating and measuring structure which originates from the United States. It uses an adjustable submerged orifice for measuring the flow and a (downstream) adjustable gate for flow regulation. Operation of the structure is based on setting and maintaining a constant head differential across the measuring orifice. Discharges are varied by changing the area of the orifice, and then adjusting the downstream gate to produce a 0.06 m differential across the orifice. They are robust, and are said to be easy to set and use, though in some locations it is found that only one of the gates is actually adjusted for flow regulation not discharge measurement.

A simplified structure using one set of gates is the Neyrpic module, which is designed to pass an almost constant discharge for a relatively wide range of variation in upstream head (Figure 11.18). Variations in upstream head of between 0.20 - 0.50 m result in variations of discharge through the module of only $\pm$ 10%. A variety of discharges can be passed by opening a combination of gates. Discharge is proportional to gate width, with each module having a set of gates with different widths. A module with 5 gates - two of 30 ls^{-1}, one of 20 ls^{-1} and two of 10 ls^{-1} will pass any discharge in units of 10 ls^{-1} from 10 to 100 ls^{-1}. The module is robust, has a relatively high modular limit (0.6) and is easy to use and to install. It has the added advantage that the discharge is "visible" to water users in that it is proportional to total open gate width, a concept that traditional water users are familiar with. Their main disadvantage is that they are prone to clogging by debris and need fairly regular clearing.

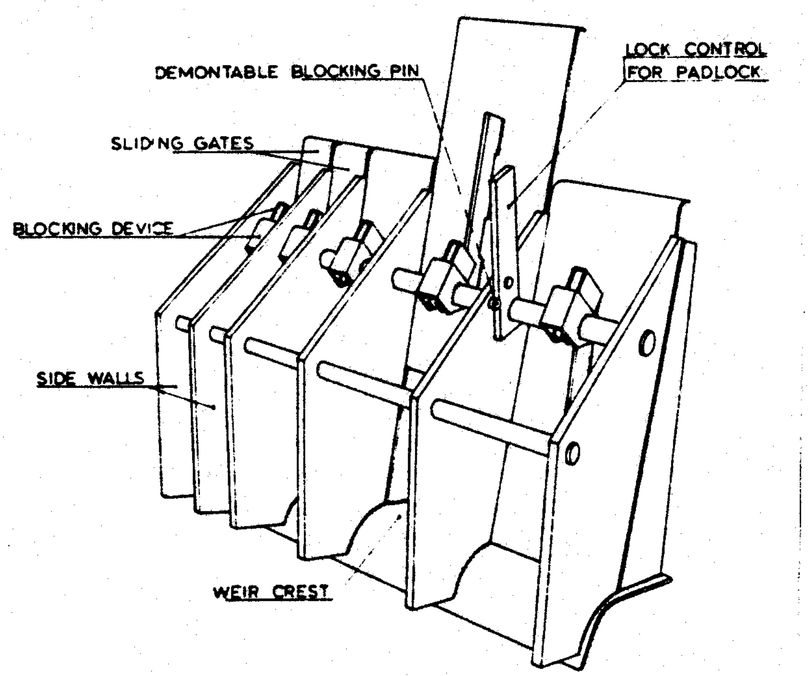

Figure 11.18 Neyrtec flow control and measurement structure

Ordinary flow regulation gates can be used for discharge measurement (Figure 11.19), though they generally have to be individually calibrated due to the variation in the flow conditions through the gate opening (dependent on gate thickness, side wall and bed shape and condition). The parameters required to determine the discharge are:

- upstream head
- downstream head
- gate width
- gate opening
- discharge coefficient

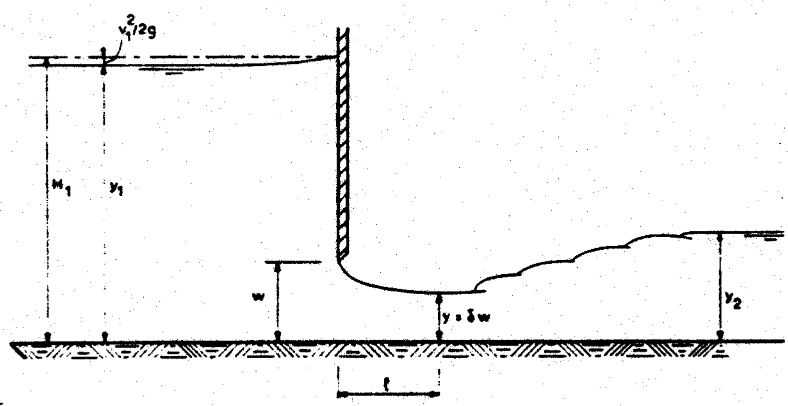

Figure 11.19 Discharge measurements through a gate

By calibrating the gate for different upstream and downstream heads, including gate openings, a discharge coefficient graph can be obtained. This can then be incorporated into the general orifice discharge equation to enable the discharge to be determined for any setting.

11.3.6 Sharp crested weirs

Sharp crested or thin plate measuring devices include Cipoletti weirs, V-notch weirs and rectangular weirs. The principal features of such devices are shown in Figure 11.20; there is a sharp edge, uniform approach streamlines upstream and an aerated nappe.

These devices, if correctly installed and well maintained, are extremely accurate (± 5%). Their disadvantages are that the sharp crest is prone to damage by floating debris, a relatively large head loss is required for correct operation and they are prone to sedimentation upstream, and thus inaccuracies in measurement.

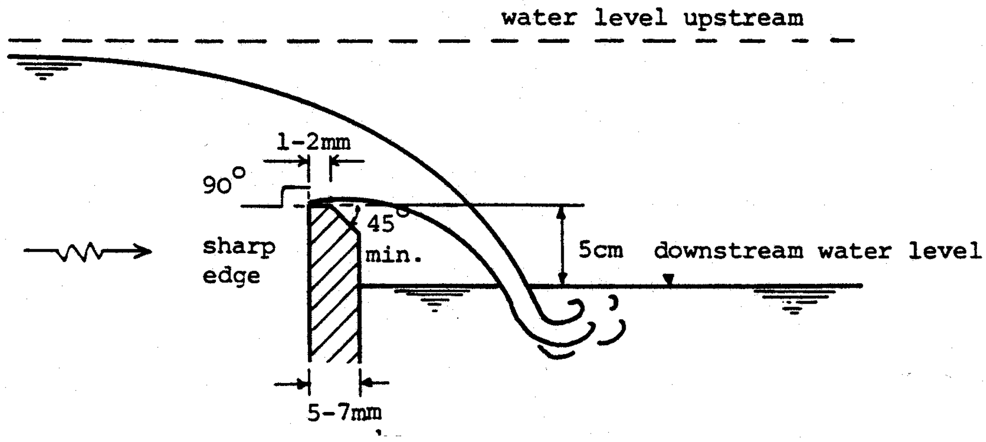

Figure 11.20 Principal features of sharp crested measuring structures

11.3.7 Flow meters

Flow meters are propellers or vanes which, like a current meter, rotate as a result of the forces acting on them by flowing water. There are two common models, the propeller meter and the Detheridge meter.

The propeller meter (Figure 11.21) is commonly used for flow measurement in pipes. It is a totalizing meter in that the number of revolutions is proportional to the total flow passing. The propeller should always be fully submerged. An alternative to the propeller meter following recent developments in electronic engineering is the use of non-intrusive ultrasonic and electromagnetic flow measurement devices. These operate in a variety of ways either through Doppler shift or the accurate measurement of time of travel of ultrasonic signals located on opposite sides of the pipes.

The Detheridge meter (Figure 11.22) is widely used for flow measurement in Australia at turnouts into farm units. It is of interest as it is one of the few totalizing (or volumetric) measuring devices available for open channel flow. It an undershot water wheel with eight blades which rotates as the water flows under the cylinder. The discharge is regulated by a small sluice gate located upstream of the water wheel. The discharge range is 40-140 ls^{-1} for the large meter and 15-70 ls^{-1} for the smaller meter. It is accurate ($\pm$ 5%), fairly simple and robust and operates with a relatively low head loss (approx. 0.15 m). Its great advantage is that it measures the volume of water delivered to the farm unit and thus enables the water supply agency to charge the water user for the volume of water used. It does, however, require regular maintenance to function correctly.

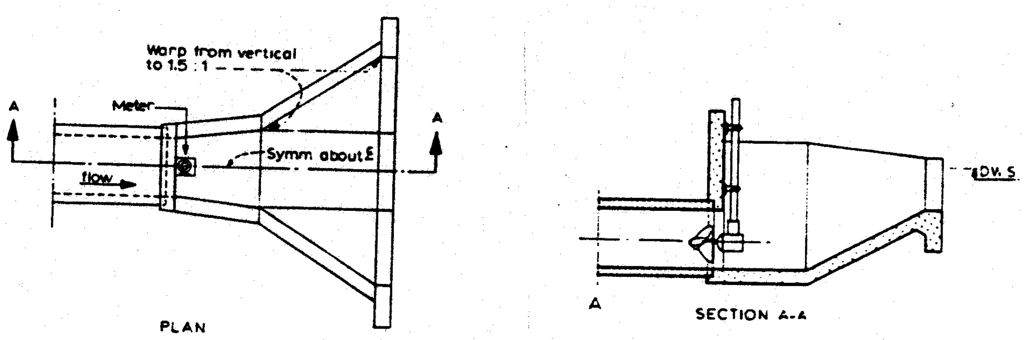

Figure 11.21 Flow meter

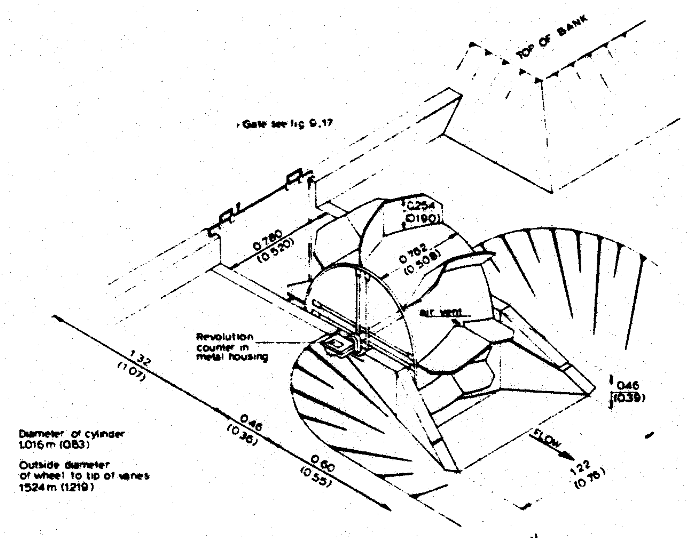

Figure 11.22 Detheridge meter

11.4 References

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Clemmens, A.J., Wahl T.L., Bos . M.G., Replogle J.A. Water Measurement with Flumes and Weirs,. ISBN 90 70754 55 X (Cat. No. WMFW). ILRI Publication 58.

.12 Farmers' Participation and Water Users Associations

12.1 Overview

There are two main routes by which a communally managed irrigation and drainage system may have come into being:

- Through community action, without government support (traditional irrigation and drainage systems).
- As part of a government programme of irrigation management transfer.

The perceptions and role of government, management and water users will be different depending on which of these processes has taken place. Traditional I&D systems, such as those seen on the slopes of Mount Kilimanjaro and in the Pare Hills in Tanzania, have grown up over a period of time as a result of local endeavour, and often originate at a time when there was little or no central government. Other schemes have been identified, designed, constructed and initially managed by government agencies before being transferred to management by the water users.

In the former model, the rules and regulations governing the management of the scheme and access to water have been formulated locally, often through trial and error over a period of time. In the latter model, the rules and regulations have been formulated by the government agency, often following models developed in other countries. Either model is valid, but significant work is needed in the second case to build up the required sense of ownership and commitment, and to develop the required levels of responsibility that comes with this sense of ownership and commitment.

12.2 Water Users' Participation

Much has been written in recent years about water users' participation in the management, operation and maintenance of I&D schemes. Though social scientists have recognised for some while that water users' (farmers') participation is essential to the long term sustainability of the I&D system, this has not always been the case with other stakeholders involved in irrigation and drainage, particularly with technical personnel (engineers) and agencies. The appreciation of the importance of involving the water users of both genders[14] is fortunately changing, and genuine efforts are now being made by technical personnel and agencies to engage with water users. Some of the key factors involved in engaging with water users are outlined in the sections below.

12.2.1 Overview

Rural communities are generally more homogenous than urban communities, but there water users are still heterogeneous – individual water users have different ages, education, level of experience, landholding size, family size, level of wealth, etc. It is therefore difficult to engage with these individuals in a way that is useful to each of them, and where there is a common interest.

Engaging individuals in common activities creates the required sense of ownership, community and communal benefit. Such activities include:

Table 12.1 Common activities within rural communities

Water acquisition and	• Acquisition

[14] HR Wallingford. Developing the skills and participation of women irrigators Ref: OD135. F Chancellor , 1997. http://books.hrwallingford.co.uk

management	• Allocation • Distribution • Drainage
Infrastructure development	• Design • Construction • Operation • Maintenance
Management	• Decision-making • Resource mobilisation • Communication • Conflict resolution
Agriculture	• Acquisition of inputs • Land preparation and planting • Weeding • Harvesting • Marketing

12.2.2 Factors affecting participation

Farmer/water user participation is influenced by the wider environment. In environments where resources are scarce, engagement with groups outside the immediate family can sometimes be problematic, as each family group are striving to gain access to limited resources. In environments where resources are abundant, group action can also be problematic as there is little perceived need to work together.

Typical factors influencing participation are presented in Table 12.2.

Table 12.2 Factors influencing participation by water users

Domain	Factor	Explanation
Physical	Water supply	The water supply availability may influence participation in water management (Figure 12.1). With an abundant supply there may be no perceived need to work together, as the scarcity increases so water users are more likely to work together. In very water scarce situations each family may be forced to fend for themselves.
	Origins of I&D infrastructure	If the water users have built the I&D system themselves they are likely to operate and maintain it reasonably well. If the I&D system has been built by government participation and thus OandM may not be so good, at least in the early years after handover.
	Condition of system	Water users may be willing to participate and work together to maintain a system that is in a reasonable state, but may not have the resources to maintain a system in a poor state.

Socio-economic	Landownership and tenancy	The distribution of water users who are landowners or tenants influences how water users work together. Tenants need a role and a say in the management of the association and in how water is allocated.
	Heterogeneity and homogeneity	In a very heterogeneous society it may be difficult to get sufficient numbers to work together for the common good. In homogeneous societies the likelihood of water users working together is increased as they have common needs.
	Role of agriculture	If agriculture is important there is a greater likelihood of participation, as working together can be of benefit to everyone's livelihoods.
	Location relative to markets	Access to markets is a key factor influencing farmers' livelihoods. Water users are more likely to collaborate and work together where there is financial advantage in doing so.
	Level of income	The level of income influences the manner of participation. If the income level is high water users will contribute with cash, if the level of income is low they are more likely to contribute in kind with labour and/or agricultural produce.
	Residence	Participation is impeded in systems with high levels of absentee landowners/landlords. There is less of a common cause around which to associate, unless the tenants are given rights within the association.
	Full- or part-time farming	There is less willingness to participate and work together in when the water user is only a part-time farmer, especially if they are deriving a significant proportion of their income from the other activities.
Political and organisational	Compatibility of objectives	A government's objectives in handing over an I&D system to water users may differ from those of the water users. Participation is less assured if water users perceive the hand-over as government divesting itself of its responsibilities, or as a method of tax-collection.
	Political status	It is important to keep politics out of water users associations, it can be divisive. There are other more suitable channels for political expression.
	Recognition of farmers	In the past government agencies and technical personnel have tended to look down on farmers. Such attitudes are wrong and outdated, and need to change if government agents and water users are to work together.
	Agency capabilities, resources and incentives	Forming of water users associations does not mean that government agencies are no longer involved in an I&D scheme. The relationship changes, as do the perceptions and attitudes of agency personnel and of water users.

Note: After Uphoff, 1990.

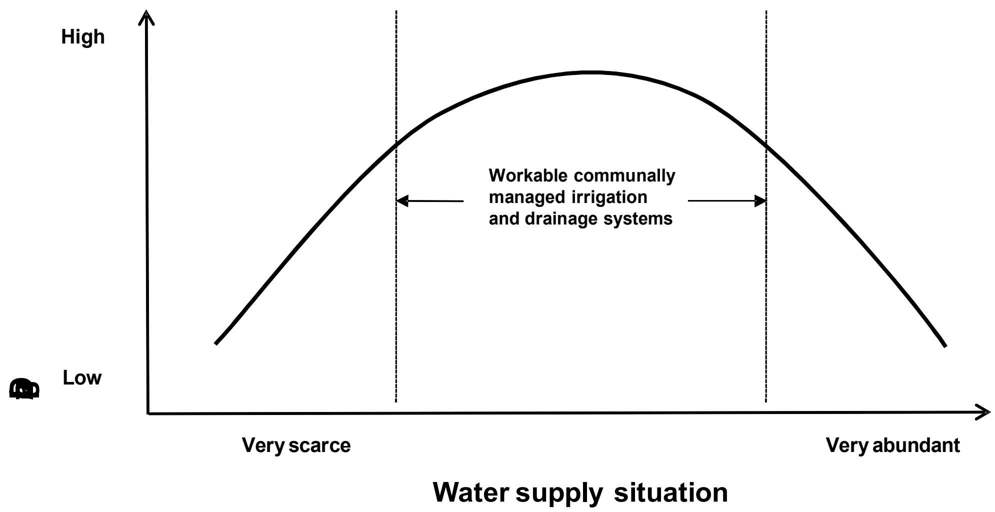


Figure 12.1 Relationship between water supply situation and water user participation

12.2.3 Diversity

It is important to recognise that farming communities are heterogeneous (diverse). Possible areas of diversity include: size of landholding; tenure status (owner/landlord/tenant); gender; age; ethnic origin, religion; location in the system (top, middle, tail); social status (village elder, local politician, trader, farmer, etc.); education level; financial status (rich, poor); family size; personal capability (good/poor farmer, good/poor communicator, etc.).

Identifying and recognising these individual characteristics helps in understanding the local dynamics of rural communities. Often the formation of new water users associations will depend on the existing local political and social dynamics, these may not be ideal but may be the only way to gain support for the association to get it going. Over time the dynamics will change, and more suitable structures emerge for the association.

12.2.4 Forms of participation

There are a variety of ways that water users can participate, and a number of stages in the development of the irrigation and drainage system. These are summarised below in Table 12.2.

Table 12.2 Forms of participation for water users

Stages of development	• Identification/Initiation • Planning • Design • Construction • Management • Operation and maintenance • Rehabilitation
Forms of participation	• Contribution of labour • Contribution of cash • Contribution of equipment • Contribution of goods • Contribution of time (for meetings, etc.) • Contribution of expertise (either for free or paid for, e.g. technical expertise to operate the system) • Contribution of political power, influence and connections

The different forms of contribution suit different members within the community. A village elder who has good connections with local politicians or government agencies can be invaluable in gaining external assistance and possibly funding to support the I&D system. Similarly, a local person with construction skills can be invaluable in organising and supervising repair work, as also are water users who are able to contribute their labour and tools to carry out the repair work.

As mentioned in the previous section, recognition of the diversity within the farming community allows different forms of participation, at different times in the development of the system. Membership of the association is associated with the nature and level of participation, it is important to recognise that membership “fees” can take different forms, including cash, contributions of labour, contributions of time, contributions of expertise, etc.

12.2.5 Origins of participation

The origin of water users’ participation is relevant. Forced participation is always less effective than voluntary participation. In some countries, government gives discounts to water users if they participate in water users associations, . However, these water users associations exist on paper only, and are not functional. In other countries associations have been formed as a result of a Presidential edict, whereby although the associations have been formed "on paper", they remain ineffective as organisations for the better management of water at the scheme level.

Questions to ask of participation include:

- Is it initiated by water users themselves (always the strongest form)?
- Is it voluntary, or coerced (either by local or external forces)?
- Is it collective or individual?
- Is it empowered or nominal?

In some locations irrigation and drainage systems have been transferred to management by water users but the transfer is nominal, with government retaining the right to control the activities of the association. Such approaches do not work; hence, participation will be nominal.

12.2.6 Measures of participation

It is important that the level of participation is visible and measured. The over-riding requirement here is that the level of participation is transparent to other members of the group. There have been many cases where associations have been formed and have subsequently failed, due to "free-riding" by some members. This was particularly so in Sri Lanka, where the fee contribution started at 80% and then declined to 10-15% over a 4-5 year period, as those paying realised that others were not. Measures can include the hours worked, attendance at meetings, numbers attending meetings, fees recovered, etc.

12.3 Water Users Associations

12.3.1 Overview

The establishment of water users associations (WUAs) came to prominence in the late 1980s, following work by a number of researchers on the management of irrigation and drainage systems. Studies of small-scale communally managed irrigation and drainage systems, primarily in Nepal, showed that farmers were well able to initiate, develop, construct and sustainably operate and maintain irrigation and drainage systems. They also found that there were formal institutional arrangements[15] governing the management of these systems.

Following on from this work, and the increasing pressure on government resources, the concept of transferring the management, operation and maintenance of government-run irrigation and drainage systems evolved. As a result, the phrase "irrigation management transfer" was coined. One of the primary reasons for governments transferring these irrigation and drainage systems to water users has been to save costs. This has been an area of concern to water users, who become concerned about the cost of managing the I&D systems. However the transfer presents the water users with significant opportunities to improve the performance of their I&D systems, and thereby improve the benefits arising from irrigated agriculture.

Many countries have started the process of establishing water user associations. There has been mixed success with the process, with considerable success in some countries, such as Mexico, Turkey and Kyrgyzstan, and failures in others, such as in South Africa.

Forming water users associations is part of a change management process and may involve changes in the following areas:

- Public policy and legislation

[15] Formalised organisational structures, with staff, and rules and regulations which had been discussed and agreed by all participants in the system.

- Social attitudes, rights, roles and responsibilities
- Financing arrangements
- Government agencies (restructuring following irrigation management transfer)
- Relationships between government agencies and water users
- Relationships between water users.

When embarking on a programme to form water users associations, it is necessary to understand the wider picture and to appreciate the fundamental changes that it will bring about through empowerment of the farming community. This empowerment takes some of the burden for managing and sustaining irrigation and drainage schemes off government agencies, but it does not mean that the agency is no longer involved in the scheme. All in all, the relationship changes, from a situation where the government agency is an implementing agency, to one where it is a service provider and facilitator, working in partnership with water users.

12.3.2 Traditional water users associations

A distinction needs to be drawn between government initiated water users associations, and traditional water users associations. As discussed earlier, there can be significant differences between these two forms of associations, though many of the processes and procedures developed for water users associations have been developed from studies of traditional water users associations.

It is strongly recommended that careful thought is given to trying to imposing a "modern" water user's association structure, on a traditional water users association. If the traditional association is functioning well there is no need to intervene. However, there is a real danger that if imposed, external structures, rules and regulations will be resented and resisted, and that the imposed association will fail. As the saying goes "If it isn't broken, don't try to fix it!" Where a new WUA Law is passed, and/or changes made to any existing Water Law, the role of traditional water users associations needs to be considered, and allowances made for the traditional associations to continue to use their existing rules and regulations.

One of the seminal publications on water users associations is by Elinor Ostrom entitled "Crafting Institutions for Self-Governing Irrigation Systems" (Ostrom, 1992). This publication outlines the importance of institutional design, and the building of social capital through community engagement, and provides guidelines on crafting functional institutions in different environments. Eight design principles are outlined for establishing functional water users associations:

> ***Design principle 1: Clearly defined boundaries.*** Clearly define the boundaries of the service area and the individuals or households with rights to use water from an irrigation system
>
> ***Design principle 2: Proportional equivalence between benefits and costs.*** Rules specifying the amount of water that an irrigator is allocated is related to local conditions, and to rules requiring labour, materials and/or monetary inputs.
>
> ***Design principle 3: Collective-choice arrangements.*** Most individuals affected by operational rules are included in the group that can modify these rules.
>
> ***Design principle 4: Monitoring.*** Monitors who actively audit physical conditions and irrigator behaviour are accountable to the users and/or are users themselves.
>
> ***Design principle 5: Graduated sanctions.*** Users who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other users, from officials accountable to these users, or both.
>
> ***Design Principle 6: Conflict resolution mechanisms.*** Users and their officials have rapid access to low-cost local arenas to resolve conflict between users, or between users and officials.

> ***Design principle 7: Minimal recognition of rights to organise.*** The rights of users to devise their own institutions are not challenged by external government authorities.
>
> ***Design Principle 8: Nested enterprises.*** Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises or groups.

The application of these eight principles can be seen in well-functioning water users associations which are organised on hydraulic boundaries, with identified membership and where there are conflict resolution committees, audit committees, zonal representatives, and mechanisms for water users to participate in the management of the association, and if required, change the rules, together with clear and applied sanctions for rule-breakers.

12.3.3 Legislation for Water Users Associations[16]

Experience has shown that a sound legal framework is essential in establishing successful and sustainable water users associations. Legislation is required to spell out the rules governing the operation of the WUA, and its relationship with other bodies. The clear and unambiguous specification of these rules enables all parties concerned, from the water users, the association executive through to government and government agencies, to function effectively and with the minimum of contention or dispute.

The main components of the legal framework are:

- An 'enabling law' which allows the WUA to be established and which describes its legal and organisational form.
- A constitution for each individual WUA, which can be amended by the water users subject to a specified majority in favour of the proposed amendment and, in some cases, agreement by the state supervisory body.
- The operating rules prepared by the WUA in accordance with its constitution and the WUA law.

It is necessary in drafting the law to achieve a balance between the rules contained in the primary legislation, the WUA law, and those contained in the constitution and operating rules. Some argue for most of the detail being provided in the constitution document, and less in the law. This may, however, have its problems in communities which are not familiar with legal forms, and has the potential for the constitution being drawn to favour certain parties. There is a case to be made in the public interest to specify minimum standards and conditions in the law to protect the rights of all potential members.

Some of the main components of the WUA legislation are outlined in the sections below:

i) **Status, name and tasks of WUAs.** The enabling law specifies that the WUAs are legal persons or enjoy legal personality. The law details:

- the generic name to be used by WUAs in order to identify it as a particular legal entity.
- the purpose or purposes of the WUA, its boundaries of operation and its permitted tasks, functions and responsibilities. These may include:
    - Abstraction and delivery of irrigation water.
    - Collection and disposal of drainage water.
    - Operation and maintenance of the irrigation and drainage system
    - Maintenance and repair of flood defence works.

[16] This information is drawn from two FAO publications on water users associations, FAO Legislative Study 79 – Legislation on water users' organizations: A comparative study (FAO, 2003), and a forthcoming publication to be published by FAO entitled "Water users organizations, rules and the law: Experiences from the transition countries". Both publications are written by Stephen Hodgson, a specialist in WUA legislation.

  - Recovery of costs from water users.

- The form of the organisation operating in the public interest, or as a body of public law, on a non-profit or non-commercial basis[17].

There is often discussion on whether the WUA should be able to carry out tasks other than those related to water delivery and removal. The consensus is that it should stick to its core function and leave other tasks, such as input supply and marketing, to other organisations, groups or individuals. Engagement in other activities dilutes the focus on water delivery and removal, and raises tax issues on the more commercially-orientated functions of input supply and marketing.

ii) **WUA constitution.** The minimum content of the WUA constitution is generally specified in the WUA law and may include (FAO, 2008):

- the name of the WUA.
- location of WUA.
- description of the WUA service area by reference to plans and maps.
- objects and purposes of the WUA's activity.
- structure and competences of management organs of the WUA.
- rights and duties of members of the WUA.
- order for joining into the WUA, bases and order for termination membership in WUA.
- procedures for the calling of meetings of the General Assembly.
- provisions on the setting fees in WUA.
- responsibility of WUA members.
- order and sources for compensation of damage of agricultural crops and agricultural plots of land to members of the WUA.
- conditions of termination activity (reorganisation and liquidation) of the WUA.

iii) **Participation.** A number of issues surround participation in WUAs, as outlined below:

  - **Voluntary or compulsory?** A key issue for the legislation to clarify is whether participation in the WUA should be voluntary or compulsory. In the case of land drainage or flood defence, it is generally a requirement that all those within the relevant command area are required to be members. The case may be less clear for irrigation in some areas where farmers may choose to rely solely on rainfall for their agricultural activities. In some countries, coercion to join an association is strongly resented, and cannot be applied. In all cases, a WUA based on voluntary, engaged and active participation is likely to be more effective than an association based on coercion.
  - **Membership.** Though it is common, it is not essential that participation in the WUA has to be by membership. Under the law, the WUA could be given the right to distribute irrigation water or manage the drainage of the land, and to levy a charge for the service provided to the landowners. The landowners might have the right to participate in governance of the WUA, by for example election of WUA officials, but may not need to be members of the WUA per se. Membership is, however, the general form of participation in WUAs, and has benefits of defined rights and responsibilities for the parties concerned. It is important to specify who has a legal right to membership, and if membership is voluntary to allow non-members to have access to the services[18].

[17] This statement can have important implications for tax purposes.

[18] In this case the service charges to non-members may be greater than those for members, up to a maximum specified level.

- **Membership rights.** In some countries, membership is open to landowners only, tenants can participate through their landlords. This is not appropriate in countries where there are large numbers of farmers who use land on the basis of leases or other rights. Allowance can be made in the legislation for those with long-term use rights to be eligible for membership, while short-term tenants may be members with the agreement of the land owner. It is important to make clear however that the land owner and tenant cannot both be members of the WUA at the same time.

iv) **Rights, duties and responsibilities.** The rights, duties and responsibilities of the relevant parties need to be specified in the WUA legislation. This will cover all relevant stakeholders – the water users, the WUA, the government agency, the regulatory authority. There is good reason for specifying the minimum rights, duties and responsibilities in the WUA law rather than the constitution. Key rights will include:

- Access to a fair share of water, or benefit from services provided by the WUA (in the case of and drainage or flood protection.
- To vote in WUA elections.
- To stand for office.
- To propose matters for discussion at meetings and the General Assembly.
- To inspect the WUA books and records.

Associated with these rights are duties and responsibilities, which may include:

- Compliance with provisions of the constitution and operating rules.
- Payment of fees (on time).
- Permitting water to pass to other users unhindered.
- Access to land for operation and maintenance purposes.
- Compliance with decisions of WUA officials, staff and/or the General Meeting.

v) **Procedures for establishing WUAs:** The procedures for establishing WUAs needs to be established in the legislation. This means setting out the steps for establishment and the people and organisations involved. The process requires specification of:

- **The Initiative group,** a small group of self-elected people wishing to form a WUA.
- **The Founding Committee:** A representative group covering the service area of the proposed WUA. The main task of the Founding Committee is to consult with all water users and to prepare the documentation required to establish the WUA.
- **Formulation of establishment documents:** This will include formulating the WUA constitution, identifying potential members of the WUA and their landholdings, obtaining maps of the service area and details of the infrastructure.
- **Approval of draft establishment documents:** There are genuine public interest reasons for requiring that the draft establishment documents are first approved by the state supervisory body before being submitted to the WUA members for approval. This is to ensure that the public interest is adequately protected and to assess the viability and sustainability of the WUA proposed in the documentation (e.g. are paid staffing levels too onerous for water users?).
- **Establishment meeting:** This meeting is held with as many members as possible attending. The proposed WUA constitution and establishment documentation are outlined and discussed. It is typically a requirement that over 50% of the members approve the documentation, and that they own or use over 50% of the land in the

WUA service area[19]. The meeting will also elect WUA office holders and approve the initial budget and work plan.

- **Formal legal establishment:** Following the Establishment Meeting the elected WUA officials lodge the establishment documents with the relevant authority. This is usually the civil courts or the supervisory authority.
- **Costs of establishment:** The legislation typically allows for reasonable costs incurred by the founders to be reimbursed by the WUA.

vi) **WUA governance structure:** The WUA law needs to outline the institutional arrangements for the WUA. This will cover:

- **The structure of the organisation:** This includes the general or representative assembly, management board, WUA Chairperson, WUA executive and WUA sub-committees, WUA representatives, etc. Care has to be taken to ensure sufficient guidance in the legislation whilst allowing adequate flexibility for WUAs to adapt the institutional framework to their specific needs.
- **Voting rights.** These need to be specified, indicating whether or not they are one member-one vote, or based on land holding size.
- **Role of the general assembly, management board and chairperson.** In some cases, the (elected) Chair of the Management Board is also the executive director of the association, and therefore responsible for and involved in all matters related to the WUA. This has its benefits and drawbacks, the benefits being that a strong Chairperson can drive the WUA forward and take action as required, the drawback being that it concentrates too much power in one person. A preferable situation is to have the elected Chairperson of the Board and a separate appointed Executive Director and staff.
- **The role and procedures of the General Assembly:** The legislation will stipulate the role and procedures of the WUA General Assembly, which include:
  - Electing the WUA Management Board, committee members and other officers
  - Setting/approving the budget and service fees.
  - Approving the annual workplan and irrigation plan.
  - Receiving, reviewing and approving the annual report and accounts.
  - Adopting the operational rules of the WUA.
  - Amending the WUA constitution.

  The legislation will also specify the number of times the General Assembly should meet, the procedures for calling emergency meetings, the minimum numbers required to make a meeting quorum, voting procedures, etc. The legislation may also allow for representation of water users and procedures for a Representative Assembly.
- **The role and procedures for the Management Board and sub-committees:** The legislation should specify the procedures for the election of the Management Board and its duties and responsibilities. It is also helpful if the law specifies minimum and maximum number of members. The law may specify sub-committees for auditing WUA accounts and dispute resolution, the composition, procedures for appointment/election of members; duties and responsibilities need to be defined.

[19] Though this may be done by a show of hands, it is preferable and sometimes obligatory to obtain signatures from those who agree to the proposals.

- **Provisions for elected officials and staff:** The legislation will detail the provisions for elected officials and staff of the association, with provisions for election and re-election, terms of office, etc.
- **WUA income:** The legislation will specify the possible sources of income for WUAs, such as:
  - Membership fees
  - Service fees
  - Grants and subsidies
  - Gifts
  - Loans
  - Interest on savings

  The list of possible sources on income will be specified in the law, the method of levying the membership and service fee will be detailed in the constitution or operating rules. There are a number of mechanisms for charging for the service fee, including the area basis, crop type and area, number of irrigations, number and duration of irrigations, etc.
- **Record keeping and accounts:** Keeping of transparent and accountable records is of paramount importance to the sustainability of a WUA. The legislation may specify the minimum level of record keeping that is required, which may include:
  - A register of all members with their names and landholding details.
  - A register showing water received and delivered.
  - Accounts books detailing sums due and sums paid.
  - Minutes of meetings (General or Representative Meetings, Management Board meetings, meetings with other organisations, etc.).
  - Copies of any contracts entered into.
- **Sanctions:** The legislation should specify the nature of offences against which action will be taken by the WUA, the process by which they will be address and the nature of the sanctions.
- **Rights of WUAs:** The legislation will confer a number of additional legal rights on WUAs which may include the right to:
  - Use infrastructure.
  - Impose sanctions and fines.
  - To expel members.
  - To acquire access rights over land.
  - To recover outstanding fees and charges.
- **Liquidation:** The possibility of dissolution and liquidation needs to be covered by the legislation. The grounds for liquidation will be specified, as will the procedures following liquidation (for example who will take over the functions previously carried out by the WUA, who will own the infrastructure if it has been transferred to the WUA, etc.). To avoid the risk of political interference or coercion, formal notice should be issued to the WUA members to enable them to take legal action if they are not in agreement with the proposed liquidation.

vii) **Supervision of WUAs:** In the public interest, it is important that the government provide some oversight and monitoring of WUAs. This should not be too heavy-handed, but at the same time must be effective in being able to assess whether a WUA is functioning properly, and not failing. The WUA law will identify the supervisory body, typically a ministry or unit within a ministry, and will describe the extent of the supervisory body's powers and the conditions under which it may intervene in a WUAs affairs. The supervisory body will need to collect data and information on each WUA, and to report on a regular (annual) basis on WUA performance.

viii) **Merging of WUAs, Federations of WUAs and National Associations of WUAs:** It is helpful if the legislation allows for the merging of WUAs to form larger WUAs, the formation of Federations of WUAs to manage higher-order infrastructure and the ability to form a National Association of WUAs. The Federation of WUAs will need to have an independent legal personality, with defined jurisdiction, roles and responsibilities. Likewise for the National Association of WUAs.

ix) **Consideration of other issues:** In formulating WUA legislation, it will be necessary to take into account other related legislation, taxation and property rights. Water resources and irrigation acts will need to be amended to take account of the changes brought about by the formation of WUAs. Tax codes will need to be amended to allow for issues such as transfer of government property to WUAs with charge, payment of VAT on service fees and maintenance work. Land tenure status can be an issue in some countries.

12.3.4 Stages in WUA Formation

The main stages in forming, establishing and supporting water users associations are shown in Figure 12.2. Formation is the process of getting water users to agree to form an association, whereas establishment is the process of getting the WUA going once the water users have agreed to its formation. Support is the process of hand-holding until the WUA is established and fully capable of running their own affairs.

Figure 12.2 Overview of stages in forming, establishing and supporting WUAs

- Review existing legislation, update and enact legislation to support WUA formation.
- Establish Support Units.
- Train Support Unit staff.
- Promote formation of WUAs.
- Gather data, produce maps, identify canal ownership, etc.
- Form WUAs.
- Register WUAs.
- Establish WUA Regulatory Office.
- Establish if water users want a Representative Assembly or a General Assembly.
- Train WUA Representative Council members.
- Train WUA Executive staff.
- Identify and form representative zones.
- Hold Representative meetings.
- Carry out asset surveys.
- Identify performance measures.
- Provide advice and guidance to established and functioning WUA.

The initial step is to review the existing legislation, and to revise it to allow for the formation of water users associations. In most cases,, a WUA Law will be required, and adjustments will be required to the existing Water Law and Tax Code.

The formation and establishment of water users associations takes time, effort and resources. One of the main resources is a dedicated team of trained personnel working with water users to form and establish the associations. In some countries, a directive has been issued to form WUAs without any specialist team formed, or any guidance of training for government agency personnel. Not surprisingly, the transfer process has not been successful.

Once formed, the Support Units work with water users to form and register the association. For this, data needs to be collected to define the boundaries of the association, the membership and the areas of land held by each member. At the same time, procedures need to be put in place to form the WUA Regulatory Office. This body will be responsible for regulating and monitoring the WUAs, and reporting to government on their progress and performance.

For larger WUAs, it is advisable to break the WUA command area into zones with a representative for the water users in that zone. The zone area varies, from 10-40 ha with 10-30 water users is typical. The representatives are elected by the water users, who attend Representative Assembly meetings on behalf of these members, and reports back to them. The alternative to the Representative Assembly is a General Assembly, in which all water users participate.

Once the WUA has been formed and the staff appointed, work can commence on establishing rules for water allocation, and in carrying out asset surveys to establish the extent, type and condition of the WUA's assets (canals, drains, structures, etc.). The asset survey forms the basis for maintenance and possible upgrading or rehabilitation of the I&D system.

Finally, procedures are put in place for monitoring and evaluation of WUA performance, both by WUA management, but also for the Regulatory Office or the project[20].

12.3.5 Establishing WUA Support Units

An important and sometimes overlooked part of the WUA formation and establishment process is the setting up of a WUA support team or unit. This team or unit can be established within the government I&D agency which is transferring the management of the I&D systems, or it can be set up as part of a project team engaged in the formation and establishment of water users associations[21]. Following training this team/unit becomes the driving force behind the transfer process and can be the key element in the success or failure of the process.

The first step is to prepare a programme for the establishment of the support unit (Figure 12.3). This will involve decisions on the level at which to provide support unit staff. In the example given here based on experience in several countries three levels have been assumed, at Central, Regional and District level[22]. The Central Support Unit staff are appointed or recruited and trained. This training is crucial, and needs to be carried out by personnel with experience in forming, establishing and supporting water users associations. Often a key part of the training programme will be study tours to countries such as the USA, Turkey and Mexico where successful WUAs have been established. The study tours will comprise the Support Unit staff and may include politicians and senior personnel from relevant government agencies. These visits are valuable in enabling these key players in the transfer process to understand the processes followed and see the outcomes of management transfer.

Figure 12.3 Steps in establishing WUA Support Units

- Prepare programme for establishment of Support Units
- Appoint or recruit Central Support Unit (CSU) personnel
- Establish Central Support Unit office
- Train Central Support Unit staff
- International study tours for Central Support Unit staff and senior government agency staff
- Appoint or recruit Regional Support Unit (RSU) personnel
- Appoint or recruit District Support Unit (DSU) personnel
- Establish Regional and District Support Unit offices
- Prepare training material and programme for Regional Support Unit and District Support Units
- Train Regional and District Support Unit staff

[20] If the WUAs have been established as part of a project.
[21] Often WUA formation and establishment is part of a rehabilitation project.
[22] The terminology for these different administrative levels will vary from country to country.

- Organise international study tours for Regional Support Unit and District Support Unit staff
- Regional and District Support Unit staff work with water users to form and train WUAs

The next step is to appoint or recruit the Regional and District Support Unit staff, and to establish their offices. In many cases, the Support Unit offices are established in the offices of the I&D agency, which has some benefits and some limitations. The benefits are that the Support Units can work closely with the I&D agency, and liaise with them on behalf of the WUAs; the constraint is that this relationship may be too close and not sufficiently independent.

Following the establishment of the Regional and District Support Units, the Central Support Unit staff prepares training material for training of Regional and District Support Unit personnel, WUA personnel and water users. This training material will cover WUA governance, water management and system maintenance. The Central Support Unit will then train the Regional and District Support Unit in the principles and practices of WUA formation, establishment and support, and in the giving of training to WUAs and water users. If funds permit, international study tours may be organised for some Regional and District Support Unit personnel, together with Regional and District I&D agency staff, and WUA chairmen and/or Board members.

Following their establishment and training, the Support Units are ready to start the process of WUA formation, establishment and support.

12.3.6 Forming, establishing and supporting WUAs

The various steps for forming, establishing and supporting WUAs are shown in Figure 12.4. The first step is to prepare information material for raising public awareness related to water users associations. This information can be in the form of leaflets, posters, booklets, etc. or radio and TV broadcasts. The next step is to meet with local authorities and government agencies to inform them on the approach and benefits of forming WUAs, and to gain their support in the process.

Figure 12.4 Steps in establishing and supporting WUAs

- Prepare public information/WUA formation material
- Meet with local authorities and government agencies (water resources, I&D, environment)
- Meet with local leaders
- Conduct WUA awareness workshops with water users
- Obtain and prepare WUA documentation (maps, landholding areas, etc.)
- Hold initial WUA formation meeting. Appoint Founding Members
- Prepare WUA Constitution and statutes
- Hold General Meeting to approve WUA Constitution and statutes
- Submit WUA documentation for legal registration
- Hold elections for WUA Board
- Interview and appoint WUA executive staff
- Prepare WUA training material
- Train WUA Board
- Train WUA accountant
- Train WUA water management staff
- Ensure participation of WUA in design and construction supervision of rehabilitation works
- Prepare asset management plan for the I&D system
- Prepare of management, operation and maintenance (MOM) manual for the WUA and I&D system
- Organise maintenance awareness workshops with water users
- Organise fee setting and fee recovery workshops with water users

The engagement with the I&D scheme begins with meeting local leaders, and explaining the benefits and process of WUA formation. With the support of the local leaders, awareness raising meetings are held with the water users with the aim to get them to sign up to the process. At this stage, locally based community motivators may be engaged to promote the WUA message, and to obtain feedback and address concerns of the water users.

Information needs to be collected on the extent of the irrigation and drainage system, the landholdings and the ownership of the landholdings. A key principle is that the WUA has clearly established hydraulic boundaries, with the area supplied solely from one or more water sources. A preliminary register of water users and their landholdings is drawn up, and forms the basis for gaining signatures from landowners to show their agreement to forming the association. In some countries, it is a stipulation that more than a certain percentage of landowners agree to form the association (this can be as low as 51%), thus signatures are required as evidence of this agreement.

A group of Founding Members is appointed to organise and oversee the initial stages of the WUA formation process. This group is generally drawn from local leaders and respected water users, within the proposed WUA command area. The Founding Members then work with the Support Unit to prepare the WUA Charter and statutes, and to prepare the documentation required for registration of the WUA (such as a map of the command area, a list of WUA members with location and areas of their landholdings).

A General Meeting is held by the Founding Members to discuss the WUA Constitution and statutes with the members. Following agreement on the constitution and statutes, the registration documents are formally submitted to the relevant authority (this is often the local magistrate's court or Ministry of Justice office).

Following registration, the Founding Members with the assistance of the Support Unit, organise and hold elections for the WUA Management Board/Council. The WUA Management Board generally comprises of some 10-12 persons drawn from landowners within the WUA command area. In some cases, the WUA charter allows or requires specific persons to be members of the Management Board, such as representatives or headmen from each village within the command area. The Management Board elects a Chairman/woman to chair the meetings, and to represent the WUA. The Management Board will also appoint an executive to carry out the day-to-day tasks associated with the running of the association. This executive generally comprises of an Executive Director, a Treasurer/Accountant, an O&M Engineer/Technician and Water Masters. Figure 9 shows a typical WUA management structure.

Following the establishment of the WUA, the Support Unit commences the training programme. The training focuses on the different elements – governance, accounting, water management and maintenance. The training carried out involves duties and responsibilities for the WUA Management Board ; financial and accounting procedures for the WUA Accountant; duties and responsibilities for the WUA Executive Director; water management and maintenance for the WUA O&M Engineer/Technician; and liaison/communication with water users. Additional training will be carried out for other elements of the management structure, such as the Audit Sub-Committee and the Conflict Resolution Committee.

The formation and establishment of WUAs may be associated with a programme or project for the rehabilitation of the I&D system. If this is the case, it is preferable that the WUA is formed before the rehabilitation works commence (particularly the planning and design phase), so that the WUA can participate in, and guide the rehabilitation work. This involvement of the WUAs from planning through to construction and implementation, creates a strong sense of ownership for the physical infrastructure, and is a key part of the process of transferring the responsibility for this infrastructure from government to water users.

Following the initial training, there may be follow-up activities and training, such as that related to preparing asset management plans for the I&D system, so that proper budgeting can be carried out for the maintenance of the system. Additionally, if the WUA formation and establishment is part of a project, WUA management, operation and maintenance manuals may be prepared. These manuals can be based on the material used to train WUA personnel.

Periodically, additional training or awareness raising meetings may be organised. This includes meetings which inform water users how the WUA budget is prepared and the irrigation service fee set, including the importance and cost of maintenance work. These meetings may be run by the Support Unit staff, or by the WUA Executive Director or Chairman.

12.3.7 Establishing a WUA Regulatory Authority

In the public interest, government needs to maintain some oversight over the established water users associations. As discussed above in the section on legislation, the formation and outline structure of the supervisory body (hereafter referred to as the WUA Regulatory Authority) should be specified in the WUA law, and should be referred to in the constitution and operating rules of the association.

A typical process for establishing the WUA Regulatory Office is:

- Prepare legal framework (for WUA Regulatory Authority)
- Enact legislation/regulation to establish the authority
- Recruit staff
- Establish office
- Monitor and report on WUAs

Typically, the WUA Regulatory Authority comprises of an office with 2-3 staff established in a relevant ministry, either agriculture, water resources or irrigation. The purpose of the Regulatory Authority is to:

- Oversee the formation and establishment of water users associations.
- Maintain a complete register of the establishment documentation for each WUA (this will be in parallel to the documentation submitted to the local authority to register the WUA).
- Collect data, usually annually, from WUAs. These data will be specified in the WUA law, and should be sufficient to monitor the progress and performance of each WUA.
- Report on the performance of WUAs.
- Support water users and WUAs where their rights are being threatened by other parties.

Other roles may include mediation in the event of disputes between water users and WUAs, and oversight of auditing of WUA accounts.

Due to the quantity of data that requires processing each year, the WUA Regulatory Authority will need to establish a computerised database. At the end of each cropping year, the Regulatory Authority will send out standard forms to be completed and returned by each WUA. Where a WUA Support Unit has been established they will assist the WUAs in the collection of data and the completion of these forms. Possible data requested is presented in Table 12.3 and includes information on WUA meetings, WUA personnel, WUA budget, water use and expenditure and income related to the water delivery service. Where the WUA provides drainage services as well there may be additional data requested.

Table 12.3 Possible data collected by WUA Regulatory Authority

A. General WUA information	**E. Income and expenditure for water delivery (cont.)**
Year	Amount owed to main system service provider at end of year (MU[1])
Region name	Amount paid to main system service provider (MU[1])
District name	Method used for determining ISF and value of ISF charged
WUA name	- per hectare basis (MU/ha)
WUA Registration Number	- per irrigation basis (MU/irrigation)
Establishment date	- voumetric basis (MU/m3)
Registration date	
Number of members	**F. Budget information (planned and actual)**
Service area (ha)	Recurrent costs (MU)
Number of WUA staff	- salaries
Number of Management Board Members	- social fund
General or Representative Assembly?	- temporary staff costs
Number of water user representatives	- transport costs
WUA Chairman name	- admin costs
WUA Executive Director name	- O&M costs
WUA Accountant name	- other operating costs
Assembly	- ISF payment to main system service provider
Number of meetings this year of WUA Management Board	- maintenance expenditure
	Investment costs (MU)
B. Irrigation area and cropping pattern	- Major repairs
Total cropped area (ha)	- Rehabilitation
Planned irrigated area (ha)	- Equipment and vehicles
Actual irrigated area (ha)	- other acquisitions
Rainfed area this year (ha)	Financial and other costs (MU)
Area not cultivated this year (ha)	- Reserve fund
Major crops (crop name, area)	- repayments of loans and credit
- List of the type and area of the main irrigated crops grown	- interest payments
Yield of crops (crop name, yield)	- taxes
- Average yields of the main crops. Give units in which yield is measured.	- contingencies
Crop market prices (crop, market price)	WUA income
- Average market price of the main crops. Give units.	- irrigation service fees
Crop area damaged and cause	- fines and penalties
	- interest income
C. Water supply (amount supplied, % of source of total supply)	- other income
Total from external sources (main system service provider, Mm^3)	Income less expenditure
- for each named main canal (Mm^3)	Repayment for rehabilitation (if any)
Total from own sources (Mm^3)	Total amount of accumulated reserve fund
- for each named source (Mm^3)	Amount in bank account
	Debts to main system service provider
D. Water distribution by WUA and application	
Contracted water delivery to water users (Mm3)	**G. Changes in WUA staff, charter or area**
Actual water delivered to water users (M m3)	Elections of new senior members
Actual water use per ha (m3/ha)	Increase or decrease of WUA service area in last year (ha)
	Transfer of assets
E. Income and expenditure for water delivery (cont.)	List of assets
(MU[1])	Regulations
Total value of water delivery contracted with water users (MU[1])	
Total value of payments received from water users for water delivery (MU[1])	
Amount owed by water users to WUA at beginning of year for water (MU[1])	
Amount owed at end of year by water users to WUA for water delivery (MU[1])	

Notes:
1. MU - Monetary unit

12.4 Structure of Water User Associations

There are a number of variations for the management structure of WUAs. A typical structure is provided in Figure 12.5.

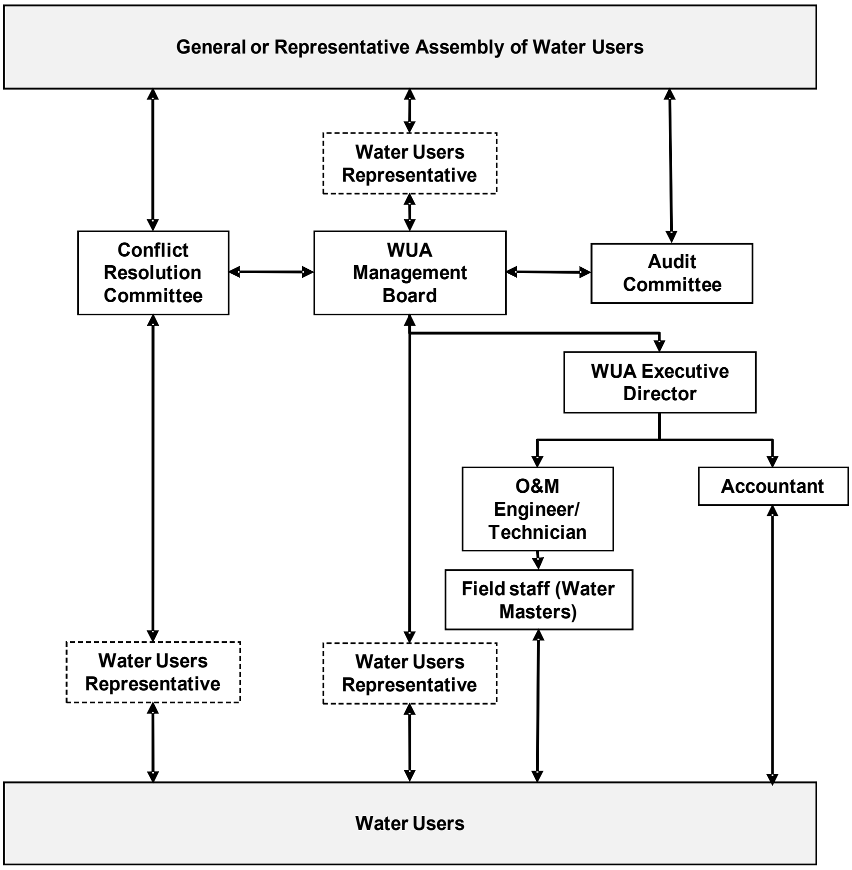


Figure 12.5 Typical WUA management structure

When the WUA is formed, the water users elect a Management Board comprising of 3-12 members (the number depends on the water users, it is up to them to decide what a suitable size is for the Management Board). The Management Board elects a Chairman, and then appoints the executive staff, generally comprising of an Executive Director, an Accountant, an O&M Engineer/Technician and field staff (Water Masters). Out of the elected members, the Management Board may also establish an Audit Committee of 3-4 people and a Dispute Resolution Committee with 3-4 people. To be effective, it is important that the members appointed to these two sub-committees are respected and trusted by the water users. In larger systems, a representative organization may be used whereby groups of water users elect a representative to attend management meetings, represent their views and report back.

The Management Board members and the Water Users Representatives are generally not paid, but the executive staff members are paid. Payment may be in cash, in kind (agricultural produce), or in the allocation of preferential access to water or land. The number of staff depends on the size of the irrigated area, its complexity and the resources available to the water users. If the organization has a good market, and is growing profitable crops, then staff can be paid in cash. Similarly, systems which deal with subsistence agriculture, allocate land, preferential access to water, or make payment in kind with agricultural produce, to the staff members. The roles and responsibilities of the various personnel associated with water users associations are summarised below. Note that these duties and responsibilities are linked to the organisational structure outlined in Figure 12.5. There are variations on this structure, for example some WUAs may not have an O&M Engineer/Technician, and these might then be divided between the WUA Executive Director and the Water Masters.

i) WUA Chairman and Management Board members

The WUA Chairman and Management Board Members are responsible for the proper functioning of the WUA, which includes the performance of the WUA staff. Their main tasks include:

- Attending and chairing General Meetings
- Attending WUA Management Board meetings
- Receiving, checking and approving reports on WUA activities, membership and performance from General Secretary
- Liaising with external agencies on behalf of the WUA
- Review and adapt WUA by-laws whenever agreed upon in general meetings

ii) WUA Dispute Resolution Committee members

The WUA Dispute Resolution Committee Members are responsible for resolving disputes that may arise between the WUA Executive and water users, and disagreements between water users. Their main tasks include:

- Bringing together the parties, taking evidence, allowing presentations of information, facilitating discussion between affected parties
- Making and enforcing a judgement
- Recording the procedures followed and the judgement made
- Reporting to the WUA Management Board and the WUA Annual General or Representatives Meeting

iii) WUA Audit Committee members

The WUA Audit Committee Members are responsible for auditing the WUA financial records on behalf of the membership. Their main tasks include:

- Receiving and checking the accounts each year
- Verifying the accounts
- Reporting to the WUA Management Board and the WUA Annual General or Representatives Meeting

iv) WUA Executive Director

The WUA Executive Director is responsible for the proper day-to-day functioning of the Water User Association. He/she reports to the WUA Chairman and Management Board and the members. His/her main tasks include:

- Representing the WUA in all matters related to its day-to-day activities
- Preparing the annual work plan and budget
- Organising regular meetings with the Management Board; preparing the agenda, and ensuring that minutes are taken
- Organising and chairing seasonal meetings with farmers to discuss scheme performance, cultivation, operation and maintenance plans; preparing the agenda, leading the meetings, formulating actions to be taken on cultivation, operation and maintenance and fee payment, and ensuring that minutes are taken of the meeting
- Liaising with the main system service provider on water delivery and service fee collection and payment
- Overseeing water distribution and maintenance as managed by the WUA O&M Engineer/ Technician

- Conducting seasonal walk through inspection of the irrigation and drainage system with he WUA O&M Engineer/Technician and WUA Representatives
- Investigating farmers complaints and taking action as appropriate
- As and when required, applying sanctions in line with by-laws and regulations
- Liaising with governmental and non-governmental authorities on issues related to WUA activities and water users' concerns
- With agreement from the Management Board, engaging local contractors for repair works
- Assessing scheme performance and reporting back to the Management Board and water users
- Monitoring of financial administration
- Providing information as requested by the WUA Regulatory Authority and other legitimate government agencies.

v) WUA O&M Engineer/ Technician

The WUA Engineer/Technician is responsible for the management, operation and maintenance of the irrigation and drainage system. He/she reports to the WUA Executive Director. His/her main tasks include:

- Preparing a seasonal water allocation plan for the service area
- Advising water users on water availability and allocation
- Keeping operational records (e.g. discharges, pump operating hours, power consumption, water use and allocation, etc.)
- In association with the Water Masters preparing daily irrigation schedules
- Identifying maintenance requirements on a regular basis and through seasonal walk-through inspections
- Presenting matters relating to system operation and maintenance to the Management Board and General/Representative Meetings
- Assessing maintenance requirements, estimating costs and preparing the maintenance budget
- Co-ordinating and supervising repair works
- Organising communal labour for periodic maintenance
- Monitoring and evaluating performance of related to the operation and maintenance of the system

vi) WUA Accountant

The WUA Accountant is responsible for the financial management of the WUA. He/she reports to the WUA Executive Director and to the Management Board. His/her main tasks include:

- Collecting and recording membership registrations and fees
- Collecting and recording irrigation service fees, donations and fines
- Keeping and issuing receipts
- Keeping cash and bank accounts
- Keeping the WUA cheque book
- Making payment on authorised procurements of goods and services
- Keeping and recording invoices
- Keeping the stock book
- Preparing monthly accounts
- Preparing seasonal and annual statements of accounts
- Preparing annual and seasonal budgets
- Arranging for seasonal or annual auditing.

vii) WUA Field Staff (Water Masters)

The WUA Field Staff (Water Masters) are responsible for operation and maintenance of the system, under the direction of the WUA O&M Engineer/Technician, liaising with water users on a daily basis, and where possible resolving conflicts arising at field level. The Water Masters report to the WUA Executive Director. Their main tasks include:

- Implementing the daily irrigation schedule
- Advising farmers of their turns and durations
- Monitoring and controlling irrigation supplies according to the schedule
- Resolving disputes at field level, where possible
- Keeping field operational records (e.g. discharges, pump operating hours, power consumption, water use and allocation, etc.)
- Inspecting the I&D system on a daily basis and reporting any problems
- Assisting in organising communal activities for periodic maintenance

viii)Water Users Representatives

The Water Users Representatives are responsible for representing the needs of farmers within the designated command area. They report to the water users in their zone or block. Their main tasks include:

- Liaising on behalf of zone/block water users with the WUA Executive Director and/or O&M Engineer/Technician on issues related to management, operation and maintenance of the irrigation system.
- Representing the zone/block user group at WUA Management Board and other meetings, and reporting back to water users
- Collecting data from landowners and tenants within their zones/blocks on behalf of the WUA
- Communicating and liaising with zone/block water users on behalf of the WUA
- Attending training sessions
- Organising and running information sessions for farmers
- In association with WUA O&M Engineer/Technician assisting farmers in the organisation of water distribution within the zone/block service area
- In association with WUA O&M Engineer/Technician identifying maintenance needs affecting the zone/block area
- Keeping records of water shortages, water supply failures, power cuts, etc. affecting water delivery to farmers
- Assessing and maintain records of agricultural performance within the zone/block command area (this may be an optional requirement)

12.4.1 WUA Records

Table 12.4 summarises some of the typical records required for WUAs. The information needs can be broken down into management, operation and maintenance categories, with data being obtained from a variety of sources. Some of the data are collected by the WUA management, and some many be collected by other organisations, such as the I&D agency (if there is one) managing the main canal system. Most of the data are required by the WUA management, but some, such as crop production and yield data might have to be collected by the WUA from farmers for passing onto to others. Some data will be required by the Regulatory Authority, in order to monitor the performance of the WUA and ensure that it is providing an adequate level of service to the water users at a fair price.

12.4.2 Training for Water Users Associations

Training is a central element in any programme to establish water users associations. Key areas for training are summarised in Table 12.5. To establish and carry out these training programmes requires significant financial and human resources to carry out the training. Without these resources, the training cannot be carried out, and without the training it is unlikely that the water users and the WUA personnel will fully understand the processes involved and be capable of carrying out the functions required of them.

Where the transfer programme is funded, the training is typically carried out by the Support Unit. Similarly, training of the Central Support Unit (CSU) is undertaken by personnel experienced in

WUA formation and support. As an adjunct to the aforementioned training, these experienced personnel will also assist the Central Support Unit in the preparation of the training material for the Regional and District Support Units, and that for the WUAs and water users. Once trained, the Central Support Unit staff will educate the Regional and District Support Unit staff, who in turn will coach the WUA personnel and the water users.

Table 12.4 Typical information needs for participatory irrigation management

Information subject/type	Obtained from	Required by	Purpose/Use
Management			
Number of farmers in the command area	Landholding records, discussion with farmers	I&D agency WUA management	To know the potential membership of the WUA
Names and addresses of members	Landholding records, discussion with farmers	WUA management	To be able to contact the members
Area farmed by each member, and location of farm plots. May also require information on the type of crop grown each season.	Landholding records, discussion with farmers	WUA management	To register farmers as members of the Association. As a basis for charging members for services provided.
Revenue collected, by source	WUA accounts	WUA management WUA members Regulatory/monitoring authority	To assess the income and the viability of the WUA. Includes all sources of income, from members and non-members, rents, sales, etc.
Management costs (salaries, office costs, equipment purchase, etc.)	WUA records and accounts	WUA management WUA members Regulatory/monitoring authority	Used to assess the service fee to be charged to water users. To monitor and control expenditure
Command area serviced	Maps of I&D system I&D agency	WUA management I&D agency Regulatory/monitoring authority	To know the potential area that can be irrigated. Key data for assessing irrigation water demand and performance
Performance of other WUAs	I&D agency Other WUAs Regulatory Authority	WUA management I&D agency Regulatory/monitoring authority	Valuable information for WUA management to know how their WUA is performing relative to others. Useful for the Regulatory Authority and I&D agency to assess if support is needed for a WUA.
Operation			
Availability of water at the water source (for the irrigation season)	Water resources agency or I&D Agency	WUA management	Needed by the WUA management in order to advise farmers on seasonal cropping patterns, or to advise on water shortages.
Daily volume of irrigation water received at main intake from water source (e.g. river)	Measurement of discharge at intake	WUA management I&D agency	To know how much water is entering the system For charging purposes For performance assessment
Daily volume of irrigation water received at tertiary canal intake from primary or secondary canal	Measurement of discharge at tertiary intake	WUA management I&D agency	To know how much water is being delivered to the WUA for: - charging purposes - performance assessment
Operation costs (cost of for water from I&D agency, operation equipment, pumping costs, etc.)	WUA records and accounts	WUA management WUA members Regulatory/monitoring authority	Used to assess the service fee to be charged to water users. To monitor and control expenditure
Maintenance			
Inventory of assets and their condition	Asset surveys	WUA management Regulatory/monitoring authority	Used to monitor the condition of the physical assets of the Association.
Maintenance requirements	Maintenance surveys (regular, periodic and annual)	WUA management WUA members	To identify the maintenance needs, costs and priorities, in order to keep the system operational

Maintenance costs	WUA records	WUA management WUA members Regulatory/monitoring authority	Used to assess the service fee to be charged to water users. To monitor and control expenditure To ensure that sufficient money is being spent on system maintenance.
Production			
Areas harvested by farmers and crop yields	Farmers	I&D agency Agricultural Department	Annual statistics for Ministry of Agriculture and I&D agency

In designing the training programme it is necessary to consider:

- Who is/are the target group/groups
- The rationale of the training programme
- The objectives of the training programme
- The training content for each course
- The training methods
- The training duration and timing
- Who will be the trainers
- The training location
- Equipment and facilities required
- The cost
- Evaluation methods
- Critical success factors

It is essential that the training for the WUA personnel and water users is practical, with the use of exercises and field work wherever possible. Water users will have limited tolerance for training material and methods which is too theoretical.

12.4.3 Key factors in establishing effective and sustainable WUAs

Some key factors to consider in establishing effective and sustainable water users associations are:

- If there is an existing (traditional) water users associations assess its performance. If it is functioning effectively, do not try to impose (external) structures, rules and regulations.
- Develop a phased development approach if establishing new WUAs; do not try to do everything at once. The priority is to improve the water management, followed by fee collection, followed by improving maintenance.
- Keep the water users association as a single function organisation focussed on improving water management. If the association is successful, consideration can be given to branching out into provision of inputs, marketing, etc. however, it is important to be careful not to lose sight of the core water management function.
- Ensure that the WUA management remain open and transparent, and responsible to the membership at all times.
- In association with water users and WUA management, set measurable and achievable targets, and provide feedback on achievement made. This creates a feeling of achievement, generates confidence and increases expectations and ambition.
- Allow sufficient time for WUAs to become fully self-sustaining. 5-10 years is a reasonable time frame.
- Key factors in the success of a WUA are the membership, the leadership and developing a sense of ownership. Good (or bad) leadership can make (or break) any organisation and WUAs are no exception. Ownership of the irrigation and drainage system by the members is

central to success. Particular effort is required if the system has been designed, built and then managed by a government agency before being transferred to the water users.

- Continuing agency support is essential, particularly in the early stages of WUA formation and establishment. Successful international examples of WUA establishment following transfer (Mexico, Turkey, Kyrgyzstan) have all involved significant involvement by the government agency responsible for irrigation and drainage.

Table 12.5 Key target groups and topics for awareness raising and training in a WUA establishment programme

Target group	Training topics
WUA members	• Purpose and benefits of WUA formation • Procedures for formation and establishment of WUAs • WUA legal framework – WUA law, statutes and by-laws • Purpose and role of Water Users Representatives and election procedures • Purpose of irrigation service fees (ISF) • Setting and paying the ISF • Maintenance processes, procedures, costs and benefits
WUA Support Unit/Team staff	• Legal aspects related to WUA formation • Organisation and role of Support Units • Support Unit functions and tasks • Formation and establishment of WUAs • WUA duties and responsibilities • WUA processes and procedures, functions and tasks • Supporting WUAs
WUA Managing Board members and sub-committees	• WUA legal framework – WUA law, statutes and by-laws • Purpose and functions of WUA Management Board and sub-committees • Management Board processes and procedures • Management Board duties and responsibilities • Dispute resolution procedures • Financial management and auditing for WUAs • WUA development – Role of the Management Board
WUA Executive Director and staff	• WUA legal framework – WUA law, statutes and by-laws • Purpose and functions of WUA Executive Director and staff • WUA management, operation and maintenance (MOM) processes and procedures • Liaison with water users • Fee collection processes and procedures – fee setting and collection • Dispute resolution
Water Users Representatives	• WUA legal framework – WUA law, statutes and by-laws • Water users rights and responsibilities • Purpose and role of WU Representatives • WU Representatives processes and procedures • WU Representatives duties and responsibilities • Liaising with and representing water users • Dispute resolution procedures • Fee collection processes and procedures – fee setting and collection
Irrigation agency staff	• WUA legal framework – WUA law, statutes and by-laws • Purpose and role of WUAs • Liaising and working with WUAs • Dispute resolution procedures • Fee collection processes and procedures – fee setting and collection • Supporting WUAs

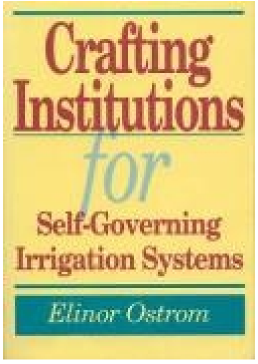
Local administrators and politicians	• WUA legal framework – WUA law, statutes and by-laws • Purpose and role of WUAs • Benefits of WUAs • Liaising and working with WUAs • Supporting WUAs • WUAs and local government

12.4.4 Reasons for failure of Water Users Associations

At an international conference on IMT held in Wuhan, China in September 1994, conclusions were drawn that IMT, if properly executed, could benefit both farmers and the government (Kloezen and Samad, 1995). However, issues identified during the conference which adversely affected WUA formation and establishment included:

- **Lack of time.** IMT needs to be carried out in carefully managed stages, and requires considerable time and supporting effort.
- **Lack of support/commitment**. Although most governments find IMT attractive, there is often only partial support for the process.
- **Inadequate legal framework.** Governments have not always formulated the requisite policies and legal frameworks for IMT.
- **Failure to upscale.** In many countries IMT has not progressed beyond the pilot stage.
- **Focus on cost reduction.** IMT is often initiated by government, and is focussed on reducing costs in the irrigation sector, resulting in a failure to invest adequately during the transfer process.
- **Failure to take account of farmers' needs.** Often farmers' needs, aspirations and capability to take over management are not considered.
- **Profitability of irrigated agriculture.** For IMT to be sustainable, irrigated agriculture needs to be profitable to farmers.
- **Need to focus on sustainability.** Initially the focus is on the IMT process, attention then needs to be focussed on ensuring the sustainability of the management of the transferred systems, especially in terms of its maintenance.
- **Failure to adequately consider government agency staff.** A major issue during the transfer process is the retrenchment of irrigation agency personnel, and the need for strategic reorientation of the irrigation agency from the role of service provider to a regulatory organisation. Failure to adequately address this issue results in resentment, resistance to the IMT process, and possible sabotage of the process.
- **Context specific nature of management.** It is recognised that post-turnover management systems are context-specific and dependent on a mixture of social, political, economic and physio-technical factors
- **Transparency and accountability**. Management accountability, financial autonomy, water rights and property rights are vital ingredients to successful IMT
- **Evolutionary process.** IMT should be seen as a long-term evolutionary process, rather than a structural adjustment programme

12.5 References



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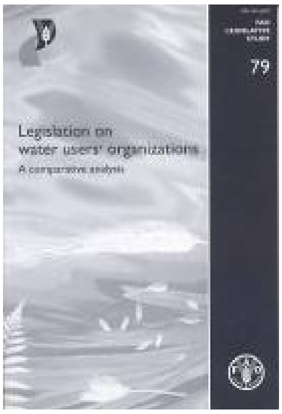
The framework presented here incorporates the recommendations of the expert consultation and makes the case for a systematic water policy review in two stages:

- Review and adaption of water policy, and
- Formulation of strategies.

Recognizing that policies and their implementation are the prerogatives of national governments, the focus of this guide is the approach and the process for formulating strategies and implementing water sector policies. This guide aims to assist countries in their effort to review national water policies and re-assess national institutional capacity to implement the required strategic reforms, with the objective of sustainable resource management and rational water use.



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.13 Management, Operation and Maintenance

13.1 Overview

Due consideration is not always given to how an irrigation and drainage scheme will be managed. Often significant resources are put into the technical work required to identify the soils, map the topography, assess the rainfall and water resources, design and build the system. However, few resources and little consideration is given to how the system will be managed, operated and maintained. Detailing of management, operation and maintenance (MOM) processes and procedures is often rudimentary, as is training for managers and staff. When consideration is given, it is particularly to technical areas of operation and maintenance (O&M), and does not cover general management areas, the missing M in MOM.

This chapter outlines general management processes and procedures[23], followed by those for operation and then maintenance.

13.2 Management

13.2.1 Management styles

In some schemes, fairly rudimentary management procedures can be successful; in others more sophisticated procedures are required. The key variables affecting the management of the scheme are its size, its technical complexity, its age and its history. Larger and more technically complex schemes generally require more sophisticated management processes, whilst the history of the scheme often determines the management framework.

Traditional irrigation schemes have been developed organically, with local community institutions eventually managing the system. These institutional arrangements may not be written down, but they are known and followed by everyone. It is worthwhile to note, that these schemes to not entail much paperwork, as most of the management is by word of mouth. In schemes which have been established by government, such as the Mwea Scheme in Kenya, the management procedures are written down and codified. These systems will tend to be more bureaucratic, having been based on government civil service procedures. If such schemes are then transferred to management by water users, these management systems will also be transferred and most likely adopted, in the initial instance at least, by the Water Users Association.

13.2.2 The purpose of management

The purpose of management can be defined as (Drucker, 1982):

- To think through and define the purpose of the organisation
- To provide a good return on the (financial) capital employed in establishing the organisation
- To make work productive and the worker achieving
- To manage social impacts and social responsibilities

Irrigation and drainage schemes often represent a large investment of resources – financial, institutional, social and environmental. Money is invested to build the irrigation and drainage system, roads, etc. Institutional arrangements are established to manage, operate and maintain the scheme. Farmers, their families and others (labourers, traders, etc.) invest their time and resources. Natural resources of land and water are committed to the enterprise for significant periods of time.

[23] Dictionary definitions – **Processes:** a series of actions that produce a change or development; **Procedure:** a way of acting or progressing in a course of action, the established mode of conducting the business. The process of irrigation water supply involves a series of actions in moving water from the river to the field; the procedures are the detail of how it is done in at each stage, e.g. the forms and calculations used for scheduling water in the main canal, and the (different) procedures used for scheduling water at the field level.

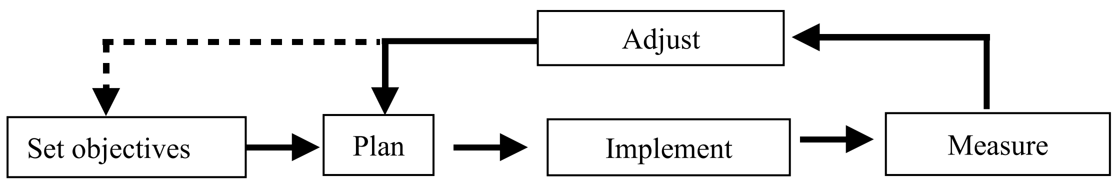
As mentioned previously though the development of irrigation and drainage, schemes often represent a significant investment by a country. Management is not treated in the same way as it would be if a similar investment were made in a business enterprise. The second and third elements of management purpose defined above are often missing in irrigation and drainage management.

Management has been defined as (Jurriens, 19##):

> *"The organised use of resources,*
> *In a given environment*
> *For the planning operation and monitoring*
> *Of certain tasks*
> *To convert inputs into outputs*
> *According to set objectives*"

Management processes can be divided into the processes which are outlined in the diagram below:

- Objective setting
- Planning
- Decision making
- Implementation
- Information systems
- Monitoring and feedback



The objectives will vary depending on the circumstances, and may include:

- To maximize the agricultural output
- To maximize the number of people settled on the irrigation/drainage scheme
- Maximize financial return on the capital investment in infrastructure
- Maximise financial return to farmers
- To ensure equitable distribution of available supplies to all water users
- To make efficient and productive use of land and water resources
- To provide reliable, timely and equitable water distribution
- To minimise adverse environmental impacts
- To minimise waterlogging and salinity
- To maintain the irrigation and drainage systems to enable proper operation
- To cover the costs of management, operation and maintenance costs through service fee recovery from water users

Some objectives may be mutually exclusive. For example, in a scheme where the water availability is limited, the objective may be to ensure equitable distribution of the available water supplies to all water users. In this case, it may not be possible to maximise the agricultural output. The management tasks can be split into two broad categories: setting the direction of the organisation, and managing the day-to-day activities. Both roles require different types of people to carry them out, the former requiring those with vision and an appreciation of both the inner world of the organisation and the outer influences, and the latter which focuses on getting the job done, and implementing the agreed actions.

13.2.3 Setting direction

Senior management need to identify the **vision, objectives** and **strategy** for the organisation. The vision sets the long-term goal(s), the objectives identify key achievements that are needed to reach the goal, and the strategy sets out how the objectives will be met. In community managed irrigation schemes, the WUA Management Board/Council, led by the Chairman, will be responsible for setting the vision, objectives and strategy, and then putting their proposals to the members. In theory, these would be set at the inception of the water users association, which in reality evolves over time as the association gains experience. Having a vision and setting objectives is important as it gives direction and purpose.

A simple set of questions can be used to prepare the vision, objectives and strategies for an organisation:

- Where are we now? - Evaluation and appraisal
- Where do we want to be? - Vision and objectives
- How are we going to get there? - Options and choices
- Which way is best? - Strategy
- How do we ensure arrival? - Implementation and control

Thus, in a situation where water delivery poor, and the irrigation system is in a poor state of repair, the WUA management might decide that they want to have a system in which water delivery meets farmers needs, and agricultural production is not constrained by the water supply. They could prepare programme of repair work which would involve members contributing labour and some cash, and submit this to the membership with details of the anticipated benefits of the work. If agreed by the members, the proposal would be implemented, supervised and reported on by the WUA Management Board/Council. There may be several different options for implementing the programme ("the strategy"), for example all the work could be carried out in one year, or the programme of works could extend over several years. This will need to be decided by the membership, and will depend on factors such as the amount of work required to be done, the resources available, etc.

The above example shows the power of management in governing the performance and outcome of an irrigation and drainage system, a significant amount can be achieved by capable and strong management, equally significant harm can be done by weak and ineffective management.

13.2.4 Day-to-day management tasks

Day-to-day management of irrigation and drainage schemes is centred on the delivery of water supplies to water users and to crops. Additional management tasks required to support this core function include:

- Employing and managing staff
- Administration
- Paying salaries
- Managing finances
- Managing human resources, including training
- Ensuring that the objectives of the organisation are met
- Liaising and working with water users
- Liaising with other external organisations and individuals

At the centre of the management philosophy should be the principle of service delivery. This is particularly important in relation to the recovery of the irrigation service fee (Figure 13.1). Good service delivery is more likely to result in good levels of fee recovery; whilst poor service delivery will almost certainly result in poor levels of fee recovery. The level of service to be provided and the fees to be paid are specified in the Service Agreement, which is a signed contract between the service provider (the WUA) and the water company.

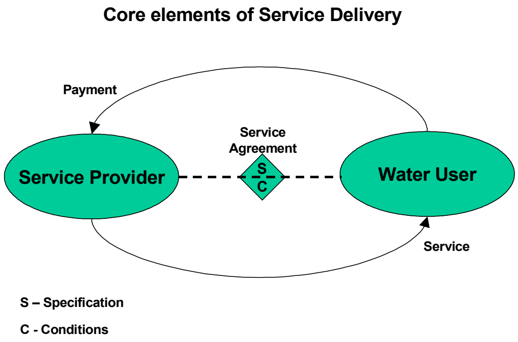


Figure 13.1 Core elements of service delivery (Huppert and Urban, 1998) user.

One of the differences, and difficulties, with irrigation and drainage in comparison with other service delivery systems, such as electricity and potable water supply, is the wide variation in the types of irrigation and drainage system. The variation is across the board, from the climatic conditions, the type of water source, the water availability, the design of the physical infrastructure, the farming system, the social and institutional context, the market availability, the local and national economy, etc.

Two key factors affecting irrigation and drainage service delivery are the configuration of the physical infrastructure, and the management processes, both of which effect ***control*** over the processes involved. Figure 13.2 outlines the areas where ***management control*** needs to be exerted to provide a reliable, adequate and timely irrigation water supply and effective drainage, and the potential benefits of such control. The management of the physical infrastructure leads to the provision of water for irrigation, and drainage of excess water; this in turn leads to agricultural crop production and farmer income, some of which can then be used to pay for the service provided. Within the internal processes of the service provider, financial, operation and maintenance control systems are required to support the delivery of the service.

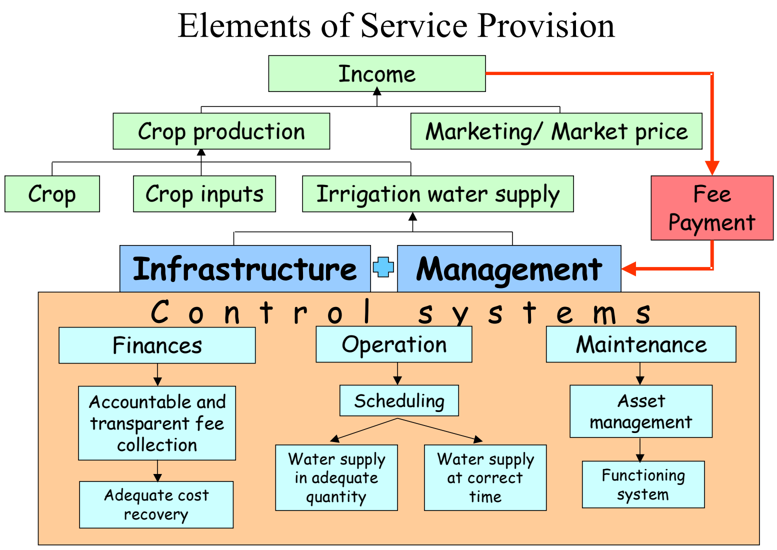


Figure 13.2 The linkage between management control systems, outputs and payment for the services provided on an I&D scheme

13.2.5 Management structure and staffing

A formal management structure is fundamental to good management. In traditional managed irrigation and drainage schemes, this management structure may be incorporated in the village management structure, perhaps with a number of individuals assigned to management, operation and maintenance of the I&D systems. In schemes which have been established by government and then transferred to water users, there may be a management structure in place, or a new structure may evolve through the formation of the Water Users Association.

Chapter 13 has dealt with the management of Water Users Associations in some detail. Figure 13.3 is presented below to show the general management structure of communally managed irrigation schemes. Typically, a communally managed irrigation scheme will have a Management Board, and Executive and staff. The paid staffing will generally comprise of an Executive Director, an engineer (for bigger schemes), and water masters. Examples of job descriptions for these positions, the Management Board and committees have been provided in Chapter 13.

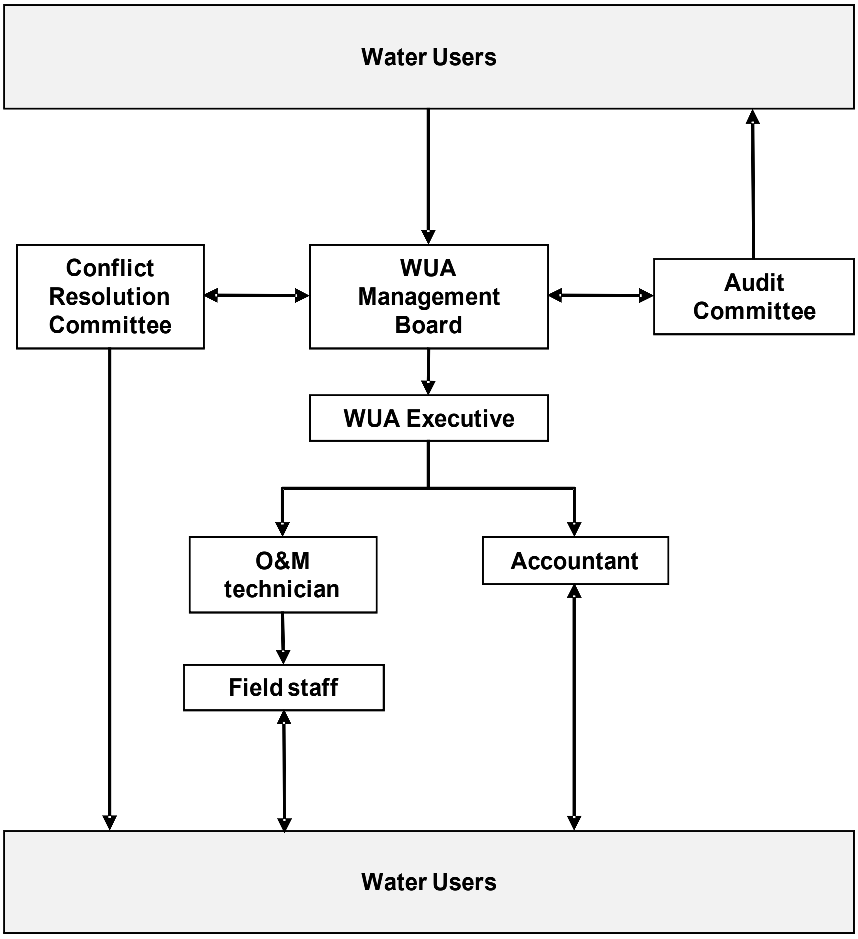


Figure 13.3 Typical organisational structure for Water Users Associations

13.2.6 Management records

The basic records required for communally managed irrigation schemes include:

- A map of the irrigation scheme, showing the boundaries, canals, drains, structure locations, and, if applicable, the representative zones.
- In some cases for schemes designed and formerly managed by government a full cadastral map showing the landholdings may be available.
- A register of members, with the names and landholding areas of each member.
- Accounts records in including a cash book, a register showing the irrigation fees paid, an accounts book showing the income and expenditure.
- An asset register, detailing the lengths of canals and drains and the type and characteristics of all structures.

13.2.7 Management processes

The overall management process for a communally managed irrigation scheme is shown in Figure 13.3. There are six stages in the annual or seasonal management cycle, with a three stage sub-cycle during the implementation phase. The components of each stage are outlines in the sections below.

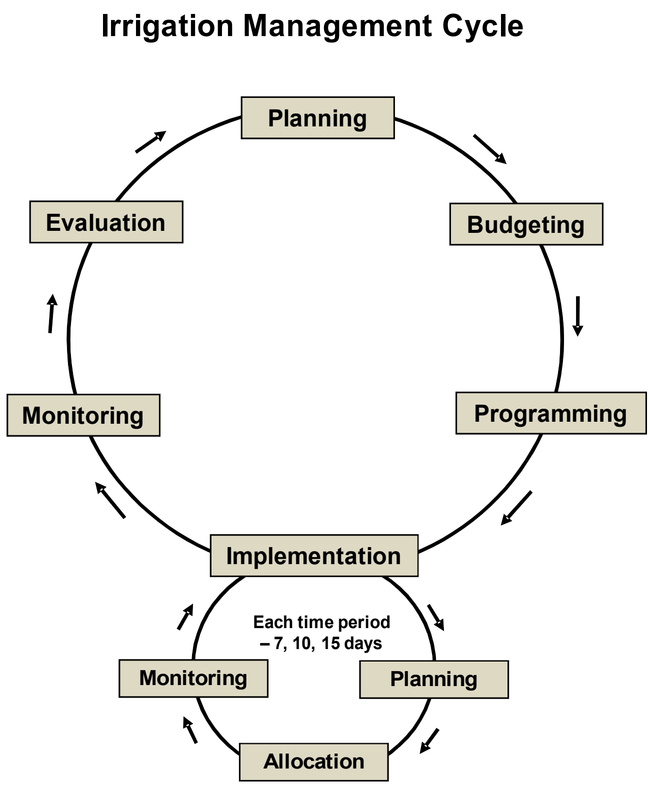


Figure 13.4 Irrigation management cycle

Planning: Pre-season planning is required in order to match irrigation water demand with the anticipated supplies. The need to carry out pre-season planning will depend on the size of the irrigation scheme and the water availability situation. It would be important, for example, in a situation where some farmers want to grow rice, but supplies are limited, and growing too big an area of rice could result in no water supplies for other farmers.

Budgeting: At the same time, the WUA executive management will prepare the budget for the year, which will include staff costs, operation costs and maintenance costs. These expenses will be balanced by the income from the water users, the total expenditure divided by the number of members gives the irrigation service fee to be charged to members.

Programming: An additional task is to programme the work of the WUA and water users during the coming year. This programme will show when certain activities need to be carried out, such as pre-season maintenance of the system. In some hill systems without fixed intake structures a major pre-season activity is to rebuild the intake and to form the diversion works (Figure 13.4). This work is carried out by the water users. Other work might include clearing canals of sediment and vegetation, ready for the irrigation season. Additional canal cleaning may need to be programmed during the season to remove the re-growth of weed and vegetation.

Figure 13.5: Water users gathering at the river intake to their irrigation system to rebuild the intake structure, Kilimanjaro, Tanzania

The irrigation plan, budget and work programme are then submitted to the Association's General or Representative Assembly[24] for approval. The WUA management will need to explain the reasoning behind both the irrigation plan and the budget, and will need to make amendments if changes are required by the General Assembly or Representative Meeting.

Implementation: Once the irrigation season commences, the system should be ready for farmers to plant their crops and receive their irrigation supplies. It is important to realise that within the irrigation season, there is a further sub-cycle involving planning, allocation and monitoring of water allocation. This sub-cycle involves looking at the specific demands in the coming time period/ planning/scheduling the available supplies, allocating them and then monitoring the allocations made.

The irrigation plan made at the pre-season stage will give the broad irrigation demands and locations of demand, the scheduling carried out within season give specific discharges, and volumes to be supplied to specific field plots, crops and farmers.

The in-season scheduling and water allocation is also the basis for charging the irrigation service fees. Though there are a number of mechanisms for charging (e.g. per irrigation, or based on crop type and area, or based just on irrigated area), they all require that a record is kept of water deliveries made. Monitoring and record-keeping are therefore important components of the in-season water allocation process.

Monitoring: During the season, the implementation of the pre-season irrigation plan and work programme should be monitored. This can be especially important in the case of a system supplied from a small reservoir, where it will be essential to keep careful track of the abstractions made, and to compare them with the planned abstractions and remaining supplies in the reservoir.

Evaluation: Evaluation is carried out at the end of the season to make several assessments:

i) To compare the actual implementation against the plan. This assessment looks at how closely the actual implementation complied with the plan, and how the planning can be improved to get as close a fit as possible.
ii) To assess the viability of the plan. This assessment looks at whether the plan was the right plan, or whether changes could be made to improve it. For example the plan may have been conservative on the estimates for the areas that could be grown to high water-demand crops, if these can safely be increased without danger of reducing supplies to other crops, then this may be beneficial to water users.
iii) To assess how implementation was carried out. This assessment would answer questions such as - Could efficiencies have been made in terms of staffing, or water use? Were the fees collected correctly? Did the water supply match the water users' expectations?

[24] A General Assembly is a meeting of all members; a Representative Assembly is a meeting of elected Representatives for groups of water users. See Chapter 12 for more detail.

The evaluation process does not have to be too laborious, it simply seeks to assess whether planning decisions made at the beginning of the season were correct, were implemented adequately, and whether any improvements can be made to improve agricultural and water productivity.

13.3 References

Huppert, Walter and Urban, Klaus. 1998. Analysing service provision: Instruments for development cooperation illustrated by examples from irrigation. GTZ publication No.263, Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), GmbH, Eschborn, Germany.

13.4 Operation

Operation covers the tasks associated with the physical operation of the irrigation and drainage network and includes:

- Annual/seasonal planning for water delivery
- Deciding on water allocations to water users
- Scheduling of irrigation supplies
- Regulation of control structures to deliver the required amount of water
- Measurement and recording of irrigation water deliveries
- Monitoring and evaluation of irrigation operation (to ensure targets are met)

The objectives for operation of the irrigation system are to supply water:

- In adequate quantity (discharge and duration)
- At the correct time (in relation to crop growth stage and water demand)
- Reliably
- Equitably
- Efficiently
- Cost effectively

For productive agriculture, irrigation water is required at the right time to suit the demands of the crop. Hence the correct amount of water delivered late is of little use to the farmer, as the crop yield will have been adversely affected. The right quantity of irrigation water is required if the crop is to survive without stress until the next scheduled irrigation. Likewise, the reliability of the supply is also important to the farmer, knowing that the next irrigation will arrive on schedule and in the right quantity.

Equitable water distribution is necessary to ensure that all farmers have equal access to the water resource. An important objective for irrigation system managers is to ensure that farmers at the tail-end of irrigation networks get similar levels of supply to those at the head-end. Efficiency is important to reduce wastage of water, not only when water is in short supply, but at all times to reduce the risk of waterlogging and salinization of the land, due to over-irrigation or excessive leakage from canals.

If farmers are paying for the service delivery associated with irrigation water supply, they want to be sure that the cost of service provision is low in relation to the total cost of production. Studies in several countries have shown that the cost of irrigation service delivery is usually in the range 5-10% of the production costs. As water is often a limited resource, it is important that it is used productively.

Productivity of water is also an important objective, but is partly out of the control of the system operators as it depends on how the farmers use the supplied water. Agricultural production per of land (crop yield, kg/ha) is a common measure of performance, increasingly the productivity per unit of water, in kg/m3 or $/m3, is of increasing interest to scheme managers and water users as water becomes more scarce. The management cycle has been presented in Figure 13.3 and outlined in the

Section on management above. The sections below elaborate on this outline with regard to operation of the system, in particular the procedures for in-season scheduling and allocation of irrigation water supplies.

13.5 Maintenance

An irrigation and drainage system which is inadequately maintained will fall into disrepair. Gates will become inoperable, measuring structures will drown out, canals and drains will silt up, vegetation will block canals and drains, canals will overtop and breach. As a result, irrigation water supplies will become irregular, unreliable, untimely, inadequate and uncontrolled. Drainage water removal will be hindered, leading to the rising of the groundwater table and salinization. In both cases, for irrigation and drainage systems, lack of maintenance will lead to reductions in crop yields and overall crop production, which in turn results into a reduction in farmers' incomes (Figure 6.1).

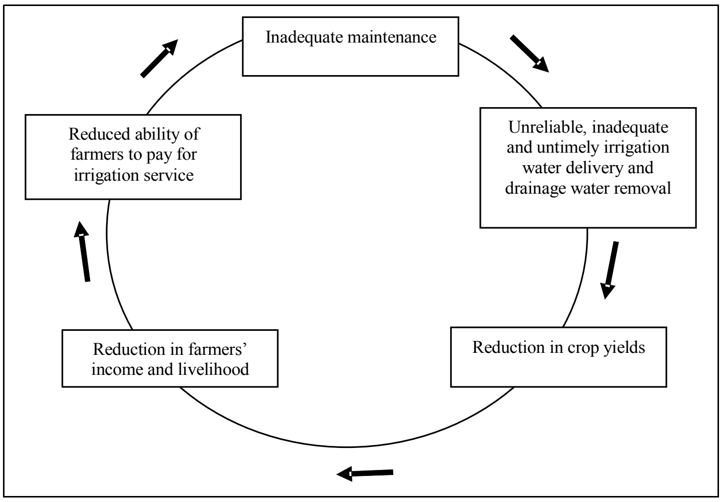
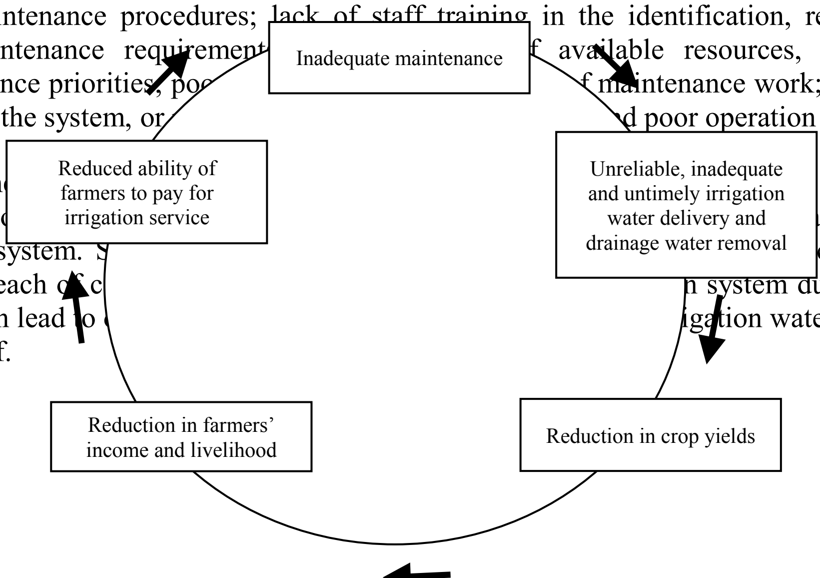


Figure 13.6 Linkage between inadequate levels of maintenance, farmers' income and irrigation service fee recovery

Unless preventative action is taken, an irrigation and drainage system will deteriorate over time as a result of natural forces, as well as from human and animal activities. The forces acting on the physical infrastructure include: rainfall; wind; erosion by surface runoff, flow of water in canals and drains; transportation and deposition of silt in rivers, canals and drains; vegetative growth in and around canals, drains and structures; rodents and burrowing animals (in embankments); human and animal traffic across canals and drains; corrosion and rusting of gates; biological degradation of organic matter (e.g. wooden gates); thermal expansion and contraction.

The main reason that this natural process of deterioration is allowed to occur unchecked, is often the lack of adequate funds for maintenance. It is not the only cause, however, other factors include: poorly defined maintenance procedures; lack of staff training in the identification, reporting and processing of maintenance requirement[illegible]f available resources, incorrect or undefined maintenance priorities, po[illegible]f maintenance work; poor design and construction of the system, or[illegible]d poor operation practices.



Poor operation of th[illegible] deteriorates. Incorrect operation [illegible]ntities of silt entering the canal system. S[illegible] can result in overtopping and breach of c[illegible]n system during periods of heavy rainfall can lead to [illegible]igation water is added to surface water runoff.

Inadequate maintenance leads to the need to rehabilitate the system (Figure 13.2). Rehabilitation of I&D systems will always cost more than a programme of regular maintenance, on three fronts. Firstly, in terms of the lost production as the system deteriorates over time. Secondly, in terms of the increasing rate and extent of deterioration as I&D components are allowed to deteriorate (the adage “a stitch in time saves nine” is applicable here). Thirdly, in the actual costs of rehabilitation itself, which may require external consultants and/or contractors to carry out surveys, studies and construction work.

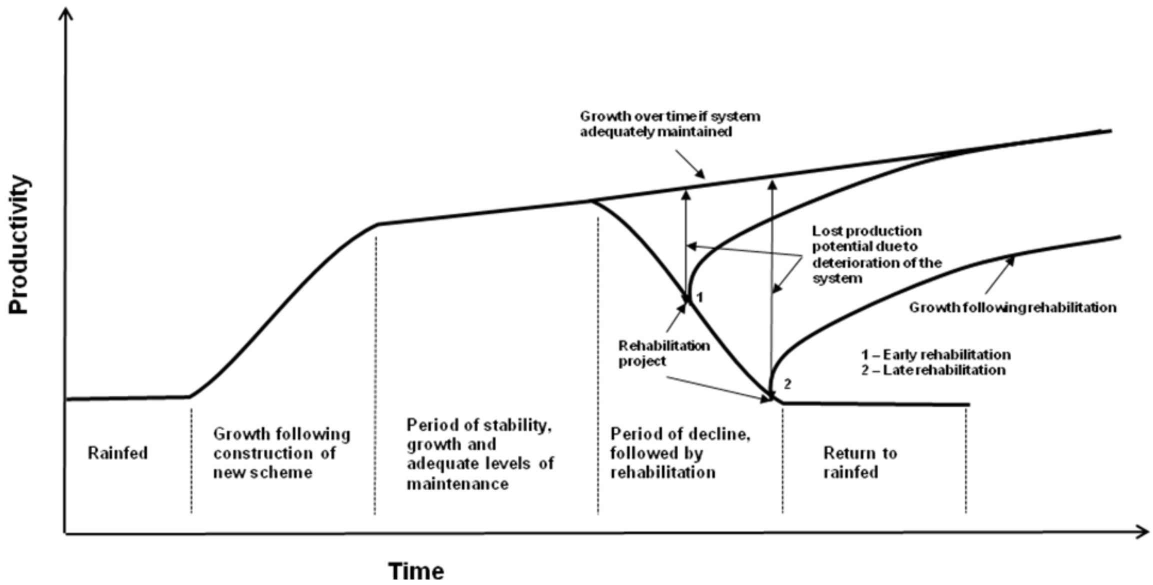


Figure 13.7 Possible stages of growth and deterioration of irrigation and drainage systems with and without adequate levels of maintenance

13.6 Objectives for maintenance

The objectives for maintenance of an irrigation and drainage system can be stated as:

1. To enable the system to be operated at its optimum level at all times
2. To ensure the longest economic lifespan of the system and its individual components
3. To achieve the operational and longevity objectives at optimum cost.

13.7 Maintenance categories

Maintenance can be classified into 6 main categories:

- Routine
- Periodic
- Annual
- Emergency
- Deferred
- Preventative

Maintenance work can be carried out under these categories by one, or a combination, of the following:

- Direct labour by water users themselves
- Contractors

13.7.1 Routine Maintenance

Routine or day to day maintenance is small maintenance work that is to be done on a regular basis. Such work includes, but is not limited to, the following:

- minor repairs to earth embankments - small gullies from rainfall runoff, animal damage, machinery damage, cracks, and small seepage holes
- clearance of silt in canals and drains near structures, especially near gates, measuring structures and siphons
- clearance of floating trash from canals and structures, trash screens and gate wells
- removal and cutting back of vegetation from within canals and drains, from embankments (trees and bushes), and from around structures
- greasing and oiling of gates

Routine maintenance is the responsibility of the water master, and will be part of his regular duties.

13.7.2 Periodic Maintenance

Periodic maintenance is small scale, often preventative, maintenance work that does not pose any immediate threat to the malfunctioning of the system. Such work may require skilled labour or machinery, and should be carried out at intervals during the irrigation season, as required. This work includes but is not limited to the following:

- repairs to concrete canal lining and structures
- repairs and maintenance to wood and metal works, in particular gates
- repairs to measuring structures, and installation of gauges
- repairs to canal embankments if there is leakage or overtopping
- painting of metal and woodwork
- repairs to machinery such as pumps and engines
- access road upkeep

Some of this work could be carried out by the water users themselves if there is sufficient expertise within the community. Alternatively, a contract can be let to carry out the work. The work would typically require a foreman, concrete/masonry artisans, carpenters, fitters/mechanics, maintenance plant operators and labourers.

13.7.3 Annual Maintenance

Annual maintenance is work that is planned as a result of maintenance inspections, which is too large, or on too wide a scale for periodic maintenance work. It could also include work related to the improvement of the system rather than maintenance. The work can be carried out by a team of water users, or by a contractor.

The maintenance work is carried out when the canal is not in use, either at the end or the beginning of the irrigation season. Such work includes but is not limited to the following:

- major desilting operations of canals and drains
- repair of canal lining
- repair of headworks and canal/drain structures
- maintenance of canal embankments, service roads and flood bunds
- repair or replacement of equipment, gates, pumps, motors, etc.

13.7.4 Emergency Maintenance

Emergency maintenance is work that cannot be planned for, and is carried out as the need arises. The uncertainty of what and where the problems are going to be, makes coping with the problems difficult. Flexibility of working practices throughout the system is required as a result. Work in this category may include:

- temporary repairs to river, canal or flood bund embankments in the event of a breach or possible breach
- preventative work to avoid structure failure, or temporary repair as a result of a structure failure
- work to alleviate flooding, landslides or mud flows.

The WUA will need to mobilise and organise water users to carry out this work, and good communication is essential to organise and coordinate the different tasks that arise.. The nature of the work requires that it is carried out quickly. Prompt action minimises the extent of any damage and of the repair work required.

Though the work will be an emergency when it occurs, the extent of the damage can be reduced if some preparations are made beforehand. For example, if flooding is a regular occurrence at some periods of the year, then the WUA can discuss beforehand the measures that need to be taken with water users. This will ensure quick mobilisation, as well as awareness of what tasks need to be carried out. Groups of water users may be assigned specific tasks or responsibilities of specific areas in the system.

13.7.5 Deferred Maintenance

Deferred maintenance is work that has been identified following inspection of the infrastructure, but which is either of low priority or cannot be carried out due to lack of sufficient funds. The work is recorded in the Maintenance Register and periodically reviewed. Some of this work may also be related to system improvements such as:

- improved footbridge crossings, road culverts
- improvements to access along canal embankments

13.7.6 Preventative Maintenance

Preventative maintenance is work that, if carried out, will result in preventing more expensive maintenance or repair work at a later date. A classic example of preventative maintenance is the prevention of seepage around or under hydraulic structures; if seepage is identified and remedial action taken in good time, the collapse of the structure can be prevented, saving considerable expense.

Priority areas for preventative maintenance include:

- checking for seepage around or under structures, especially if there is a high pressure differential across the structure
- grading or smoothing of embankments and canal/drain inspection/access roads to avoid ponding of water and gullying
- closing river intake gates before high flood levels in the river, both to avoid excessive discharges in the canal and intake of water with high sediment loads
- painting of metal and wood components, particularly gates and gate frames

13.8 Maintenance cycle

The maintenance cycle is shown in Figure 13.8 and discussed in the sections below:

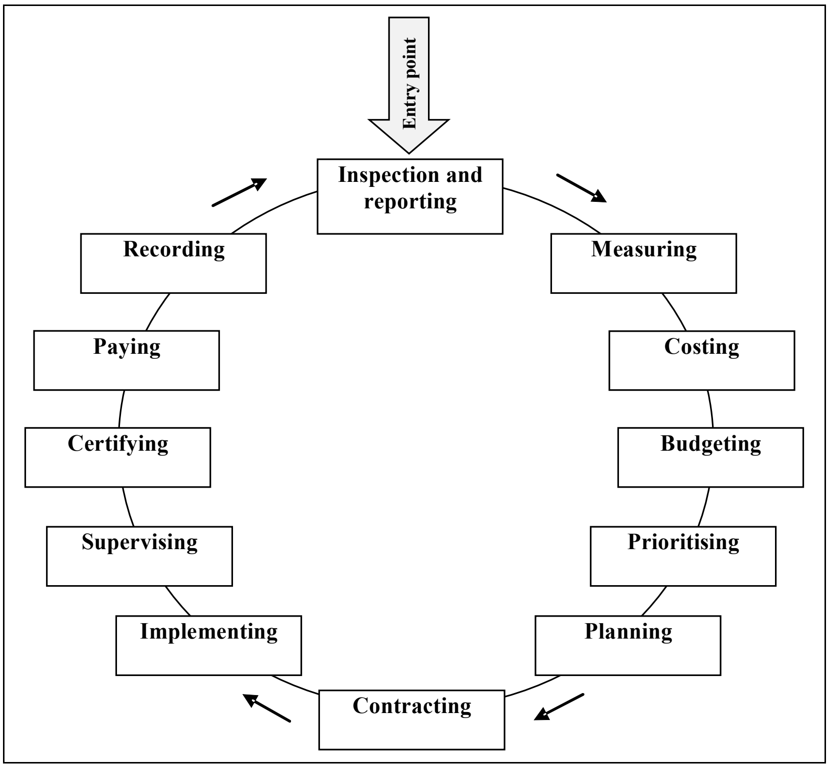


Figure 13.8 Annual maintenance cycle

13.8.1 Maintenance inspections and reporting

Inspection of irrigation and drainage works for maintenance can be carried out by the WUA engineer or the water masters. There are two forms of maintenance inspection:

i) Inspections as part of the day-to-day work
ii) Annual or seasonal inspections

Standard procedures for inspection and reporting of maintenance are an obvious prerequisite for effective maintenance. Unfortunately, such procedures are not always properly developed; thus, the following are required:

- A set of clearly defined instructions and procedures detailing when inspections should be carried out, by whom and how often;
- Clearly defined reporting procedures, comprising a set of reporting forms and a maintenance register. The maintenance register should have a record of all the maintenance work required, and it current status and categorisation (required, periodic, annual, deferred, etc.).

Water masters should have field books in which identified maintenance work can be written down and then reported to the office. Daily routine maintenance, such as greasing of gates, need not be reported and booked, thought the annual and periodic inspections should check that this work is being carried out by the water masters.

(i) Inspections as part of the day-to-day work

Inspection and monitoring of maintenance needs is part of the water master's work, and should be part of their daily routine. Pump operators will also be responsible for identifying and reporting any maintenance requirements.

Any maintenance requirements observed by these staff that they cannot carry out, should be reported and recorded in the Maintenance Register. In the case of emergency maintenance, the water masters should take action immediately, and do what they can to get help in dealing with the emergency. The sort of maintenance needs that should be looked for during the irrigation season are listed in Table 13.1 below.

(ii) Annual or seasonal inspections

Annual or seasonal maintenance inspections should be carried out by experienced personnel. There should be one pre-season inspection to identify work that has to be carried out before the irrigation season starts, and one inspection at the end of the season that identifies work that may need to be contracted out and completed before the following irrigation season commences.

Ideally, the annual or seasonal inspections should take place under two conditions, (i) when the canals are empty of water, and (ii) when the canals are flowing at design capacity. Inspection when the canals are empty enables inspection of infrastructure below the normal water line, whilst inspection when the canals are full and flowing at design capacity allows assessment of the carrying capacity of the canals, and the functioning of conveyance, control and measuring structures. In the case of drains, similar practices apply, with inspections required when the drains are relatively dry, and when they are full after periods of heavy rainfall and runoff. Points to look for during the annual/seasonal inspection are presented in Table 13.2.

Table 13.1 Points to look for during in-season maintenance inspections

Where to look	Typical problem and maintenance need	Consequence	Possible solution
Canal section	Vegetation obstructing flow	Capacity of canal is reduced	Cut or remove vegetation
	Rubbish obstructing flow at siphons, aqueducts, culverts, etc.	Capacity of canal is reduced. In severe cases may cause overtopping of the canal embankment resulting in a breach in the canal	Remove rubbish
	Undersized culverts or structures	Pipe culverts placed in the canal will obstruct and may reduce the maximum flow capacity of the canal	Do not allow construction of pipe culverts in canals, insist on bridges. Remove and replace culverts that are obstructing flow
	Siltation	Canal capacity reduced	Remove sediment
Canal embankments	Seepage through embankments	Loss of water, but in the longer term the embankment may collapse. Large breaches in canals often start with small leakages	If severe close the canal, excavate damaged section and refill with compacted material.
Structures	Seepage through structures (through concrete or masonry)	Loss of water, but in the long term the seepage through the structure may damage the concrete or masonry, creating a large hole in the structure. Seepage through reinforced concrete will lead to rusting of the reinforcement and eventual spalling of the concrete.	Need to break out the poor concrete or masonry section and replace with sound concrete or masonry.
	Seepage or piping around structures	Loss of water from the canal, but very likely hazard that the seepage will erode the soil material around the structure and it will collapse. This form of structure failure is one of the most common, and the most expensive to repair.	Monitor the situation on a daily basis if it is not possible to close the canal. If the seepage loss increases close the canal and repair by excavating backfill material and replacing with well compacted backfill.

Gates	Leakage through closed gates	Loss of water	Some leakage is unavoidable. If excessive then replace the gate plate or the whole gate. For gates with rubber seals, replace seals as they wear out.
	Unable to operate gate properly	Inability to control water, resulting in wastage of water and inability to deliver water according to demands. Serious consequences for downstream users	Replace broken or damaged portion of gate (spindle, nut, plate, frame) or whole gate.
Measuring structures	Drowned out or damaged measuring structure	Cannot measure flow. Inability to match supply and demand for water leading to inefficient operation and either shortage or wastage of water	Repair damaged section. If drowned out look for cause of drowning and either raise measuring structure crest level (if head available) or remove vegetation/obstructions downstream, or calibrate canal section and/or use float measurement.

Table 13.2 Points to look for during annual or seasonal maintenance inspections

What to look at	Typical problem and maintenance need	Consequence	Possible solution
Canal or drain section	Vegetation in canal or drain section	Capacity of canal or drain is reduced	Cut or remove vegetation
	Adequate functioning of weep holes to relieve pore pressures	If weep holes become blocked then pressure will build up behind the canal lining and the lining will collapse	Clean out weep holes or install new ones.
Embankments	Vegetation along canal or drain embankments	If vegetation is large, such as trees and bushes, then the canal or drain embankment might be damaged by the roots.	Cut down and remove large bushes and trees that might damage the canal or drain embankment
	Vegetation obstructing access	Cannot fully inspect or move along the canal embankment or drain, operation and maintenance will be impaired	Remove vegetation.
Structures	Cavities beneath concrete or masonry floors or side walls. Test by banging with a stout pole - a hollow sound indicates a cavity. Also important to test for lined canals	Indicates seepage or piping behind the concrete or masonry. If not dealt with the structure or lining may collapse, requiring costly repairs.	Locate and repair the cause of the loss of backfill (e.g. piping, seepage, etc.). Break out the concrete or masonry and backfill the affected areas Alternatively excavate behind the concrete or masonry, place compacted backfill.
	Cracks in masonry or concrete. Check depth and extent of cracking. Check if reinforcement exposed	Water is lost through the cracks. This can result in undermining of the backfill material and eventual collapse of the lining or structure. If reinforcement is exposed, or water leaks through reinforced concrete the reinforcing steel will rust and the concrete will spall.	Cut out affected area and replace with well compacted concrete.
	Scour hole downstream of structures, such as cross regulators or drop structures. These cannot always be drained out by gravity. Plumb holes with plumb line, or drain with a pump.	The structure may be at risk of collapse.	Check if the situation is stable or not. If scour is continuing then a full engineering inspection may be required.
	Condition of metal and wood work, like gates and stop logs.	Deterioration of wood or rusting of metal can lead to failure of the component.	Protect wood and metal parts with creosote, varnish or paint.
Gates	Unable to operate gate	Inability to control water, resulting in wastage of water and inability to deliver water according to demands. Serious	Replace broken or damaged portion of gate (spindle, nut, plate, frame) or whole gate.

		consequences for downstream users	

13.8.2 Maintenance Register

A Maintenance Register is useful for the following purposes:

- To help in processing the data collected on maintenance requirements
- To assist in prioritising and allocating maintenance work
- To record the maintenance work carried out in a transparent and accountable format.

As discussed above the maintenance work is identified in the field, and the work required measured and quantified. To assist in the measurement and quantification, a Maintenance Work Sheet can be used (Figure 13.8), or alternatively the data can be recorded in a notebook.

The data collected from the field (measurements and quantities) can be recorded in the Maintenance Register (Figure 13.9), and data entered on the unit costs of the work items, to determine the total estimated cost of the work. The work can then be prioritised, and a decision made as to who will do the work (direct labour, contracted labour, contractor, etc). Once the work has been completed, details of the work done will be recorded, including the sum paid, who carried out the work, and the date completed.

Figure 13.9 Maintenance work sheet for in-the-field recording of maintenance work required

MAINTENANCE WORK SHEET

CANAL/DRAIN: ________________________________

LOCATION: ____________________________________

Description of work required:	**Units**	**Quantity**

SKETCH (If required showing location and/or damage details)

Hand drawn sketch to be added

Figure 13.10 Example of a sheet from a Maintenance Register

MAINTENANCE REGISTER

WUA Name:_____________________________

LOCATION		WORK REQUIRED	BILL OF QUANTITIES				Priority	ACTION TAKEN		
Canal/structure type	(m)Chainage	DESCRIPTION AND DRAWING OF THE WORK REQUIRED	Unit	Quantity	Rate	Amount		completedDate	Cost	Work carried out by:

13.8.3 Maintenance measurement and costing

Measurement of the maintenance work is needed to quantify the work, as well as to provide a basis for estimating the cost and time required to do the work. Typical work items and measurement units for different types of work are presented in Table 13.3, whilst Table 13.4 gives an example of the summary of costs in a table of maintenance inspection and measurement.

13.8.4 Maintenance budgeting, prioritisation and planning

It is not possible to carry out all the required maintenance work, generally due to financial, resource or time constraints. In some cases, it is not efficient to carry out the maintenance work, for example in the case of sedimentation of canals or drains where it is more efficient and cost-effective to remove sediment once every 3-5 years, rather than on an annual basis.

Once the required maintenance work has been identified, it can be prioritised and planned to fit within the available budget. An example of priorities for maintenance work is presented in Table 13.5, emphasising the importance of considering the location, nature of the work, and the potential problems if the required work is not carried out. For any given irrigation and drainage system, such a list of priorities should be drawn up by experienced personnel to act as a guide for the selection and prioritisation of maintenance work.

It is difficult to set a generic set of rules for prioritisation of work for irrigation and drainage systems. For some systems with heavy sediment loads in the river, the priority is sediment removal. Similarly in a system with low sediment levels, the priority might be vegetation removal (as weeds grow more quickly in clear water). The factors influencing the setting of priorities are:

- *How sophisticated is the system?* In simple systems measurement may not be as important as conveyance, whilst in more sophisticated systems measurement has a high priority as it is the basis for charging for service delivery;
- *What are the consequences of not doing the (maintenance) work?* What is the risk of failure, and what is the cost of such failure on crop yields, agricultural production and repair work?
- *Will water be lost or used inefficiently?* On the one hand, if the system is water-short then conserving water will be a priority. On the other hand, if there is sufficient water, then the loss of water may be less important, but waterlogging and salinization may be an issue;
- *Will control be lost or impaired?* An inability to control the flow at division points can mean that some downstream users get too much water, whilst others do not get enough, leading to wastage on the one hand and possible crop yield reduction on the other;
- *What command area is affected by the maintenance work?* Is the work in an upstream location (large area downstream affected) or a downstream location (smaller area affected)
- *How cost-effective is the maintenance work?* A classic example here is masonry lining of canals, which has little effect on seepage losses, versus repair of damaged control gates. Repairs to gates are cost effective relative to canal lining ; leakage and wastage are reduced as flows can be stopped to locations where water is not required and distributed to where it is required;
- *Can it wait until next year?* In some cases work can be deferred, in other cases there is a high risk of failure and increased costs if the work is not carried out. “A stitch in time saves nine!”

Table 13.3 Example of maintenance items, measurement units and maintenance costing

Item	Measurement unit	Annual quantity	Unit rate ($)	Amount ($)
(i) Earthworks				
Compacted fill for embankment construction	m^3			
Removal of sediment from canal	m^3			
Repair of access road	m^3			
Removal of sediment from drains	m^3			
(ii) Canal lining				
Excavation of unsuitable material	m^3			
Placement of compacted backfill	m^3			
Concrete for lining	m^3			
Repair canal lining joints	m			
(iii) Structures (and associated earthworks)				
Excavation of soil	m^3			
Placement of compacted backfill	m^3			
Concrete (including shuttering)	m^3			
Masonry	m^3			
Stone rubble protection (rip-rap)	m^2			
Steel reinforcement	kgs			
Concrete pipe 40 cm dia.	m			
Concrete pipes 60 cm dia.	m			
Concrete pipes 80 cm dia.	m			
Steel pipe <60 cm dia.	m			
(iv) Control and measurement				
Greasing/oiling of gates	No.			
Painting of gates	No.			
Repair to gates – small < 60 cm wide)	No.			
Repair to gates – medium 60-120 cm wide	No.			
Repair to gates – large >120 cm wide	No.			
Replacement of gates <60 cm wide	No.			
Replacement of gates 60-120 cm wide	No.			
Replacement of gates >120 cm wide	No.			
Repair to measuring structure	m^3			
Replacing/painting of depth gauge	No.			
(v) Miscellaneous				
Removal of floating vegetation	hrs			
Removal of vegetation from canal section	m			
Removal of vegetation from canal embankments	m			
Removal of vegetation from drain section	m			
(vi) Other items				
			Sub-total	

Table 13.4 Example of identified maintenance work within a secondary command area

Location/ Chainage (measured from secondary canal intake)	**Structure**	**Problem**	**Description of work required**	**Priority**	**Quantity No.=Number, L=Length, B=Breadth W=Width, H=Height, D=Depth, A=Area, V=Volume (T)=Trapezoidal section, (V)=Vertical section**						**Cost (000's Shilling)**
					No.	**L (m)**	**B/W (m)**	**H/D (m)**	**A (m^2)**	**V (m^3)**	
U3-5 0+000	U3-5 Secondary canal measuring structure	Discharge measurement difficult as no gauge	Paint new gauge upstream of measuring structure	High	1 No.						1
U3-5 0+040 to 0+100	Canal lining, both banks	Canal lining is crumbling and holed. Loss of function and rapid deterioration	Repair canal lining	Medium		200	0.10	1	200	20	140
U3-5 0+200 to 0+400	Both canal banks	Left bank covered in reeds, impairing canal flow. Right bank needs vegetation cutting back	Left bank – cut down reeds and remove roots Right bank – cut back vegetation (brambles) at start of next season	High		100	-	-	-	-	2.5
U3-5 0+500 to 0+550 (approx.)	Left canal banks	Left bank top is low, resulting in high risk of over-topping	Raise bank top level by 30 cm	High		80	1.5	0.30		43.5	6.6
U3-5 0+600	Tertiary gate	Whole gate frame and plate badly rusted	Install new gate	High	1 No.						3.5
U3-5 0+800	Tertiary gate	Gate not operable, no spindle or plate	New gate plate and spindle	High	1 No.						2.0
U3-5 0+950	Left bank just u/s of B-18	Canal at risk of overtopping	Raise embankments with compacted fill	High		30	1.0	0.20		6	0.9
U3-5 1+000	Tertiary gate	One gate inoperable, no spindle. One gate partially operable, no spindle nut	New spindle required New nut required	High	1 No. 1 No.						1.5
U3-5 1+178 to 1+300	Both canal side slopes	Canal lining in poor condition, crumbling and holed.	Repair and replace canal lining	Medium		20	0.10	0.50	10	1	7.0
U3-5 1+401	Secondary canal	Very badly damaged secondary canal left bank. Severe overtopping of canal and loss of water to drain.	Reform canal bank, placing compacted backfill behind canal lining and compacted fill to level of 20 cm above top of lining	Very high		50	1.5	0.30		22.5	3.5
U3-5 1+405	Aqueduct over drain	Some leakage from aqueduct	Monitor situation, If leakage gets worse seal leakage with mortar	Low	-		-	-	-	-	-
U3-5/2 0+190 to 0+390	Tertiary canal	Heavily weeded	Remove weeds and kill roots	High		100	0.30	0.60	18		0.9
U3-5/4 0+050 to 0+400	Left and right banks of tertiary canal	Heavy vegetation growing over canal banks	Cut back and remove vegetation	Medium		200	0.30	0.60	36		1.8
				Total cost							171.2

Note: Costs are indicative only

Table 13.5 Example of priorities for maintenance work

Priority	Type	Comment
1	Diversion Weir and intake	Failure of this structure would have serious consequences for the operation of the system. Therefore it has to have top priority for maintenance, particularly the gates.
2	Leakage, unauthorised off-takes and overtopping	Losses of water to the canal system as a result of leakage through canal banks, unauthorised offtakes and overtopping of the canal embankments are a serious matter.
3	Gates and control structures	Without gates, or stop logs in cross regulators, control of water is difficult. The system cannot be operated efficiently without control structures in good condition.
4	Masonry Repair	Repairing of cracks in masonry is necessary before water gets in behind the masonry and causes cavities, leading to collapse of the masonry.
5	Embankment Protection	Protection of canal embankments takes several forms, that is protection from: - erosion by canal water, - gulleying caused by low spots and crab holes, - removal by farmers cultivating close to or even on top of embankments, - erosion by human and animal traffic across the canal
6	Measuring structures	Inefficient and incorrect water management will result from having measuring structures in poor condition. Measurements will be incorrect. Water allocation planning will be wrong and so will water distribution.
7	Silt Removal	Silt removal upstream of measuring structures has higher priority, general silt removal has a lower priority, except where excessive silt build up has reduced canal capacity or caused the water level in the canal or drain to rise leaving inadequate operating freeboard.
8	Vegetation Removal	Vegetation removal such as cutting grass on embankments, is a very low priority. Removing grass from cracks in masonry and removing strong rooting shrubs and trees from the vicinity of structures is more important.

13.8.5 Maintenance contracting

Once the maintenance work has been drawn up, estimated and prioritised, a decision can be made on who should carry out the work. If the agreement is to be awarded to a contractor, tender documents with bills of quantities, specification and the contract terms are drawn up and contractors invited to bid.

It will be important to include guidance in the contract, as well as penalty clauses to ensure that the contractor takes due account of the constraints that they will be working under. This may include ensuring that irrigation water supplies are maintained to water users during the maintenance period, and that the maintenance work is completed before the start of the irrigation season. Delays in re-opening canals can have serious financial consequences for farmers, and must be avoided.

Contracting out of maintenance work is increasingly being used in many countries, as the private sector strengthens. Contracting out maintenance work can have benefits over direct labour maintenance work, provided that the tendering process is open and transparent, and there is a vibrant contracting sector where competitive bidding exists.

13.8.6 Implementation and supervision of maintenance work

Once the maintenance work is underway, it is important that it is properly supervised, whether the work is carried out by direct labour or by a contractor. All relevant persons should be involved in the supervision process – if the work is being carried out at the on-farm level, then farmers should be informed of the nature of the work so that they can keep an eye on the work, as well as the formal supervising body, which might be the WUA management team. For some of the smaller work, the water master may be delegated to carry out the day-to-day supervision; whereas for more major works, the WUA engineer or WUA Director will be responsible for day-to-day supervision.

The timing of carrying out the maintenance work is important. Considerations to be taken into account include:

- the cropping season. Some work is best done at the start of the season, for example removal of vegetation from canals and drains, other work can be done at the end of the season, such as repairs to structures, etc.;
- the climate. It is advisable to avoid averse climatic seasons, such as rainy seasons when access is difficult, flood periods, winter when fresh laid concrete can be damaged by frost and freezing conditions;
- the availability of labour. If it is intended that work is to be carried out with community assistance, then the work has to be time to avoid peak agricultural labour demands.

13.8.7 Certification and payment for maintenance work

Following completion of the work by a contractor, it must be certified as having been completed to the specified standards. Such certification will usually involve a final inspection of the completed works by delegated WUA representatives, following which payment will be made.

13.8.8 Recording maintenance work done

It is important to record that maintenance work has been carried out, and to document the time that the work has taken, where it was located, who carried it out and how much it cost. These data can then be used to build up a database of the type and cost of work carried out; this will be of considerable assistance in the planning and costing of future maintenance work.

In practice, it is often disappointing to see how little recording of maintenance work is carried out. If better use is to be made of available funds, then proper recording of maintenance work is a fundamental component of improved maintenance management systems.

13.9 The maintenance "bicycle"

Figure 13.11 shows the "maintenance bicycle" linking the various elements related to maintenance management. The key processes and categories of maintenance are linked by the organisational framework and its processes and procedures, with the direction set by the organisation (the irrigation and drainage service provider - a WUA, government agency or private entity). Social and political will and finance are important factors in the "pedal power" driving maintenance, whilst the vision and direction can be identified through research, avoiding or mitigating where possible natural hazards.

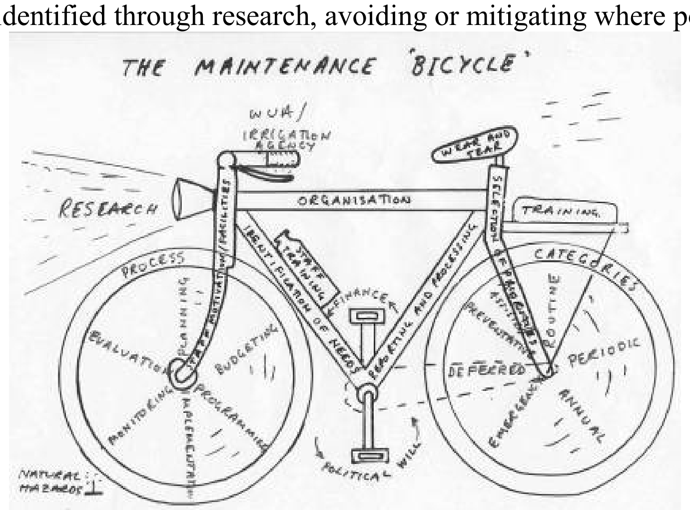


Figure 13.11 The "maintenance bicycle" framework for maintenance planning and implementation

13.10 Asset management procedures

13.10.1 Introduction

The term "asset management" originates from the world of business and finance. The Chambers Twentieth Century Dictionary defines assets as "the entire property of all sorts belonging to a merchant or trading association". Asset management is therefore the process of managing assets so as to maximise or optimise the benefits arising from them.

Asset management is routinely applied to a variety of engineering infrastructure, including water supply, transport (roads and bridges) and property. At present it is not widely applied in the irrigation sector, though this is changing. A key principle behind the use of asset management for infrastructure is that the assets (canals, drains, structures, etc.) serve a function from which benefits can be derived. Maintaining or enhancing that function results in sustained or enhanced benefits, either financial or social. Asset management can be more formally defined as:

> *"A structured and auditable process for planning, implementing and monitoring investment in the maintenance of built infrastructure to provide users with a sustainable and defined level of service."*

Asset management planning identifies asset stock (irrigation canals, drains, structures) and quantifies its condition and performance. From the assessment of asset condition and level of performance estimates can be made for the investment required to either:

- Maintain existing asset condition and system performance
- Enhance or extend asset condition and system performance

Asset management can be used by the owners and managers of infrastructure, as part of the process of assessing, monitoring and maintaining the value and utility of the assets. It can also be used by regulatory authorities where publicly owned infrastructure has been sold, franchised or transferred to non-governmental bodies. Such infrastructure often serves a monopoly function (delivery of irrigation water, potable water supply and sanitation, etc.), and the government has a responsibility to ensure that the infrastructure is properly managed and sustained over time. Failure on the part of government in this respect may mean that the management entity "mines" the value of the assets by failing to invest sufficiently in the infrastructure over time, leading to failure of the system in the longer term.

An important current application of asset management is in the process of transferring the management, operation and maintenance of the irrigation and drainage system to water users associations. Applying asset management procedures at the transfer stage can have important benefits, including identification and audit of all infrastructural assets; identification of water users' desired level of service; identification of the cost of maintaining the system over time commensurate with the agreed level of service provision; understanding by the water users of the relationship between infrastructure condition and system performance; and development and ownership by water users and irrigation service provider of the relationship between fee payment and service provision.

A word of caution is required. Asset management is a management tool; how it is used, and how effective it is, depends entirely on who uses it, and in what context. In the wrong context, where management is weak or lacks control over finances and budgeting, asset management will not work. What asset management can do, if used correctly, is identify infrastructural constraints to performance, and formulate plans to address them within the context of the ability and willingness of the users to pay for a specified level of service.

13.10.2 Overview of asset management

Asset management planning is at the core of planning for long-term investment and expenditure in irrigation and drainage infrastructure. Asset management planning seeks to relate investment and expenditure to specified, user-defined levels of service. The process (Figure 13.12) involves defining the level of service to be provided, quantifying the ability of the water users to pay for the specified service, identifying the condition and performance of the assets (canal, drains, structures, roads, etc.) and quantifying the investment and expenditure required to maintain, improve or extend the assets in order to satisfy the specified levels of service.

An explanation in terms of the asset management of a group of houses owned by a housing association helps to explain asset management. In the group of 30 houses there are, say, 10 houses which are Grade A (4 bedrooms), 10 which are Grade B (3 bedrooms) and 10 which are Grade C (2 bedrooms). The monthly rental value of Grade A, B and C houses are $500, $400 and $250 respectively. The houses will require different levels of maintenance at different intervals, possibly painting of the exterior woodwork every 3 years, painting of the interior woodwork and walls every 6 years, etc. In addition, there will be major capital expenditure at generally longer intervals, rewiring of the electricity circuit every, say, 20 years. A fundamental principal in this process is that the income from rental is able to cover these costs, including an allowance for management overheads. It may also be that the housing association at some stage decides to modernise the houses by providing new kitchens. This modernisation will enhance the level of service provided to the tenants for which an increased rental may be charged.

A similar process can be applied to irrigation and drainage infrastructure. The function and value of the infrastructure can be assessed and the infrastructure categorised, according to the potential level of service that it can provide (ability to deliver water to match crop demands)[25]. The level of expenditure required to keep the system operational over time at a specified level can be ascertained, and the fee level to be charged to water users determined. If further investment is made in the irrigation or drainage system and the system is modernised, then the fee level can be changed to reflect the increased level of service provision. For example, the conversion of a system with manually operated gates to a system with automatic level control gates will increase the level of service by facilitating water distribution on-demand, thereby better matching supply and demand, and facilitating enhanced agricultural production. There will be capital expenditure to remove and replace the control structures whilst the day-to-day operation costs may be reduced due to the saving of labour costs. The balance of the costs and savings will need to be determined by discounting over a 10-20 year time frame, to ascertain if the irrigation service fee level needs to be increased or decreased to pay for the changes made. Table 1 shows conceptual relationships between level of investment, canal control systems, the level of service, O&M costs and potential income levels. The level of service potential outlined in Table 13.7 assumes a close relationship between the control infrastructure and the management capability.

[25] It is important to note that there are at least two aspects here, the condition and performance of the physical infrastructure, and the performance of the people and organisations which operate the infrastructure. Whilst asset management primarily focuses on the infrastructure, an assessment of the ability of management to use and operate the infrastructure is also required.

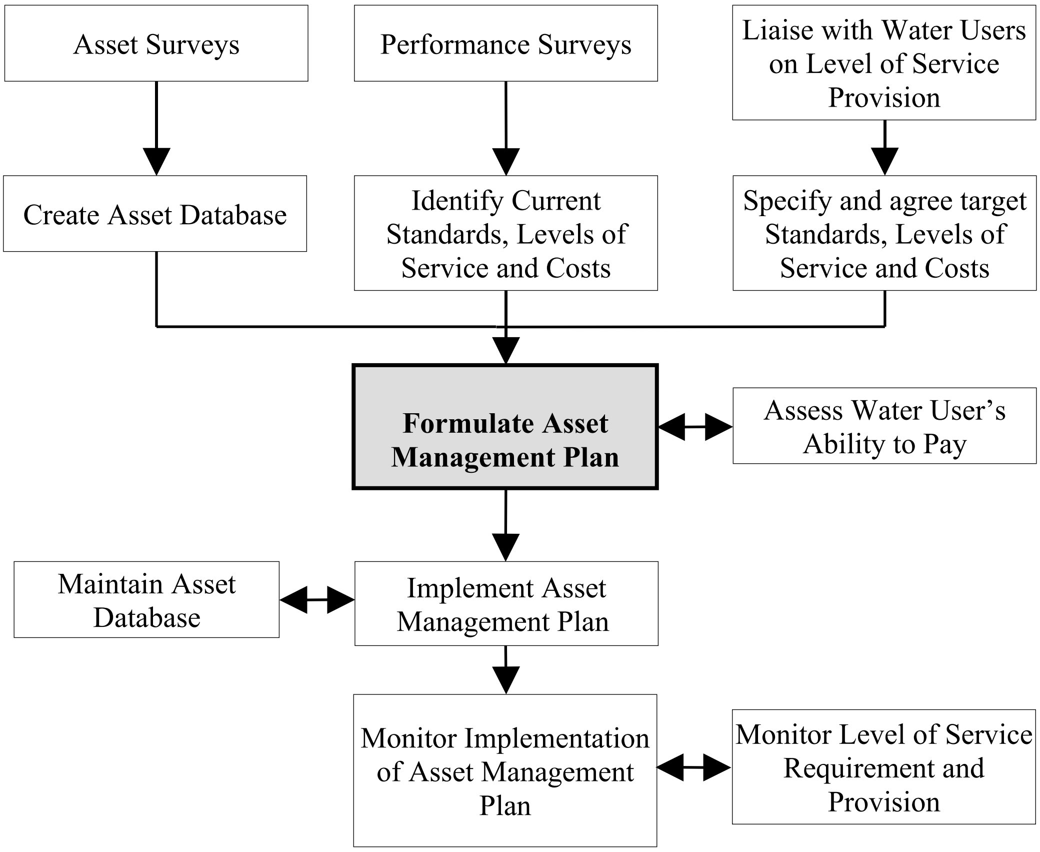


Figure 13.12 Framework for asset management and strategic investment planning for irrigation and drainage infrastructure

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Table 13.6 Indicative relationship between level of investment, canal control, level of service, O & M requirements and costs

Type	Canal control system	Water delivery system	Level of service potential	OandM requirements	OandM costs	Capital invest-ment level	Indicative OandM cost level $/ha	Possible potential income level
1	Fully automated downstream level canal control, fully adjustable and responsive to farmer demands	Demand	Very high, fully responsive to farmers demands for water. Highly efficient in water use	Low staffing levels due to automation, but work force need to be highly skilled.	Low on day-to-day basis but may be high on occasion as control equipment is expensive. High capital cost, moderate O&M cost.	High	35	High
2	Manual control with some automation at key locations. Discharge measurement at flow division and delivery points.	Arranged-demand	High, responsive to farmer's demands for water though farmers need to order water in advance. High interaction between service provider and farmer.	High staffing levels due to manual operation and need for measurement to match supply to demand.	High due to cost of O&M staffing and associated facilities (offices, motorbikes, etc.). Maintenance costs high to maintain and replace gates over time.	Moderately high	40	Good
3	Manual control throughout the system. Discharge measurement at flow division and delivery points.	Supply-demand	Moderate. Supply driven with irrigation service provider controlling/ allocating available water taking into account farmers cropping patterns. Relatively low interaction between service provider and farmer	Moderate staffing levels due to manual operation and need for some measurement to match supply to demand	Moderate due to O&M staffing and need for some O&M facilities. Maintenance costs high due to need to maintain control gates.	Moderate	25	Moderate
4	Manual control at main control points, ungated and/or proportional distribution at lower locations. Limited measurement.	Supply	Moderate, not responsive to farmers demands, limited control over water distribution to match demands.	Moderate to low staffing levels due to manual operation, though little measurement	Moderate to low due to O&M staffing and need for some facilities. Maintenance costs moderate due to need to maintain main control gates, kept lower by low-cost control at delivery points.	Low	10	Low
5	Fixed proportional control system, supply controlled, not responsive to demand. Measurement at water source intake only.	Supply	Moderate to low, not responsive to farmers' demands for water but farmers can plan ahead and adjust cropping pattern to suit supply. Inefficient in water use.	Low level of staffing, only low skill levels required	Low due to low O&M staffing levels and to low-cost proportional division structures.	Very low	5	Subsistence

The interacting factors of asset condition/performance, current and desired levels of service are incorporated into the asset management plan (AMP) and the investment over time calculated. The resultant expenditure profile (Figure 13.13) is compared with the ability of the water users to pay, in certain cases the standard of the desired level of service may need to be reduced to match the users' ability to cover the planned expenditure.

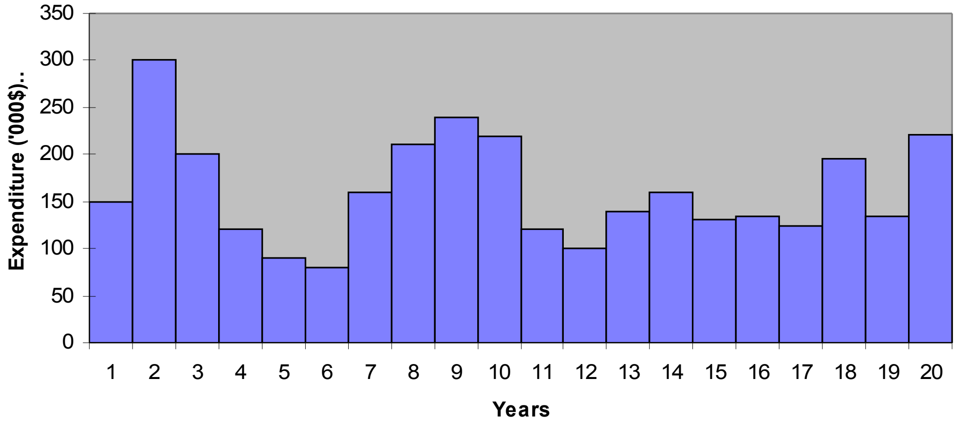


Figure 13.13 Example of a 20-year investment plan profile

The asset management plan is then implemented through shorter-term implementation plans, often of 5 years duration. The asset database will be upgraded as work is carried out, and the implementation of the plan and the level of service provision will be monitored.

13.10.3 Asset management processes

The key elements of preparing an asset management plan have been presented in Figure 13.14. Figure 13.15 gives a more detailed breakdown of the key elements and inter-relationships, each of which is discussed in greater detail in the following sections.

Asset surveys

Asset surveys are a central feature of asset management planning and are carried out at regular intervals, generally ranging between 1-5 years. The initial survey represents a significant effort in terms of defining the nature and extent of the various assets, as time goes on the database on the assets is updated and refined and the required survey effort reduces.

It is important to note that if a large area is being surveyed with the intention of determining a budget for the sustainable management of the assets, it is not necessary to survey all assets. Instead a statistically- based system can be developed for sampling typical systems or sub-systems, and then the investment needs and costs for the full set of assets estimated by extrapolation from the investment needs and costs of the sampled set. For more regular types of asset management, all the assets are surveyed.

Asset surveys are the starting point for asset management planning. The asset survey determines:

- the **category** of components of the system (canal, head regulator, etc).
- the **extent** of the assets that exist (how many and in what categories).
- the **size** of the asset (these can be grouped into Size Bands to facilitate costing).
- the "**importance**" of the asset. This relates to the impact that malfunction of the asset might have on the system as a whole. The head regulator at the river intake is more "important" than a secondary canal head regulator lower down the system.

- the **value** of the assets in each size band. The value is based on the Modern Equivalent Asset (MEA), that is the cost of replacing the structure at today's costs.
- the **components/facets** of each asset (e.g. gates and masonry in a head regulator structure). Different asset components/facets asset may deteriorate at different rates.
- the **condition** of the asset and its components/facets. The condition will affect the level of investment required. **Condition Grades** are used to categorise condition.
- the **serviceability** of the asset, that is, how well it performs its function. An asset may be in a poor condition (masonry damaged) but performing its function satisfactorily (gates operating and passing design discharge). For irrigation serviceability of structures can be divided into **Hydraulic Function** (ability to pass design discharge) and **Operations Function** (ability to control flow across a specified range, ability to provide command level, etc.). **Serviceability Grades** are used to categorise performance (Table 13.8).

The assets can be grouped into categories (Water capture, conveyance, control and measurement, ancillary, etc., Table 13.7) and can be grouped within these categories in terms of their size. The size can be based on one or two leading variables (such as crest length and height for a river weir, or design capacity for a canal). Grouping in this way means that average costs can be determined for categories and size bands of assets for maintenance, and for assessing the Modern Equivalent Asset (MEA) value. The MEA value represents the cost, in today's prices, of replacing the asset, and as such gives a complete valuation for the asset base.

To carry out the survey, the asset surveyor first gathers available data (maps, design drawings, structure inventories, etc.) before starting on the field work. For the fieldwork the surveyor generally commences at the top of the primary canal system and works down to the tail, then returning to survey each secondary canal in turn. The distance along the canal is measured using a tape or measuring wheel, and condition and performance assessments made of each stretch of canal, and at each structure. The level of detail collected depends on the resources available, in some cases full profiles of the canal are measured each 100 metres, in other observations only are taken. For structures, key measurements are taken (gate widths, height, etc.) and in some surveys full measurements are taken for all components/facets of each structure. Standard forms are used to record the survey data (Figure 13.9). The survey may need to be carried out firstly with the canals flowing and then with them dry to capture all the data required

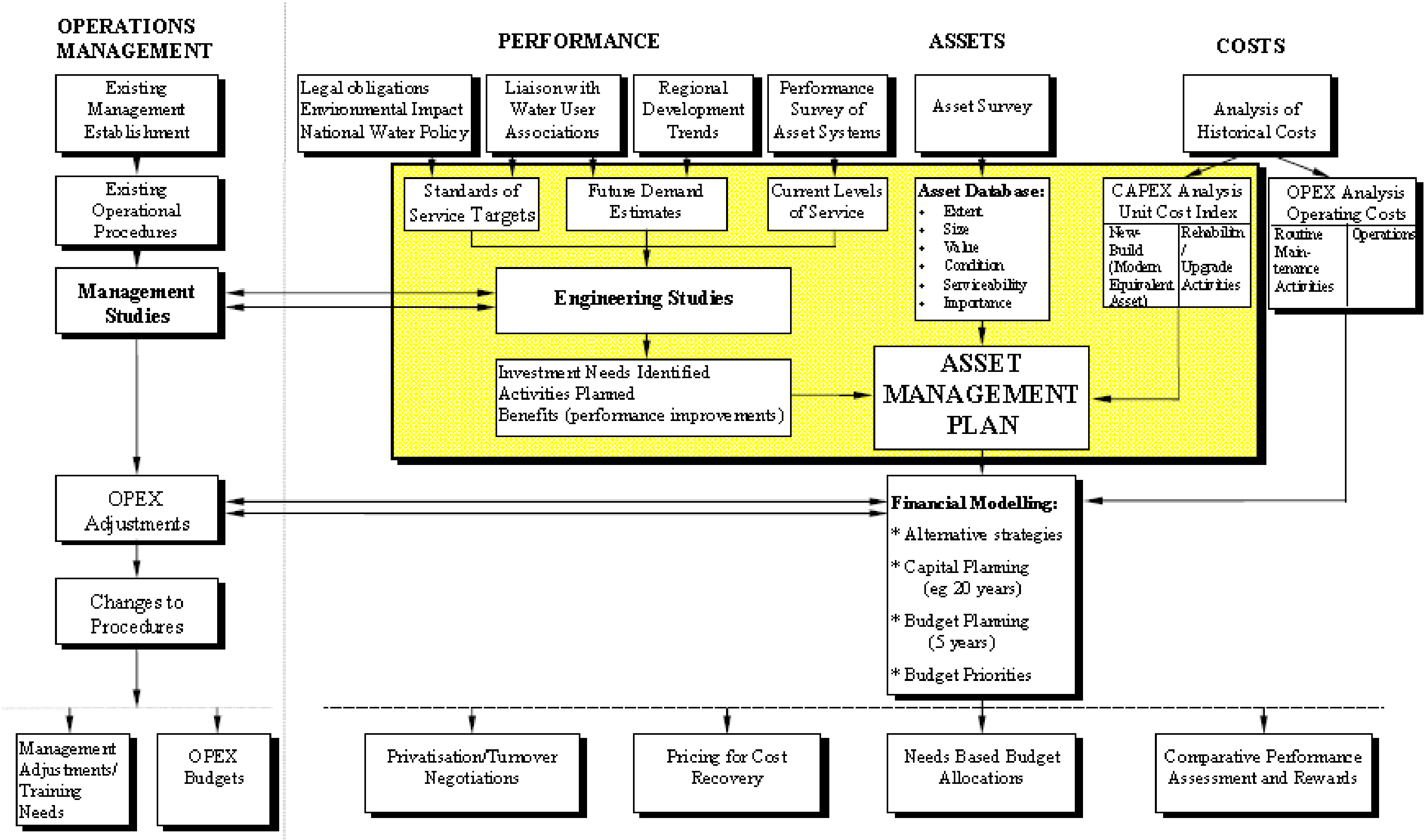


Figure 13.14 Overview of asset management planning for Irrigation

Table 13.7 Example of Condition and Serviceability gradings for canal cross regulator

COMPONENTS	CONDITION GRADES (implying COST)			
	GRADE 1	GRADE 2	GRADE 3	GRADE 4
Structure Upstream Wingwalls Downstream Wingwalls Superstructure Notice Board Control Section (note type)	**GOOD**: Structurally sound with no deformation of dimensions or profile. Well maintained with little or no signs of deterioration. Upstream and downstream bed having only minor, or no, silt deposition and clear of debris.	**FAIR**: Generally sound but with some deterioration of structure and/or dimensional deformation. Needing maintenance attention with a review of condition in the medium term. **- OR -** Structural and dimensional condition as (1) but with silt and/or debris significantly affecting functionality.	**POOR**: Significant deterioration of structure and/or dimensional deformation, requiring urgent corrective work. **- OR -** Structural and dimensional condition worse than (1) with silt and/or debris significantly affecting functionality.	**BAD**: Serious structural problems causing actual or imminent collapse and requiring partial or complete reconstruction.
Gauge(s)	Gauges securely fixed and readable	Gauges generally satisfactory but may be difficult to read under some flow conditions	No proper readable gauge but level mark present from which to measure	No gauge or level mark available **OR** unreadable **OR** unreliable
Bench mark	Bench mark secure, apparently undamaged and readable	Bench mark condition generally as (1) but difficult to read	Bench mark present but of uncertain reliability	Bench mark missing, damaged or unreadable

FUNCTIONS	SERVICEABILITY GRADES (implying PRIORITY)			
	GRADE 1	GRADE 2	GRADE 3	GRADE 4
<u>**Hydraulic:**</u> To pass the design flow safely. <u>**Operations:**</u> To control **'command'** (water level) across the required range (except for a **fixed** crest) AND...To allow measurement of flow	**FULLY FUNCTIONAL**: Apparently properly designed and constructed with capacity to pass the design flow safely AND fully capable of being operated to control command across the desired range AND allowing measurement of flow by means of its own components or an adjacent measuring structure. Performance unaffected by silt or debris.	**MINOR FUNCTIONAL SHORTCOMINGS**: Normally able to pass the required flows AND capable of being operated to control command in a measured manner BUT performance likely to be unsatisfactory under extreme conditions of demand or climate. Deficiencies may be due to inadequacies in design or construction, insufficient maintenance, measuring devices which are difficult to read or due to the presence of silt and/or debris.	**SERIOUSLY REDUCED FUNCTIONALITY**: One or more of the three defined functions seriously impaired through deficiencies in design, construction or maintenance, or due to the presence of silt and/or debris. (Likely to have a significant detrimental effect on System Performance.)	**CEASED TO FUNCTION**: Complete loss of one or more of the three functions or serious reduction of all three for whatever reason.

Table 13.8 Examples of asset types, function, components and estimated life span

Asset Type	Size measures to be recorded	Functions to be assessed	Components to check	Depreciation Life (est.)
River weir	crest length crest height	HYDRAULIC -provide level -pass offtake design flow -pass design flood OPERATIONS -gates -gauges	weir wall dividing walls abutments crest apron sluice gate offtake gate stilling basin superstructure	civil 50 years mechanical and electrical (M&E) 10 years
Head Regulator	total gate width design flow	HYDRAULIC -pass design flow OPERATIONS -control flow -gauges	gate(s) structure notice board shelter	civil 25 years M&E 10 years
Cross Regulator * options -fixed crest -gate(s) -stop logs -flume	total gate width design flow	HYDRAULIC -pass design flow OPERATIONS -control command (level) -gauges	control section* structure notice board u/s wingwalls d/s wingwalls gauge(s) shelter	civil 25 years M&E 10 years
Measuring Structure	total crest width design flow	HYDRAULIC -pass design flow OPERATIONS -measure flow	control section gauges structure u/s w/walls d/s w/walls stilling box	25 years
Canal (linings -earth -masonry -concrete tile -cont. concrete)	design flow length	HYDRAULIC -pass design flow OPERATIONS -n/a	embankment side slopes (note type) bed	civil 25 years
Drain (linings -earth -masonry -concrete tile -cont. concrete)	design flow length	HYDRAULIC -pass design flow OPERATIONS -n/a	embankment side slopes (note type) bed	civil 25 years
Hydraulic Structure -aqueduct -culvert -drop struct. -escape struct. (note type)	(depends on structure) design flow length fall	HYDRAULIC -pass design flow OPERATIONS -n/a	conveyance support struct. u/s w/walls d/s w/walls stilling basin	civil 25 years M&E 10 years
Supplementary Structure e.g.: -bridge -cattle dip	(depends on structure) design flow length	HYDRAULIC -pass design flow OPERATIONS -n/a	structure safety other features	civil 25 years M&E 10 years
Access Roads	width length	OPERATIONS -access to system	structure surface drains	civil 25 years

ASSET SURVEY

Form CR for Cross Regulator

CR

System Details

Section ____________________

Sub-Section ____________________

Irrigation District (ID) ____________________

ID Reference No. ____________________

Data Collected

By (Name) ________________

On (Date) ___0___0___

Asset Details

Area Served (ha) ________ Asset Ref. No. ________________

Location (km) ________ Canal Name ____________________________

Type of Canal: Primary ☐ Secondary ☐ Supplementary ☐

Reported Age (years): 0-5 ☐ 5-10 ☐ 10-20 ☐ 20+ ☐

Control section width (m) ______ Design Flow (l/s) ______

Control section type: Gate(s) ☐ Fixed Crest ☐ Stop Logs ☐ Flume ☐

Component Condition

	General Condition Grade				Worst Case Local			
	1	2	3	4	1	2	3	4
Structure	☐	☐	☐	☐	☐	☐	☐	☐
Control Section	☐	☐	☐	☐	☐	☐	☐	☐
Upstream Wingwalls	☐	☐	☐	☐	☐	☐	☐	☐
Downstream Wingwalls	☐	☐	☐	☐	☐	☐	☐	☐
Gauges	☐	☐	☐	☐	☐	☐	☐	☐
Bench Mark	☐	☐	☐	☐	☐	☐	☐	☐
Superstructure	☐	☐	☐	☐	☐	☐	☐	☐
Notice Board	☐	☐	☐	☐	☐	☐	☐	☐

Asset Serviceability

Overall Serviceability Grade			
1	2	3	4
☐	☐	☐	☐

Notes:

Figure 13.15 Example of asset survey form for cross regulator

Asset database

Data collected from the asset surveys have to be entered into a database. This can either be a spreadsheet file in the simplest case, or a specially designed database file. An example of the structure of a relational database is given in Figure 13.10. In some cases, the database will include photographs of each asset linked to the survey date.

Historical costs profile

The historic records of capital and O&M expenditure provide a valuable basis for assessing the future capital and O&M expenditure. Past expenditure figures can be brought up to date using standard cost index tables. Records of maintenance costs and work done, can inform on cost items and recurrence intervals (vis. How often the main canal is desilted, what volume and at what cost, etc.). Figure 13.16 shows an analysis of a pumped irrigation scheme where in real terms the funding for OPEX costs has declined significantly. Consequently, the physical condition of the assets had declined markedly, requiring (expensive) rehabilitation in 2003. In the meantime, the productivity of the scheme declined significantly, in part due to due to poor water delivery caused by improperly functioning infrastructure, especially the pumps.

Costs can be split into two parts – CAPEX and OPEX. CAPEX is capital expenditure, and will include any new, upgrading or rehabilitation works, OPEX is the regular costs for routine maintenance and operations.

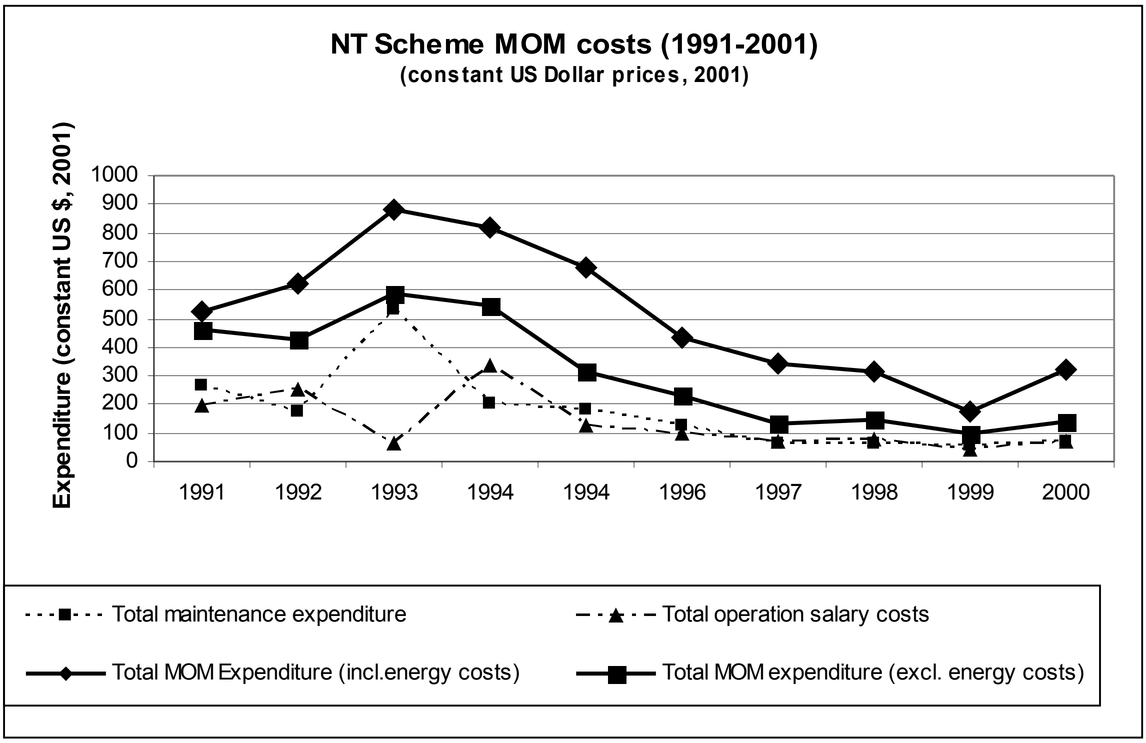


Figure 13.16 Analysis of historical OPEX costs using constant prices

Performance surveys to identify current levels of service

One of the most difficult elements of the asset management planning process for irrigation and drainage systems is to assess the level of performance. By comparison, performance assessment for water supply systems is relatively straightforward. For irrigation, a clear distinction needs to be made between the performance of the *scheme* (that is the irrigation and drainage network, the fields, the crops, the farmers, etc) and that of the *system* (just the irrigation and drainage network alone). Asset management planning is concerned with the performance of the *system*, the principle performance measures are concerned with water delivery in a reliable, adequate, timely and cost effective manner. Other common scheme performance indicators such as crop production, crop yield, etc are not of direct interest for asset management planning (though improvement in system performance may be quantified in terms of these variables). The distinction between performance of the different parts of the irrigation process is represented in Figure 13.17, where outputs from one "system" are the inputs to another "system". The performance of each part of these nested systems is measured by the efficiency of the processes used to convert inputs into outputs. Impacts also need to be assessed, such as the impact on the environment of application of fertilisers and pesticides in the "irrigated agricultural system".

Performance assessment of the "irrigation system" will relate to the reliability, adequacy, timeliness, equity and cost-effectiveness of the water delivery service. Possible performance criteria and indicators for this system are shown in Table 13.9.

Table 13.9 Possible performance criteria & indicators for performance assessment within the irrigation system

Criteria	**Indicator**	**Where measured**
Command	Relative Water Level, RWL	At delivery points
Adequacy	Relative Water Supply, RWS Water Delivery Performance, WDP Management Performance Ratio, MPR	At intake, division and delivery points At intake, division and delivery points At intake, division and delivery points At intake, division and delivery points
Equity	Relative Water Supply, RWS Water Delivery Performance, WDP Management Performance Ratio, MPR	At intake, division and delivery points At intake, division and delivery points At intake, division and delivery points At intake, division and delivery points
Reliability	Relative Water Supply, RWS Reliability Index, RI	At intake, division and delivery points At intake, division and delivery points
Efficiency	Project Water Use Efficiency, PWUE Conveyance Efficiency, CE	At intake and field At intake and delivery points

In the context of asset management planning, it is important to distinguish the performance constraints arising from the condition and performance of the infrastructure, and the performance constraints arising from the operation and use of the infrastructure. Asset management seeks to minimise infrastructural performance constraints in order that system operation is not inhibited, and that it does not directly deal with operational issues.

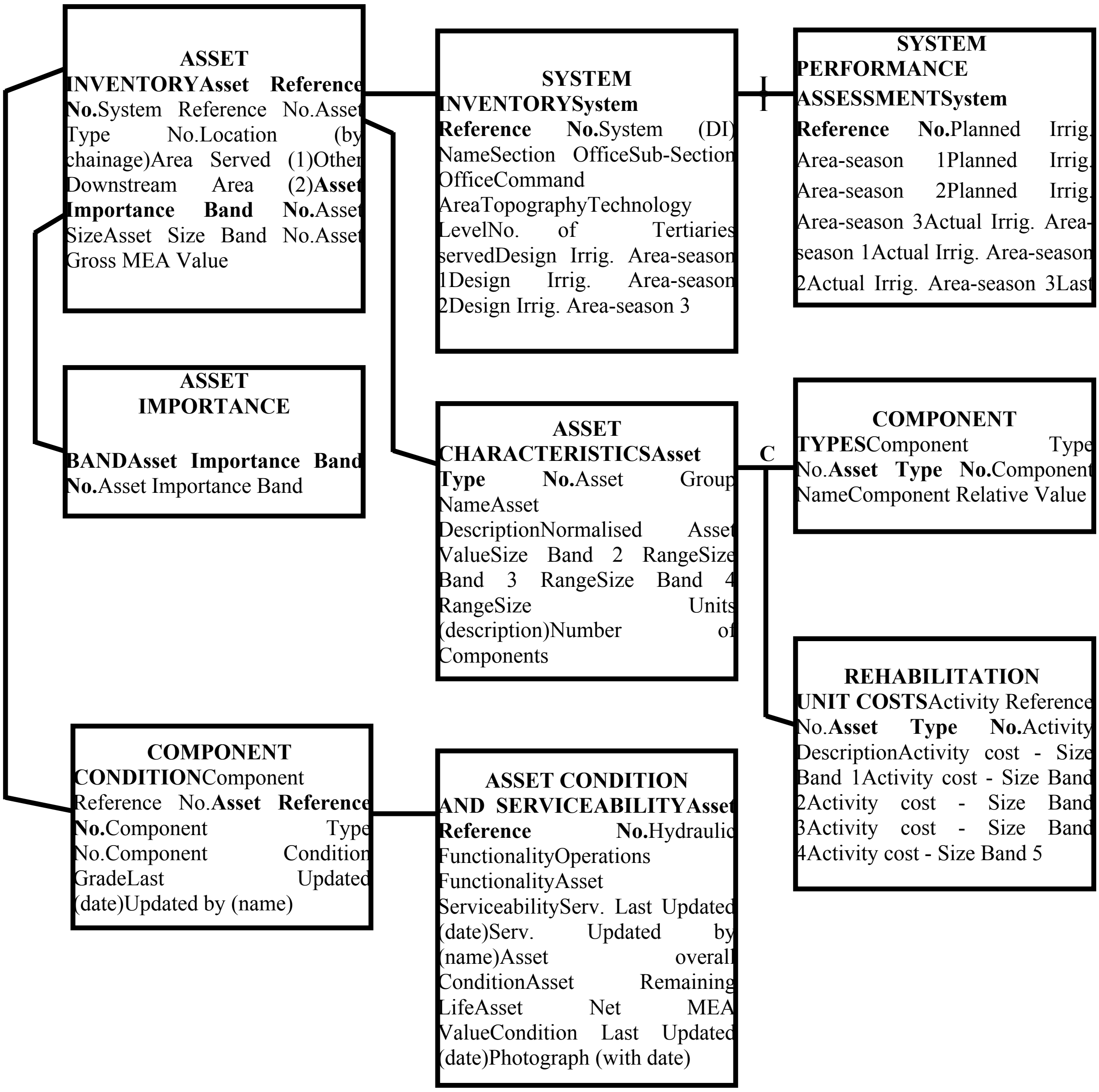


Figure 13.17 Possible structure of a relational asset database

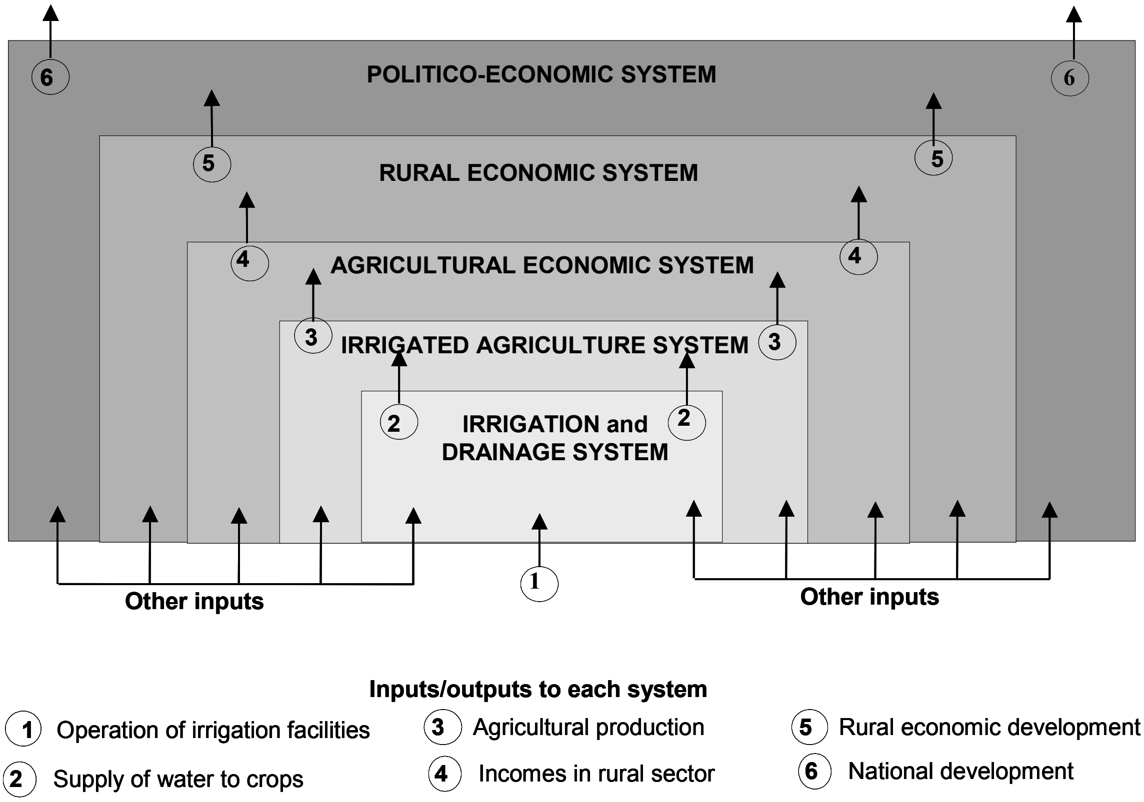


Figure 13.18 Irrigation in the context of nested systems (Small and Svendsen, 1992)

Agreeing on standards and desired level of service provision

A key feature of the asset management planning process is to specify the *desired* level of service, and to then determine the performance shortfall by measuring the *current* levels which are being provided by the assets (assuming there are no management constraints).

The ability to deliver the desired level of service will primarily depend on:

- the type of irrigation infrastructure provided
- the performance of the infrastructure
- the capability of the O&M management

Assessment of the desired level of service can be made prior to the preparation of the asset management plan, through interviews and discussions with water users. However, the cost of providing a given level of service will not be known until the asset survey has been completed, and the asset management plan prepared. Establishing the desired level of service will not be easy, as in many schemes such a concept has often not been communicated explicitly to water users. The Warabandi system[26] used in Northern India and Pakistan is an exception to this rule. In this instance, farmers are well aware of the stated level of service provision, with time shares, and times and duration of water turns, being set out well in advance of each irrigation. One of the benefits of the asset management process is that it requires the stipulation of the standards by which performance will be measured, and that it also requires the stipulation of the desired level of service. Making these explicit facilitates communication between the irrigation service provider and the water user.

[26] A system which defines the allocation and distribution of irrigation water on a time-share basis which is in proportion to the size of each farmer's landholding within the tertiary unit.

From the engineering studies (discussed below), an understanding will be gained from the anticipated improvements in performance benefits arising from different levels of investment. These improvements need to be assessed against the investment costs. The benefits will accrue to the irrigation (investing) service provider from the revenue generated from the water users, who will, in turn, derive their income from agricultural production generated as a consequence of the (improved) water delivery service provided by the irrigation service provider. The link between level of service provision and fee payment is central to the process of asset management.

Engineering Studies

Engineering studies are required to study generic issues such as the deterioration rate of different types of assets and asset components (facets); development of Cost Models (costs for rebuilding/upgrading/rehabilitating assets); and relationships between individual asset performance and system performance

Through engineering studies, the cost database for maintaining or enhancing the condition/performance of each *type* of asset (river weir, canal head regulator, aqueduct, culvert, etc.) can be ascertained and applied to the asset condition/performance of each asset. In this way, the cost of maintaining or enhancing the condition/performance of the irrigation and drainage system is determined. The deterioration rate of individual components, such as rubber gate seals, or pumps and motors, are estimated and standard profiles drawn up for each type of asset.

The importance of the asset will influence the priority given to investing in it. An asset's importance relates primarily to the asset's function, position in the irrigation or drainage network, and its replacement value. A river diversion weir is more important than a secondary canal head regulator, for example, because of its central function in diverting and controlling inflow to the scheme, its position at the head of the system, and its (usually) significant replacement cost.

An additional feature of the engineering studies is to look at alternatives, for example replacing manually operated gates with automated gates to save operating (OPEX) costs, or replacing a structure that is at the end of its useful life with a new structure, possibly of a different design, or with different features. Replacing a structure may cost more in terms of capital invested (CAPEX), but less in terms of operating costs (OPEX).

Formulating the asset management plan

Utilising information developed from the asset surveys, the performance surveys and the engineering studies, the investment requirement in the assets over time is determined. This calculation leads to the formulation of the long-term investment profile as presented in Figure 13.18. This long-term plan needs to be broken down into a schedule of planned activities, and a short-term budget prepared for a 2-5 year period.

Financial modelling is an integral part of the preparation of the asset management plan, as adjustment may be needed to the initial plan to match the investment required with the finances available. Alternative strategies may be need to be looked at, for example reducing the specification for the desired level of service in order to save investment costs, or accelerating or delaying investment. These strategies will take account of the source and profile of funding available (such as capital loans or grants from government, irrigation service fees, etc.). Figures 13.8 and 13.9 show examples of different investment profiles that can be generated depending on the level of service required. In the first case, the level of service required is high, resulting in high initial investment and high operational expenditure. In the second case, the level of service is lower, with deferred investment and lower operational expenditure. From these calculations, the average annual budget can be prepared and linked to the irrigation service fee.

The final asset management plan comprises the information outlined in Table 13.10.

Table 13.10 Summary of information contained in the asset management plan

Report	**Content**
Asset stock, condition and serviceability profile	A statement of all the assets, divided by category and size. Total value of the assets is quoted as gross MEA and net (depreciated) value. Condition and Serviceability Profiles provided for all assets, together with an Importance Profile.
Unit costs report for MEA value and capital investment activities	Presentation of the information contained in the Cost Model – provides the build up of costs for work required on each type of asset.
Investment programme	Report on the total investment estimates for Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) as programmed by each 5 year-period for the next twenty years[27]. Investment is presented in different formats: by each Asset Category; by each Importance Band; by each Purpose Category.
Activity report	Compliments the Investment Programme by detailing the timing of the activities to be carried out. Details how many kilometres of canal to be relined, desilted, etc, each year.
Benefits report	Provides details of the historical trends and the anticipated future benefits of the investment programme, based on the identified performance indicators. Maintaining or improving the Asset Condition Profile will be an important output performance measure.
Asset depreciation categories	A summary report on the assumptions made in the AMP about asset depreciation rates and life span.

An indication needs to be given in the AMP on the accuracy and reliability of the data used in preparation of the AMP. Tables 13.11 and 13.12 present guidelines used by the UK Office of Water Services for confidence grades. There are a number of sources of variance in the data – cost variations for physical works, differences in asset survey assessments, engineering judgement on life spans of assets, etc.

Table 13.11 Data ACCURACY bands

Band	Definition
1	Better than or equal to +/-1%
2	Not band 1, but better than or equal to +/-5%
3	Not bands 1 or 2, but better than or equal to +/-10%
4	Not bands 1, 2 or 3, but better than or equal to +/-25%
5	Not bands 1, 2, 3 or 4, but better than or equal to +/-50%
6	Not bands 1, 2, 3, 4 or 5, but better than or equal to +/-100%

Source: UK Office of Water Services - AMP2 Manual

Table 13.12 Data Reliability bands

Band	Description	Definitions	
		Actuals	Forecasts
A	HIGHLY RELIABLE	Data based on sound records, procedures, investigations or analysis which is properly documented and recognised as the best method of assessment	Based on extrapolations of high quality records covering or applicable to more than 100% of the study area, kept and updated for a minimum of five years. The forecast will have been reviewed during the current year
B	RELIABLE	Generally as A but with some minor shortcomings, for example the assessment is old, or some documentation is missing, or some reliance on unconfirmed reports, or some extrapolation	Based on extrapolations of records covering or applicable to more than 50% of the study area, kept and updated for a minimum of five years. The forecast will have been reviewed during the previous two years
C	UNRELIABLE	Data based on extrapolation from a limited sample for which grade A or	Based on extrapolations of records covering more than 30% of the study area.

[27] The selected short and long-term time frames may vary depending on the situation.

		B data is available	The forecast will have been reviewed in the previous five years
D	HIGHLY UNRELIABLE	Data based on unconfirmed verbal reports and/or cursory inspections or analysis	Based on forecasts not complying with bands A, B or C

Source: UK Office of Water Services - AMP2 Manual

Assessing water user's ability to pay

The investment plan may need to be revised to match the ability of the water users to pay for the service. If this occurs, the potential level of service provision arising from the condition and performance of the infrastructure may be reduced. A reduced level of service may result in a reduction in crop yield and a diminished ability to pay for water. There is obviously a balance to be struck between these two factors[28].

It is important to note that there is a difference between the water users' *ability* to pay and their *willingness* to pay. For this reason, it is important that the asset management process is clear, transparent and auditable, and that the water users are active participants in the process.

Implementing the asset management plan

Though asset management plans generally look at a longer term time frame (15-20 years), they are implemented in short-term time segments. The asset management plan will have given a profile of the investment needed in the infrastructure over time, and will have been used to establish the financial plan to sustain the assets over time. This plan may incorporate contributions from different sources, including the irrigation service fees and government subsidies. The short-term budgeting and expenditure sets out to manage the investment, such that necessary maintenance and replacement work is carried out to sustain the agreed level of service. Cost control and performance monitoring are key parts of this process, which ensure that the expenditure is made transparent and accountable to users.

Maintaining the asset database

The asset database will undergo continuous revision. Maintenance work will be recorded, and periodical updates made to asset condition and performance grading, through further assets surveys. With experience adjustments will be made to the information available on deterioration rates, cost models, CAPEX and OPEX costs, etc. and the asset management plan refined.

Monitoring and evaluation of implementation and service provision

Monitoring and evaluation are important parts of the asset management process, allowing for the monitoring of the levels of investment, and its impact on the service delivery. M&E systems need to be set in place which is transparent and accountable, so that those paying for the investment (water users, and/or government) can be satisfied that their money is being efficiently and effectively used. Feedback mechanisms are an important part of the M&E process.

Asset surveys will monitor the condition and performance of the infrastructure, whilst monitoring of key indicators (such as water delivery versus water demand) coupled with user surveys will assess the level of service provision.

Management Studies

In irrigation and drainage, the sustainability of the assets can be influenced by how the system is managed. Poor operation of the headworks for example, can lead to the intake gates being left open

[28] In practice this is not a direct one-to-one linkage, it has to be moderated by other factors.

during high river flow levels. These results in i heavily silt laden water entering and being deposited in the canal network. Poor regulation of the gates can result in excess water entering canals leading to breaches.

For this reason, it is prudent to study the operational procedures of the irrigation and drainage system, and look at how these influence the management of the physical assets. It may be that changes to the operational procedures can increase the longevity of the physical infrastructure and reduce maintenance costs. It is also likely that through the asset management planning process, the maintenance planning can be improved.

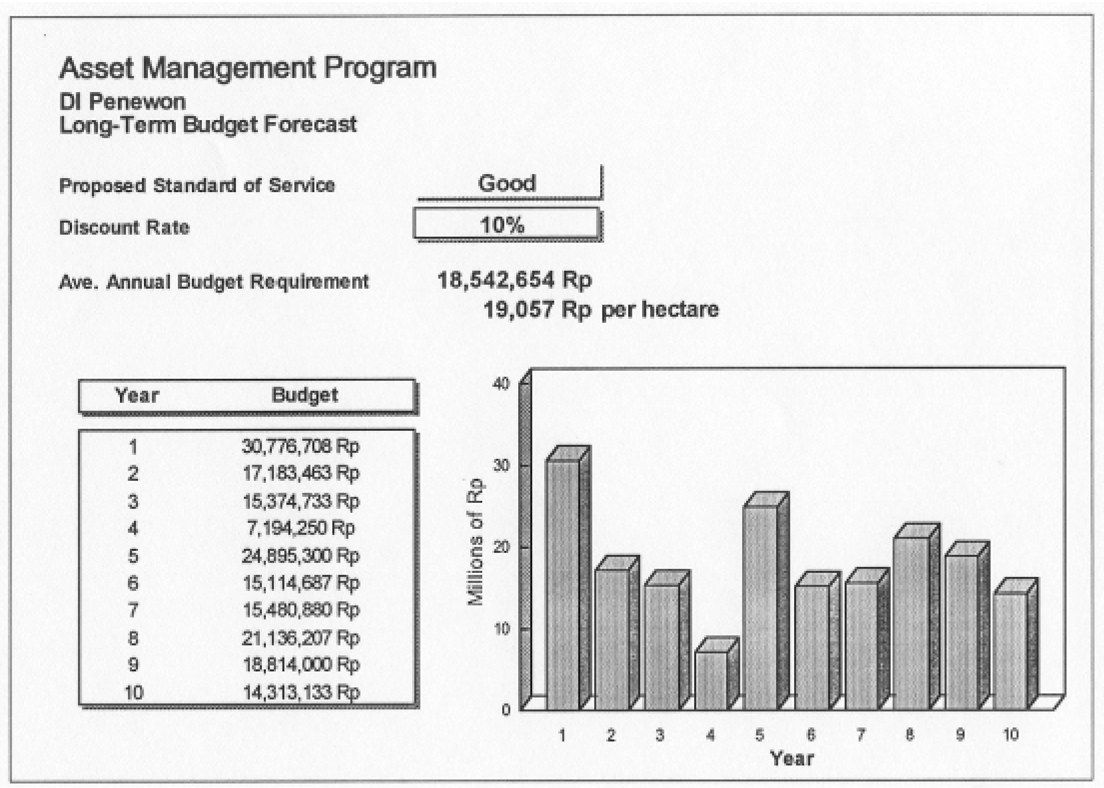


Figure 13.19 Investment profile designed for provision of a "Good" level of service rating

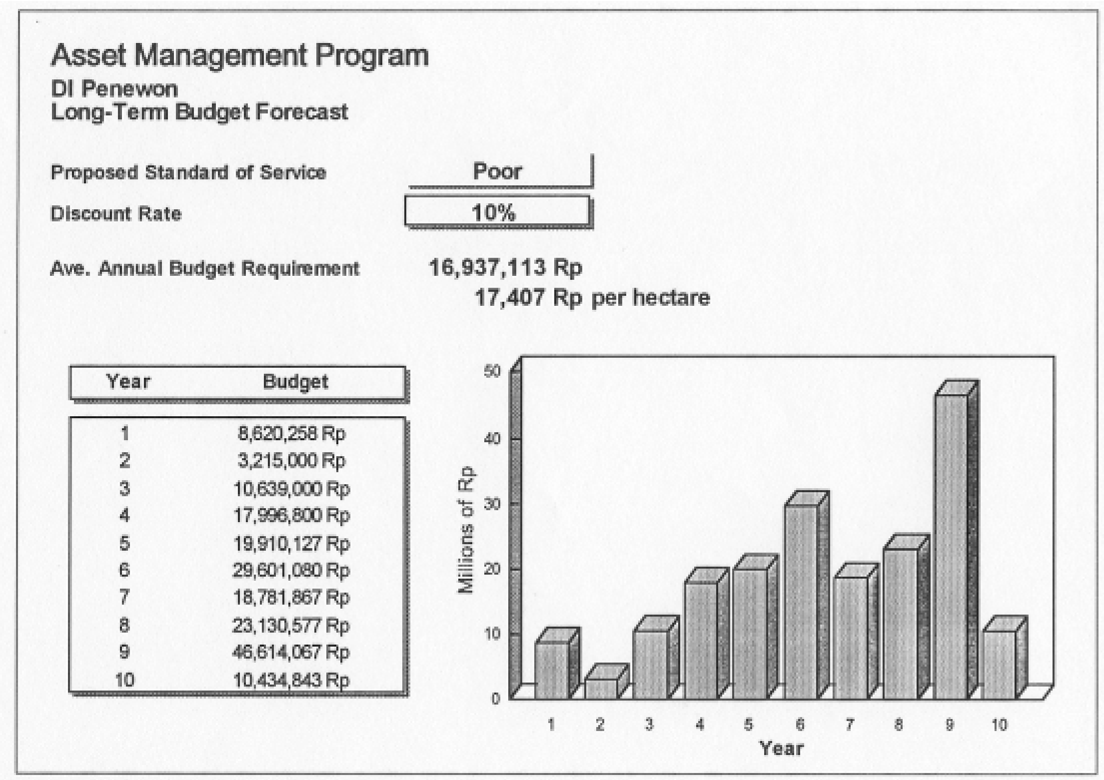


Figure 13.20 Investment profile designed for provision of a “Poor” level of service rating

13.11 13.11 Canal and Farm Water Management

Canal and farm water management practices can have a significant influence on the design of the canal system. Too many canal systems are designed with hydraulic convenience and low cost in mind, rather than ease of canal management and farmer preferences. Many irrigation schemes in the past have been designed on a continuous flow (24 hour irrigation) or rotational basis, with little thought given to how this will be managed in practice. The theme in irrigation for the past 10 years has been design for management and this is still very relevant today. The need to introduce flexibility in the design is more widely accepted as a necessary condition of adapting to future cropping patterns.

Continuous flow this can be the cheapest to construct and operate from a canal management point of view. However, it requires farmers to irrigate day and night, with very low discharges which usually leads to very poor irrigation efficiency.

Rotational flow costs more in construction but can improve efficiency. Flexibility is reduced among farmers who must follow the same cropping patterns, irrigate in sequence and cooperate with each other. Irrigation again may be on a 24 hour basis. Both continuous and rotational flows are supply oriented systems in which farmers have little choice once the system has been constructed. It is very difficult to adapt rotational systems to modern irrigation systems like micro sprinkler and localized irrigation, because the high frequency of application required is incompatible with the established rotations. On farm storage is a solution that can solve or reduce this problem, but represents an important additional cost.

Demand oriented systems give farmers more choice e.g. farmers may wish to irrigate only during the day or during certain days of the week. Such systems tend to be more difficult to design and operate and cost more, but the increase in operational benefits may mean that output is also greatly increased with a greater area irrigated. Systems which can provide on-demand irrigation include:

Canal storage or night storage - storage in canals or at strategic points along the canal system allows demand for water to be met more easily and reduces night irrigation. This system has been very successful in the Sudan for storing water overnight, but there have been problems of sedimentation and weeds in the canals, including the increased risk of malaria and schistosomiasis. Canal construction costs will be higher than for continuous flow schemes as the design capacity must be larger.

Downstream control is a method of canal control which is not widely used, but is much more responsive to farmer demand than all the above canal operating methods which use the principle of upstream control. The method requires special automatic gates to control water levels and is more expensive to construct than upstream control. However, its advantage of meeting farmer demands in a flexible way means that this approach requires much more consideration from irrigation engineers than it has received in the past.

Pipe systems are ideal for on demand irrigation. They respond rapidly to changes in demand. (See pipelines section for details). Most of the examples of irrigation schemes that do not work well have a history of supply orientation and a little consideration for farmer preferences. These past errors need not be repeated. This means avoiding continuous flow (24 hour irrigation) and rotational flow schemes unless they have simple control systems and have the full backing of the farmers.

13.12 On Farm water management

Increasing the irrigation efficiency within the project area may reduce the amount of drainage water to be disposed of. Sound irrigation application is necessary in order to reduce surface runoff water losses. Deep percolation can be reduced if the amount of irrigation water applied effectively and uniformly only covers crop water requirements, plus the leaching fraction necessary to control soil salinity. In many irrigation schemes, there is room to improve irrigation water conveyance and application efficiency by:

- improving local and regional scheduling of irrigation supplies;
- improving the irrigation practice in order to eliminate surface runoff;
- ensuring uniform water application over all the field;
- adjusting the irrigation requirements to the actual evapotranspiration needs, considering the soil moisture storage capacity, while ensuring the annual leaching requirement for salinity control; considering the soil moisture storage capacity, while ensuring the annual leaching requirement for salinity control;
- making optimal use of rainfall in the annual salt/water balance in order to reduce irrigation applications in the drier part of the year;
- improving the existing surface irrigation systems;
- changing to pressurized systems, such as sprinkler or drip irrigation.

While upgrading the irrigation management to save water, care should be taken to ensure a minimum leaching fraction, to wash out the salts applied with the irrigation water. Moreover, in arid and semi-arid regions, continued availability of relatively fresh drainage water flows (stemming from inefficient irrigation practices in upstream areas) is gaining importance in an increasing number of downstream areas (tail ends) within contiguous irrigated perimeters (Croon and Risseeuw, 2005).

13.13 Crop water productivity

Crop water productivity is the amount of water required per unit of yield, and a vital parameter to assess the performance of irrigated and rainfed agriculture. Crop water productivity will vary greatly according to the specific conditions under which the crop is grown. FAO has initiated a programme to address the above mentioned issues, and consulted a panel of experts on procedures to assess crop water productivity.

Water stress affects crop growth and productivity in many ways. Most of the responses have a negative effect on production, but crops have different and often complex mechanism's to react to shortages of water. Several crops and genotypes have developed different degrees of drought tolerance, drought resistance or compensatory growth to deal with periods of stress. Highest crop productivity is achieved for high yielding varieties with optimal water supply and high soil fertility levels. However, the same varieties are often highly sensitive to water stress and will obtain low yields or fail under conditions of even mild water stress during sensitive growth periods (see figure below).

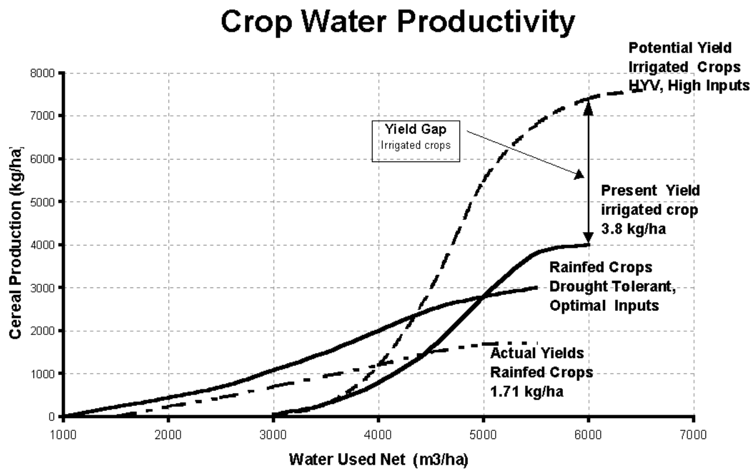


Figure 13.21: Crop Water Productivity

Under conditions of irrigated crop production, water supply is assumed to be maximal, as irrigation supply capacity is traditionally designed to avoid crop water stress even in dry years and to meet maximum ET needs. With agricultural water supply increasingly limited, the original assumptions can not be maintained anymore. Many schemes are routinely operated according to maximum supply conditions, and lack appropriate procedures and mechanisms to adjust supply and cropping pattern to water availability. Optimal supply may achieve maximum yield, but imposing water stress can be highly beneficial in terms of economic returns as taste and quality can be favourably effected by stress. Accurate knowledge on the impact of reduced water supply on yield and quality is required to define appropriate strategies to adjust crop water supply and scheme operation according to strict economic criteria that allow the optimization of net income under limited water supply.

Drought tolerance is a necessary trait for rainfed crops under varying rainfall conditions. Over centuries, farmers have developed crop genotypes and cropping systems which are well adapted to the ecological conditions, and minimize risks of crop-failure. A wealth of indigenous knowledge is still available, often insufficiently recognized, when introducing new varieties and new cropping practices.

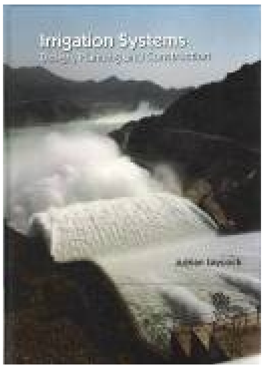
The development of appropriate strategies to optimize crop production and economic benefits, while maintaining environmental requirements, is of much importance as the assessment of the effects of water stress on production, yield and quality of certain crops both at experimental level as well as at farm level. This includes the integration of new and traditional knowledge through participatory research and extension.

Precise knowledge on crop response to water is essential in a range of applications for policies and investment strategies at the national and regional level. This includes the practical management tools at basin, scheme and farm level, as outlined below:

- To assess the impact of drought, rainfall variability and climatic change on yield, production and environment;

- to evaluate water use efficiency and crop water productivity under prevailing rain patterns and traditional farm practices and define with farmers options for improvement and appropriate strategies to optimize yields and to reduce risks of crop failure related to crop choice, planting time, soil cultivation and crop cultural practices (weeding, density , fertility,) and to define options for water conservation and supplemental irrigation;
- to define under irrigate crop conditions water supply strategies for optimal crop production and economic returns under conditions of reduced water supply and to advise farmers to optimize timing and application rate of crop irrigation for optimal yields and income also under limited water supply;
- to define national and regional policies to meet food requirements under conditions of drought and limited water supply in rainfed and irrigated agriculture;
- to identify research programmes in crop improvement and natural resources management for improved water productivity in both rainfed and irrigated crop production, including identifying opportunities for biotechnology;

13.14 References



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.14 Environmental Considerations

14.1 Introduction: What is an EIA?

Economic, social and environmental change is inherent to human development. For instance, irrigated agriculture often radically changes land use and is a major consumer of freshwater. Irrigation development thus has a major impact on the environment.

The Environmental Impact Assessment (EIA) procedure was developed in the 1970s, as a management tool for planners and decision-makers. It was developed to:

- help predict environmental impacts of any development activity
- provide an opportunity to mitigate against negative impacts
- and, enhance positive impacts.

The third function is of particular importance as the EIA provides a unique opportunity to demonstrate ways in which the environment may be improved as part of the development process.

14.2 What EIAs are not

All too often, EIAs are seen as just part of the approval process, with volumes of reports produced for such purposes, most of which are neither read nor acted upon. A key output of the EIA process should be an action plan, to be followed during implementation, and afterwards during the monitoring phase. For an action plan to be effective, an EIA may also recommend changes to laws and institutional structures.

Initially, EIA was seen by some project promoters as a constraint to development. Nowadays, this is a less dominant view, and many agencies see the technique as useful for ensuring the twin aims of human development and environmental enhancement as mutually reinforcing. While there will always be a trade-off between economic development and environmental protection, an objective EIA can ensure that decision-making is well informed.

14.3 The Context of Environmental Analysis

Environmental analysis needs to be set within a context, of which there are perhaps five main areas to consider:

Policy Framework:

- An EIA should outline the policy environment relevant to the study in question
- It is within the remit of an EIA to highlight regulations and policies which are conflicting and contribute to degradation (e.g. an agricultural policy to subsidize agro-chemicals to increase production, and an environmental policy to limit the availability to persistent chemicals)
- A useful study is on policy issues is FAO Legislature Study 38 (FAO, 1991) which looks at the environmental impact of economic policy for agricultural production.

Social Context:

- The social structure of an area (including cultural practices, institutional structures and legal arrangements) will have a direct impact on the project and the EIA. This includes local, regional and national regulations and laws, organisations, and customary practices.
- The needs of the poor, their influence on the project and the project's influence on vulnerable groups, all require particular understanding in an EIA.

Institutional Framework and EIA:

- Environmental, water and land issues involve many disciplines and many governing bodies. Data will therefore have to be collected and collated from a wide range of technical ministries, other government authorities and parastatals.
- One of the main conflicts arising from irrigation and drainage project is between those responsible for agriculture and those for water. With new institutions being created, existing institutions reorganised, the institutional aspects are complex.
- The EIA should highlight contradictions, weak or impractical legislation and institutional conflicts, and propose appropriate solutions.

Legal Framework for EIA:

- Environmental policy without appropriate legislation will be ineffective as, in turn, will be legislation without enforcement.
- New legislation may include a statutory requirement for an EIA to be done in a prescribed manner for specific development activities.
- As part of an EIA, relevant water, land law and environmental protection legislation needs analysing.

Building Institutional Capacity:

- In order to carry out an EIA
- To implement the recommendations of an EIA

14.4 The EIA Process

The process of conducting an EIA consists of five main stages: screening; scoping; prediction and mitigation; management and monitoring; and the audit (see Figure 14.1):

(i) **Screening** – *the process of deciding whether an EIA is required.*

This may be determined by:

- Size, such as a greater than predetermined surface area of irrigated land would be affected, or more than a percentage or flow to be diverted, or more than a certain capital expenditure.
- Site-specific information, such as the repair of a recently destroyed diversion structure is unlikely to require an EIA, whereas a major new headwork structure may.
- Legislation – country-specific laws or norms of operation require an EIA.

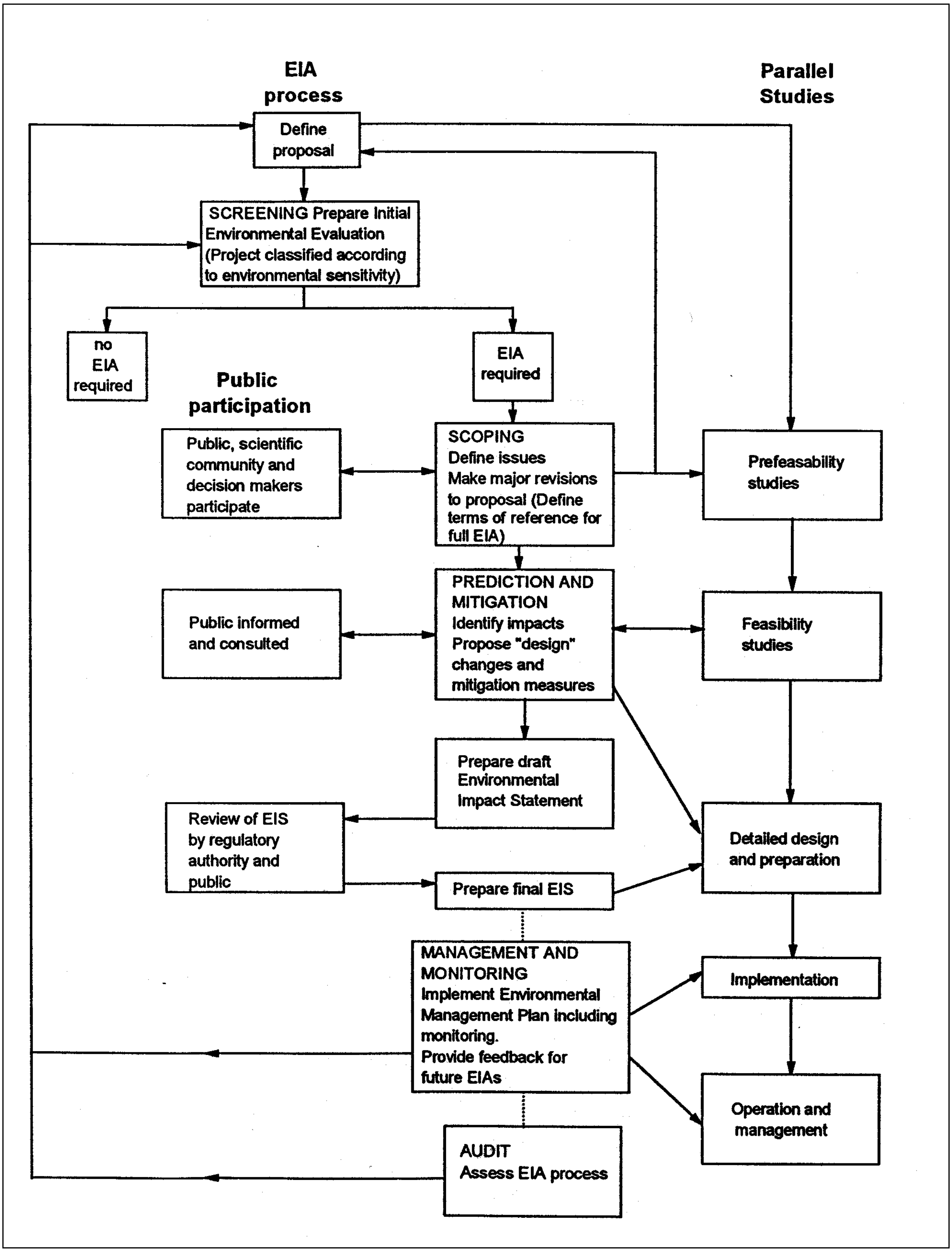

Figure 14.1 Flow Diagram of the EIA process and parallel studies

(ii) Scoping – *the process of identifying the key environmental issues.*

Scoping occurs at the same time in the project-cycle as planning and pre-feasibility studies. It is important because:

- Problems can be pinpointed early, allowing mitigating design changes to be made before expensive detailed work is carried out.
- To ensure detailed prediction work is only carried out for important issues (i.e. it is not the purpose of an EIA to carry out exhaustive studies on all environmental impacts for all projects).

(iii) Prediction and Mitigation – *the process of identifying measures to mitigated adverse impacts.*

An important outcome at this stage will be the recommendations for mitigating measures, to minimize adverse impacts and enhance positive impacts:

- It is important to assess the required level of accuracy of predictions, e.g. using mathematical modelling.
- When comparing mitigation or enhancement activities, it is important to agree the relative importance of impacts, to clearly note the uncertainty in predicting the impact, and to indicate the timeframe in which the impact will occur (including whether it is irreversible).

(iv) Management and Monitoring – *measures to implement the actions identified in earlier stages*

- There are a number of options available for environmental management, including changes in the law, prices, governmental institutions, and in culture (e.g. through education or information dissemination).
- The purpose of monitoring is to compare predicted and actual impact particularly is the impacts are either very important or the scale of the impact cannot be accurately predicted.

(v) Audit – *the process of evaluating if the EIA recommendations have been implemented*

The last stage of an EIA is to carry out an Environmental Audit after project completion. The audit will determine whether recommendations and requirements made by the earlier EIA steps were successfully incorporated into project implementation. Additional issues to consider include:

Public Participation: Projects and programmes impact on the local population. Without consultation, legitimate issues may go unheard leading to conflict and un-sustainability of the project. It is important therefore to consult and engage widely, using mechanisms such as public meetings, workshops, key informant interviews, Participatory Rural Appraisals (PRA)/Raid Rural Appraisal (RRA) techniques, etc.

Managing Uncertainty: It is also important to manage uncertainty, of which there are two types associated with:

a) the **process** (have the most important impacts been identified and acted upon?)
b) the **predictions** (are the findings accurate?)

The results of an EIA should indicate the level of uncertainty with the use of confidence limits and probability analyses wherever possible. A useful management axiom is to preserve flexibility in the face of uncertainty.

14.5 Techniques

There is a range of techniques available for carrying out an EIA. These include:

Baseline studies: These are required at the scoping stage, using available data and knowledge. A full year of baseline data is desirable to capture seasonal effects of many environmental parameters.

The ICID checklist: This checklist has been prepared for non-specialists and enables much time-consuming work to be carried out in advance of expert input. It is particularly invaluable for scoping and defining baseline studies.

Matrices: A major use of matrices is to indicate cause and effect by listing activities along the horizontal axis and environmental parameters along the vertical axis. A variety of symbols can be used to indicate different attributes of the impact (see Figure 14.2).

Network diagrams: Network diagrams are used for illustrating how impacts are related and what are the consequences of the impacts. For example, it may be possible to fairly accurately predict the impact of increased diversions or higher irrigation efficiencies on the low flow regime of a river (see Figure 14.3).

Overlays: These illustrate the geographical extent of different environmental impacts. Each overlay maps a single impact, such as saline affected areas, deforested areas, limit of groundwater pollution plume, etc.

Mathematical modelling: One of the most useful tools for prediction work, especially both flow quantities and qualities (e.g. salt/water balances; pollution transport; changing flood patterns). It is essential to use methods with an accuracy that reflects the quality of the input data, which may be quite coarse.

Expert advice: This should be sought for predictions which are inherently non-numeric and particularly for estimating social and cultural aspects.

Economic techniques: Economic techniques have been developed to value the environment, though work in this area is still continuing. The most commonly used methods are cost-benefit and cost-effectiveness analysis, though valuing the environment raises complex and controversial issues. For example, it is difficult to quantify the value of the environment to actual users (e.g. fishermen) and potential users (future generations, or migrants) plus factor in the intrinsic values (e.g. "quality of life").

14.6 The Environmental Impact Statement (EIS)

Once the assessment has been completed, the final report of an EIA is often referred to as an Environmental Impact Statement (EIS). Its purpose is not to reach a decision, but to:

- Present the consequences of different choices of action
- Make recommendations to decision-makers.

Features likely to be affected	Roads and trails	Colony construc-tion	Blasting operation	Borro-wing of materials	Import of labour	Dam constr-uction	Canal constr-uction	Evacu-ation and rehabili-tation	Soil conser-vation and lands-caping	Reservoir filling	Irrig-ation	Hydro-power generation
Forestry/Vegetation	-1P	+2P			-1T	-1P	-1P	-1P	+4P	-3P	+3P	+ 1P
Birds			-2T			-2T	-1T		+3P	+4P	+2P	
Fisheries						-1T				+4P	+2P	
Other wildlife/land animals	-1P	-1T	-1T		-1T	-1T	-1T	-1P	+2P	+3P	+2P	
Sedimentation/erosion	-1T	-1T		-2T		+2P	+2P		+3P	-1P	-1P	
Floods						-1P	-1P		+1P	+3P		
Historical/cultural monuments		+2P								-2P		
Communications	+3P	+2P				+1P	+2P			-1P		+2P
Land/area development	-2P	+2P				+2P	+2P	-2P	+2P	+2P	+4P	+3P
Agriculture	+2P	+1P				-1P	-1P	-1P	+2P	-1P	+4P	+3P
Food production	+2P	+1P	.			-2P	-1P	-1P	+2P	-1P	+4P	+3P
Public revenue/income	+2P	+2P				+3T	+2P	-2P	+2P	-2P	+4P	+3P
Drinking water		+1P			-1T	-1T				+4P	+3P	+2P
Water quality			-1T	-1T	-2T	-2T				-1P	+1P	
Air quality	-1T		-1T	-1T		-1T			+1P	+2P	+1P	
Climate									+1P	+2P	+1P	
Groundwater table										+2P	+2P	
Industrialization	+2P	+1P				+3T	+2T	+2P			+3P	+3P
Housing		+2P				+1P	+1T	+2P		-2P	+1P	+1P
Employment/training	+ 1T	+ 1T				+4T	+2T	+2P			+2P	+2P
Health and safety			-1T	-1T	-2T	-1T	-1T	-2T	+2p	+2P	+2P	
Scenic views and vistas	+1P	+2P		-1P	-2T	+2P	+2P		+3P	+4P	+2P	+2P
Tourism	+2P	+2P							+3P	+3P	+1P	+2P

Notes: Likely effect is symbolized as follows:

	Mild	**Considerable**	**High**	**Very high**
Beneficial	+1	+2	+3	+4
Detrimental	-1	-2	-3	-4

T = temporary effect; P = permanent effect

Figure 14.2 Environmental impact matrix – Net EIA at a glance, Feitsui reservoir

Primary impacts	**Secondary impacts**	**Tertiary impacts**	**Quaternary impacts**	**Mitigation**
Lowering of groundwater in dry season	Loss of income and water from domestic hand pumps	Use of poorer quality water	Increased health risks	1. Ensure that the new DTW either hold domestic water locally or feed into distributary system Note Effected group are poorer people
		Income diverted to buy water	Decreased income and time	
		Travel to distant source	Reduced quality of life	
	Loss of income and water from shallow tubewells for irrigation	Income diverted to buy water	Decreased income and time leading to possible food shortage	1. Deepen STW
		Crop failure	Reduced quality of life	2. Ensure new DTWs supply STWs in dry season
			Abandonment of land and migration	3. Provide compensation from DTW taxation
	Drawdown of surface water bodies	Decreased fish capture/fish mortality	Loss of protein intake	1. Artificially stock water bodies
			Loss of income for fishermen	2. Recharge water bodies from DTW Note: Fishermen are already poorer than farmers in general
		Loss of wetland	Loss of wetland flora/fauna migratory birds, fish spawning areas	
			Loss of wetland products	1. Restrict DTW development in vulnerable areas Note Landless and Rural poor are greatest users of wetlands
		Reduced navigation possibilities	Increased transport costs	1. Increase navigation depth by dredging

STW = shallow tubewells
DTW = deep tubewells

Figure 14.3 Network Analysis reflecting the impact of a groundwater utilization policy by subsidizing tubewells

14.7 Major Impacts of Irrigation and Drainage Projects

The most common environmental impacts associated with irrigation schemes are described in FAO Irrigation and Drainage Paper, No. 53 (Sections 4.1 to 4.7, FAO 1995). These are categorised as follows:

- Hydrology
- Water and air quality
- Soil properties and salinity effects
- Erosion and sedimentation
- Biological and ecological change
- Socio-economic impacts
- Ecological imbalances
- Human health

When considering impacts, two perspectives must be taken into account:

- The **project's impact** on the environment
- The impact of external factors **on the project,** termed *the externalities*

14.8 The ICID Check-list

14.8.1 Introduction

The ICID Check-list provides a practical guide for identifying potential or actual environmental impacts. It consists of a number of tools for carrying out EIAs of irrigation and drainage projects. The components of the process are shown in Figure 14.4 and include:

The Summary Table [Table 1] – This is the Checklist in its simplest form, listing those environmental effects which must be considered in relation to irrigation, drainage and flood control projects and their dams (Figure 14.5).

Detailed Descriptions, including Matrix of linkages [ICID Appendix 1, Table A1.1][29] **–** Detailed Descriptions define the scope of each item in the Check-list. Because of the possible overlap in scope of some items, a matrix is provided to indicate the dependence between different items on the Checklist. Figure 14.6 shows the ICID Table A1.1.

Related references [Appendix 2] – A selected list of references, chosen to provide the non-specialist reader (who has a broad scientific or technical education) with an introduction to the nature and causes of each item.

There are then two types of data sheets provided to enable the user to systematically collect and record data/information for a specific project and of relevance to the assessment of environmental effects:

Cover Sheet and General Data sheets [Appendix 3] – Particularly for use by irrigation/drainage professionals, for data which is largely of a non-specialist nature.

Specialised Data sheets [Appendix 4] – For types of data not routinely collected for the planning or operation of irrigation, drainage or flood control projects (e.g. as found in specialist reports, or collected separately by an expert)

Finally there is:

A Look-up Table showing linkages [Appendix 5] – Shows which items of data collected in the data sheets [A3 and A4] are relevant to which environmental effects listed in the Check-list (Figures 14.7 to 14.9).

Results sheets [ICID Table 2] – This uses all the above components to make an overall assessment (Figure 14.10)

[29] The references here in bold and square brackets refer to the Appendices in the ICID document.

Figure 14.4 Components of the ICID checklist assessment procedure

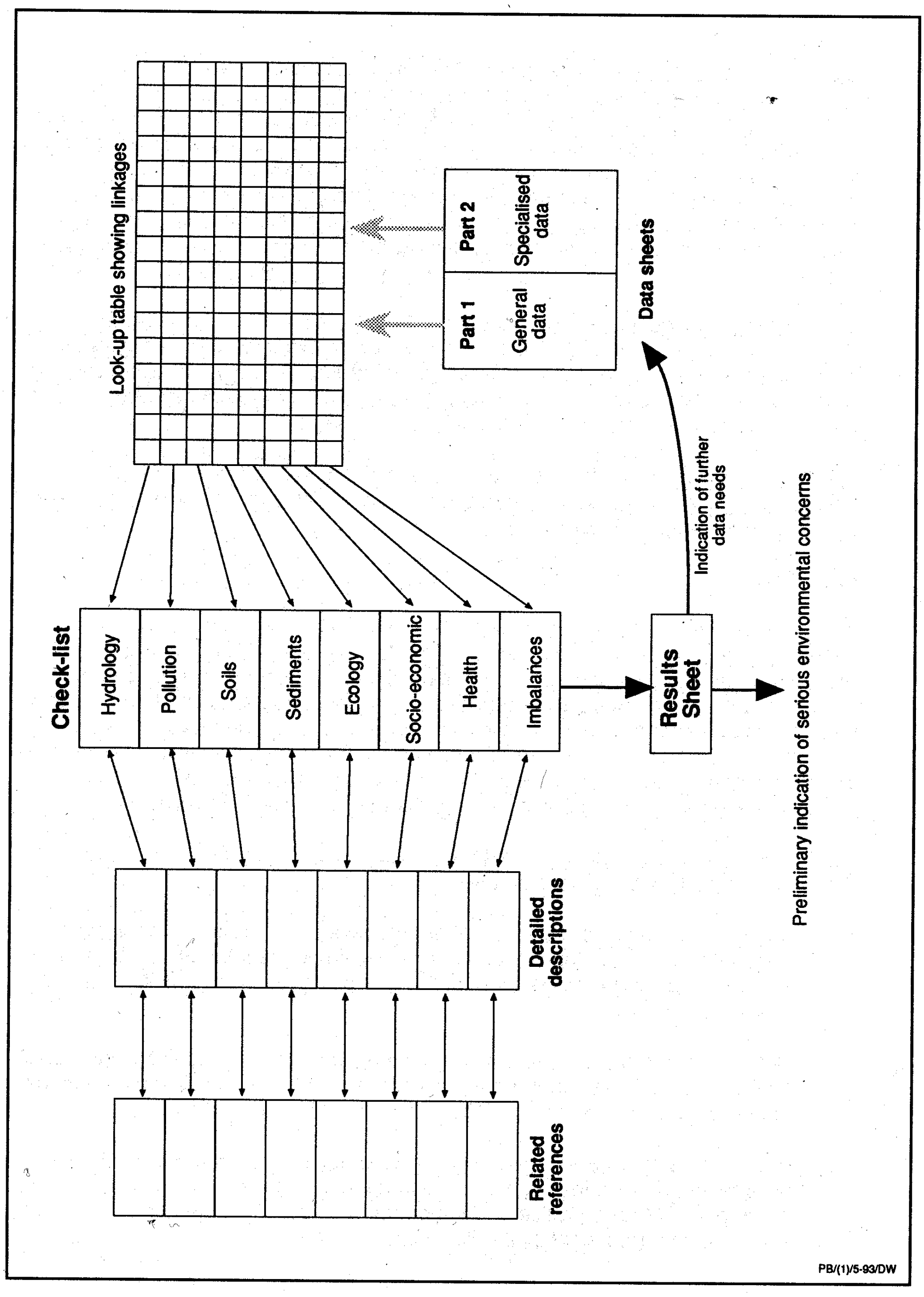

Figure 1 Components of the Check-list assessment procedure

Table 1 The ICID check-list of possible environmental impacts of irrigation, drainage and flood control projects

Hydrology	1-1 Low flow regime	
	1-2 Flood regime	
	1-3 Operation of dams	
	1-4 Fall of water table	
	1-5 Rise of water table	
Pollution	2-1 Solute dispersion	
	2-2 Toxic substances	
	2-3 Organic pollution	
	2-4 Anaerobic effects	
	2-5 Gas emissions	
Soils	3-1 Soil salinity	
	3-2 Soil properties	
	3-3 Saline groundwater	
	3-4 Saline drainage	
	3-5 Saline intrusion	
Sediments	4-1 Local erosion	
	4-2 Hinterland effect	
	4-3 River morphology	
	4-4 Channel structures	
	4-5 Sedimentation	
	4-6 Estuary erosion	
Ecology	5-1 Project lands	
	5-2 Water bodies	
	5-3 Surrounding area	
	5-4 Valleys & shores	
	5-5 Wetlands & plains	
	5-6 Rare species	
	5-7 Animal migration	
	5-8 Natural industry	
Socio-economic	6-1 Population change	
	6-2 Income & amenity	
	6-3 Human migration	
	6-4 Resettlement	
	6-5 Women's role	
	6-6 Minority groups	
	6-7 Sites of value	
	6-8 Regional effects	
	6-9 User involvement	
	6-10 Recreation	
Health	7-1 Water & sanitation	
	7-2 Habitation	
	7-3 Health services	
	7-4 Nutrition	
	7-5 Relocation effect	
	7-6 Disease ecology	
	7-7 Disease hosts	
	7-8 Disease control	
	7-9 Other hazards	
Imbalances	8-1 Pests & weeds	
	8-2 Animal diseases	
	8-3 Aquatic weeds	
	8-4 Structural damage	
	8-5 Animal imbalances	

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Figure 14.5 ICID Checklist summary table (ICID Table 1)

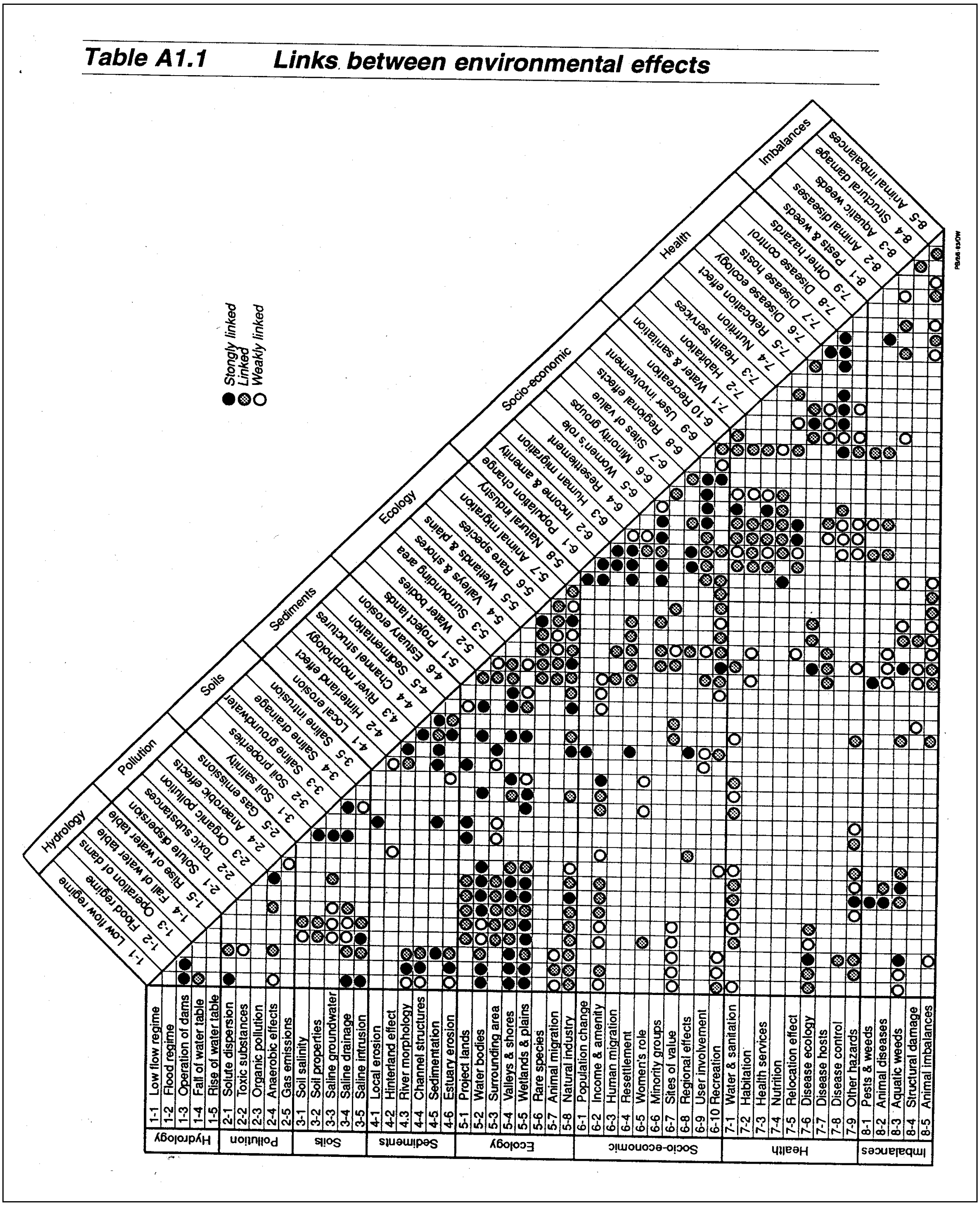

Figure 14.6 ICID Checklist Table A1.1 showing the links between environmental effects

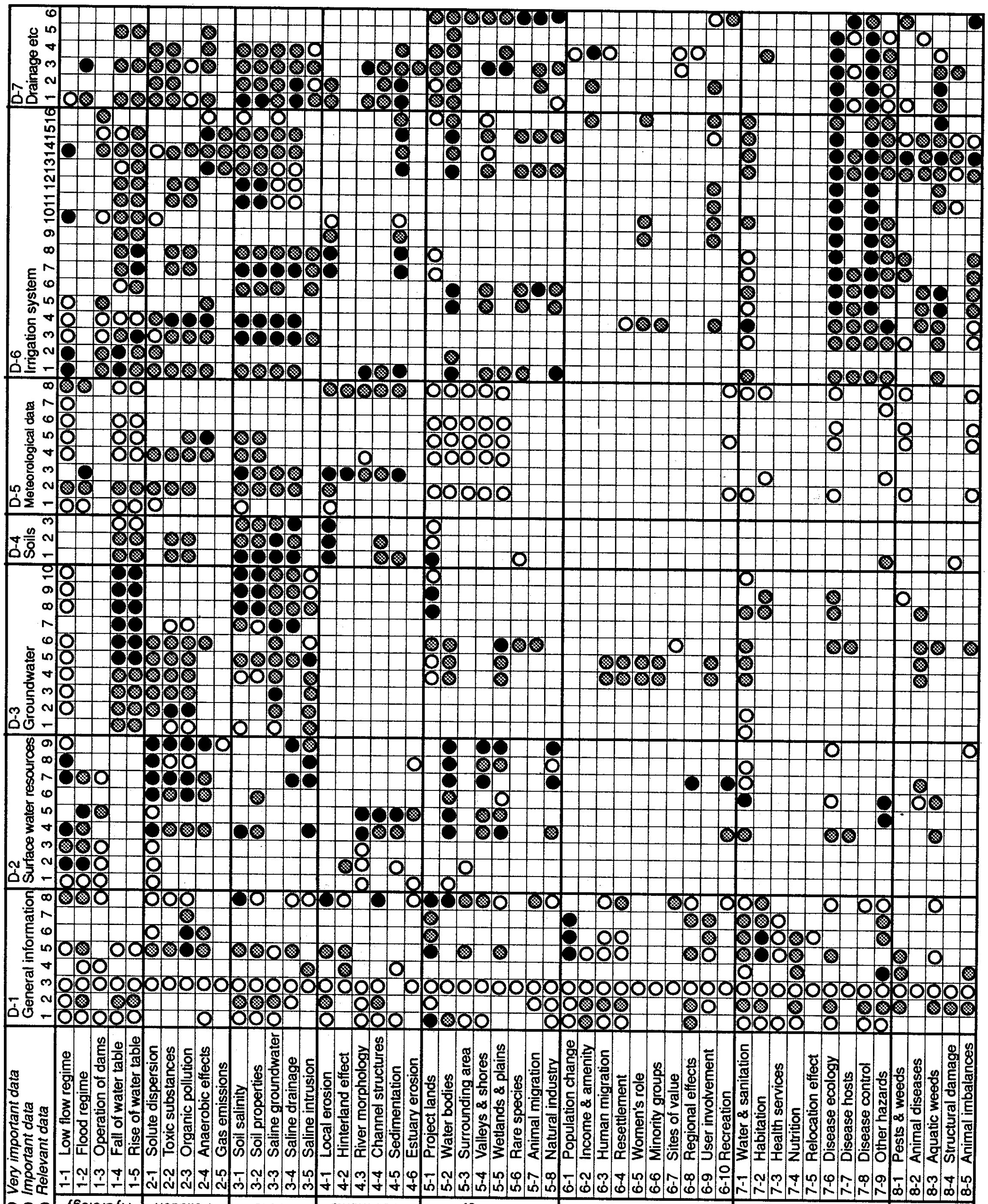

Figure 14.7 ICID look-up tables showing linkages, Sheet 1

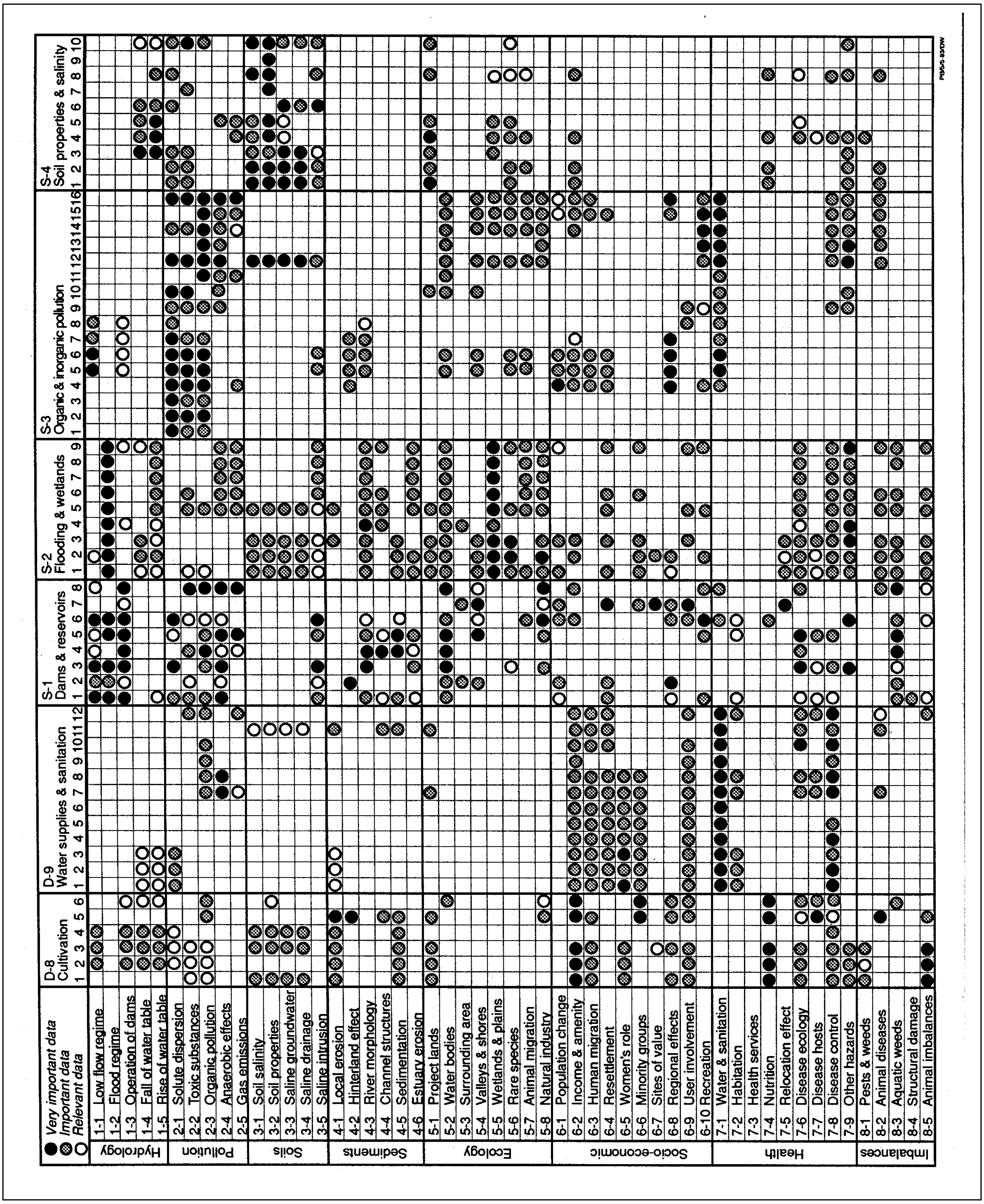

Figure 14.8 ICID look-up tables showing linkages, Sheet 2

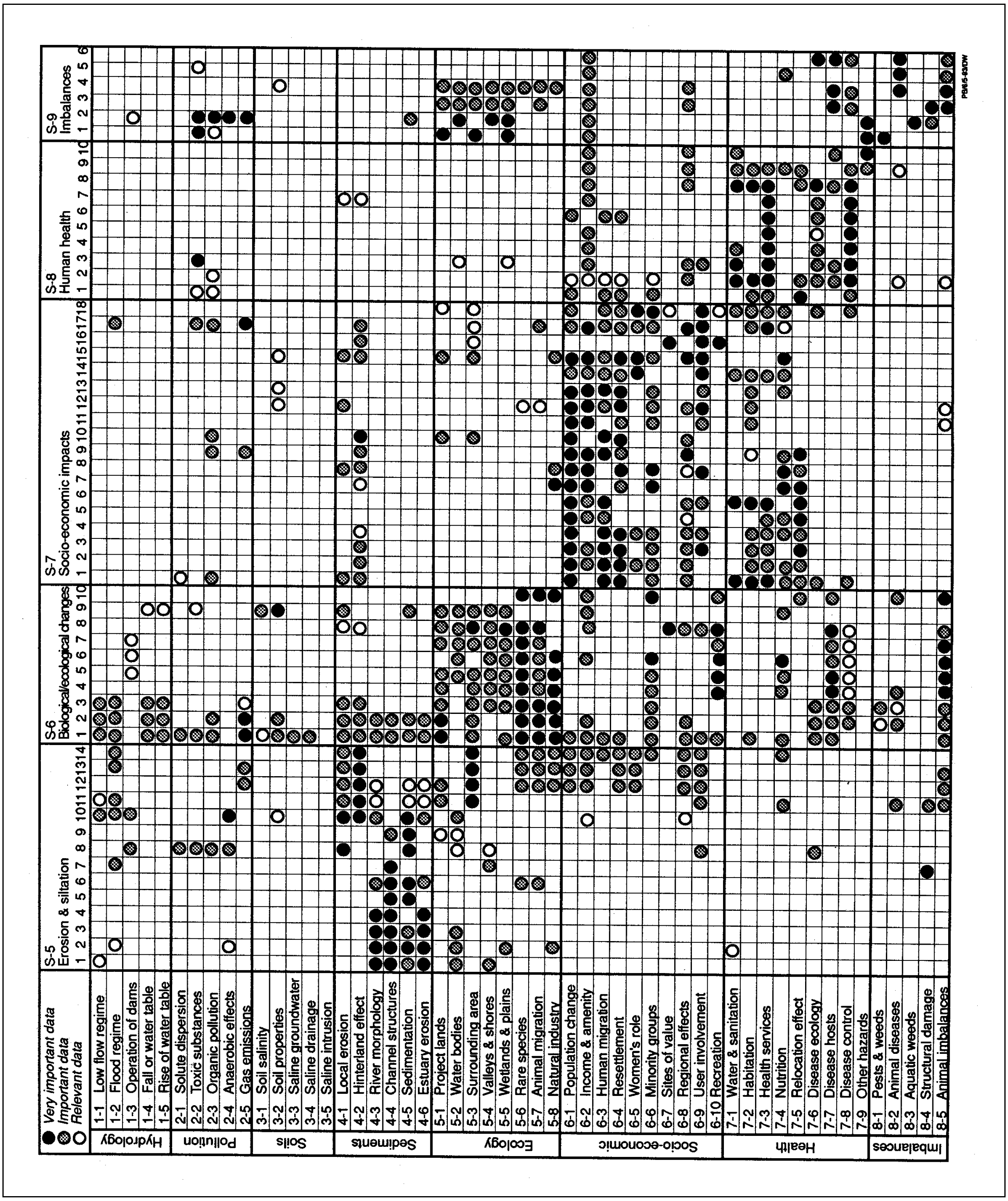

Figure 14.9 ICID look-up tables showing linkages, Sheet 3

Table 2 Results sheet for assessing the ICID check-list

Project name/location: .... ***Assessment: 1st/2nd/...*** ..

Assessor's name/position: .... ***Date:*** ....

	For each environmental effect place a cross (X) in one of the columns	Positive impact very likely	Positive impact possible	No impact likely	Negative impact possible	Negative impact very likely	No judgement possible at present	Comments
		A	B	C	D	E	F	
Hydrology	1-1 Low flow regime							
	1-2 Flood regime							
	1-3 Operation of dams							
	1-4 Fall of water table							
	1-5 Rise of water table							
Pollution	2-1 Solute dispersion							
	2-2 Toxic substances							
	2-3 Organic pollution							
	2-4 Anaerobic effects							
	2-5 Gas emissions							
Soils	3-1 Soil salinity							
	3-2 Soil properties							
	3-3 Saline groundwater							
	3-4 Saline drainage							
	3-5 Saline intrusion							
Sediments	4-1 Local erosion							
	4-2 Hinterland effect							
	4-3 River morphology							
	4-4 Channel regime							
	4-5 Sedimentation							
	4-6 Estuary erosion							
Ecology	5-1 Project lands							
	5-2 Water bodies							
	5-3 Surrounding area							
	5-4 Valleys & shores							
	5-5 Wetlands & plains							
	5-6 Rare species							
	5-7 Animal migration							
	5-8 Natural industry							
Socio-economic	6-1 Population change							
	6-2 Income & amenity							
	6-3 Human migration							
	6-4 Resettlement							
	6-5 Women's role							
	6-6 Minority groups							
	6-7 Sites of value							
	6-8 Regional effects							
	6-9 User involvement							
	6-10 Recreation							
Health	7-1 Water & sanitation							
	7-2 Habitation							
	7-3 Health services							
	7-4 Nutrition							
	7-5 Relocation effect							
	7-6 Disease ecology							
	7-7 Disease hosts							
	7-8 Disease control							
	7-9 Other hazards							
Imbalances	8-1 Pests & weeds							
	8-2 Animal diseases							
	8-3 Aquatic weeds							
	8-4 Structural damage							
	8-5 Animal imbalances							
	Number of crosses							**(Total = 53)**

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Figure 14.10 ICID Checklist Results Sheet

14.8.2 Recommended Approach

The Checklist can be used in a variety of ways, including:

- As an educational tool
- As a guide for formulating an appropriate assessment procedure
- As the core of an assessment using the ICID Data Sheets.

For this third approach, it is recommended that Data Sheets **[ICID Appendices 3 and 4]** are first completed, though only with readily available data. This will initially result in a large number of gaps and partial answers. Then, if appropriate, the user or expert should collect further data and re-assess relevant items in the Check-list

14.8.3 Assessing Checklist Items

After having initially completed the Data Sheets **[ICID Appendices 3 and 4]** then:

For each Checklist item:

- Read the **Detailed Description [ICID Appendix 1]**, plus any items shown to be closely linked **[ICID Appendix 1, Table A1.1]**.
- When the Detailed Description has been adequately understood, the user should begin assessing the environmental effects. The **Look-up Table [ICID Appendix 5]** has been provided to guide the user to the most relevant questions in the Data Sheets **[ICID Appendix 3, Appendix 4]**
- Using this information, complete the Results Sheet **[ICID Table 2]**, and 'Findings' in the Detailed Description **[Appendix 1]**

Advice for completing the Results Sheet:

Mark 'x' in column F if:

- No data have been found under a significant number of the questions identified as very important, as it is unlikely that an assessment can be made of them.
- There are sufficient data but the user does not have the expertise necessary to make an assessment of the significance of these data.

Otherwise:

- The user should make an assessment by putting 'x' in the columns marked A to E from 'positive impact very likely' through to 'negative impact very likely.'
- Then under 'Findings' in the Detailed Description **[ICID Appendix 1]**, the user should add details on:
    - the type of impact expected (both positive and negative)
    - the time-scale involved
    - the cause of the impact

When the assessment is complete the number of crosses in each column should be summed to give an indication of the responses in each category. **Note that** these numbers should not be given strict quantitative significance, as certain changes will be more significant than others.

14.8.4 Interpretation of Results

The Results Sheet identifies those environmental effects that are likely to be key issues in relation to environmental impacts and sustainability of the project:

- *A large number of items of potential adverse effects* should give a warning to the user that environmental issues must be taken seriously (with the necessary resources and expertise)

- *If there are a few items of potential adverse effects,* environmental changes may still be highly significant, since a single item may have a significance that overrides all other considerations.

It is therefore necessary to assess the significance of effects by:

- *Preparing a separate list* of those items which have been identified as leading to a 'possible' or 'very likely' negative impact
- In pre-feasibility planning this list will form the basis for recommending areas requiring particular *specialist expertise* in the project planning and design phase

Detailed study of each 'possible' or 'very likely' negative impact should *assess whether the changes have serious implications*, and might be considered reason to abandon or seriously modify the project (a 'fatal flaw').

14.9 References

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14.9.1 Selected reading

i) ***Wathern (1988)*** *and* ***Biswas and Qu Geping (1987)*** *are two of the most useful books on the general philosophy of EIA and are a good basis for those wishing to gain a more in-depth understanding of EIA techniques.*

ii) *The "ICID Checklist to Identify Environmental Effects of Irrigation, Drainage and Flood Control Projects" (**Mock and Bolton, 1993**) is a valuable aid to screening, scoping and defining data requirements. Indeed, the layout in Chapter 4 generally follows that of the checklist which makes it an ideal companion volume. (website address: www.dfid-kar-water.net/w5outputs/irrigation_environment.html)*

iii) *The **FAO series of Irrigation and Drainage Papers**, currently about 50 in number, cover a wide range of topics pertinent to environmental aspects of irrigation. The information is comprehensive and technical and many volumes are available in several languages, most notably in English, French and Spanish. (website address: www.fao.org/documents)*

iv) *The German development agency, GTZ, have published "Irrigation and the Environment", by **Petermann (1993).** This is a comprehensive two volume handbook, totalling about 500 pages, which gives very detailed technical information. An information package is planned shortly following the research by Petermann. This package is planned with a number of standardized sheets that may prove useful in EIA work.*

v) *UNEP (United Nations Environment Programme) and ESCAP (Economic and Social Commission for Asia and the Pacific) have produced several useful volumes on EIA and water resources projects. The major donors such as the World Bank, Asian Development Bank and African Development Bank have prepared their own guidelines on EIA although these tend to relate mostly to internal procedures. They are important documents for those seeking external financing. (website addresses: http://www.unep.org/; http://unescap.org/).*

vi) *"The Environmental Assessment Sourcebook", **World Bank Technical Paper No. 140 (1991)** covers environmental issues relating to development in most sectors. It contains special sections on dams and reservoirs and on irrigation and drainage. Apart from providing information on the Bank's policies and procedures it gives general information on potential environmental impacts. Updates are issued from time to time. The Sourcebook is particularly useful if financial support is required from the World Bank. The World Bank Directive on Environmental Assessment (OD 4.01) describes the bank's policy and procedures on EIA at regional, sectoral and project levels, (1991).*

vii) *PEEM, the joint WHO/FAO/UNEP/UNCHS Panel of Experts on Environmental Management for Vector Control, published a technical guidelines series in which the following volumes are already in English, French and Spanish: Guidelines for the incorporation of health safeguards into irrigation projects (**Tiffen, 1989**), Guidelines for forecasting vector-borne disease implications of water resources development (**Birley, 1989**) and Guidelines for cost-effectiveness analysis of vector control (**Phillips et al., 1993**). Under preparation are Guidelines for the promotion of environmental management by agricultural extension workers and Guidelines for monitoring health status during water resources development. The PEEM Secretariat is located at WHO in Geneva.*

viii) *A number of governments and international organizations have developed guidelines or manuals on EIA. Some developing countries have produced guidelines for the EIA of water resources development (example website addresses include: http://www.sida.se/; http://www.gtz.de; http://www.eldis.org/; http://www.iied.org/) which cover the irrigation sub-sector to some extent. Existing guidelines are often oriented towards local requirements but offer information which is of value to readers from all countries. A useful text of value to most Asian countries is the Guidelines for Sustainable Water Resources Development and Management by the Central Water Commission, India **(CWC 1992)**.*

.15 Financial and Economic Analyses

Irrigation can be financed by public and/or by collective or individual private investment. The main reason why large-scale irrigation projects have in the past been financed from public sources is because the scope of work was beyond private endeavour. Economics of scale in water resource development (falling average costs with increased size) often made the scope of work so massive, that only government could command the resources necessary to get to the optimum level of investment.

Most African governments have reached a stage in which the scope for continuation of many of the direct and indirect financial subsidies of the past is extremely limited. However, to allow irrigation facilities to deteriorate, and to stop the development of new facilities in these countries at a time when there is urgent demand for increased food and cash crop production, would be irrational. Therefore, most governments in developing countries are being forced to reconsider their policies towards payments to farmers for irrigation investments and services. In this situation, financing irrigation with funds provided by farmers through one means or another becomes nearly inevitable.

There is, however, considerable evidence that since the mid-1980s, new irrigation technologies have made small-scale irrigation schemes a much more viable alternative in many developing countries. The advent of cheap, dependable motors and pumps and the increasing availability of fuel and electric power have revolutionized irrigation more than any technological or managerial innovation. In many parts of the world, large areas of land could not be economically irrigated by gravity flow. A case in point is land located on the banks of large rivers, where construction of diversion structures is not feasible for technical and economic reasons. Such land is now available for pump irrigation.

Investments in irrigation require expenditure for the creation, operation, upkeep and occasional upgrading of irrigation facilities. These costs are commonly grouped into two categories: capital costs and recurrent costs. Capital costs of irrigation are those associated with the initial construction, upgrading and major rehabilitation of the irrigation facilities. They are incurred at the time the irrigation project is first constructed, and then sporadically over the life of the project.

Recurrent costs, on the other hand, are annual costs of operating the scheme, maintaining the facilities and producing the crops. For practical reasons they are in this paper divided into two groups. First, there are water costs and other expenses directly related to the irrigation services. Second, there are the seasonal crop production costs which include all other variable costs of production such as field machinery services, land preparation, seeds or plants, fertilizer, chemicals, transport, fuel, labour and marketing costs.

Both capital and recurrent costs are part of the real economic costs of irrigation, so that when a proposed irrigation project is being evaluated from the economic perspective, the distinction between capital and recurrent costs is important only to the extent that the difference in the timing of costs affects their present economic value. Nevertheless, when a project has been built, the initial economic cost becomes a sunk cost, meaning that no future decisions can affect its magnitude. Therefore, during much of the project life, decisions about the recurrent costs of irrigation are the most important investment-related decisions affecting the productivity of the existing irrigation infrastructure.

15.1 Assessing the Viability of Investment

15.1.1 Scheme investment analysis

The scheme investment analysis for the irrigation scheme is based on the gross margins, investment costs and the operation and maintenance costs. The analysis compares the anticipated 'with-project' situation to the 'without-project' situation for the duration of the project. The analysis seeks to judge the likely incremental benefits to project participants, and the incentive for farmers to participate in the project, thus looking at the attractiveness of the project to the participating farmers. The analysis also indicates the contribution of the various agencies to the project in terms of finance and technical assistance. The farm investment analysis utilizes the information collected from the farmers to determine the income levels with and without project to derive the incremental income or net benefits. Using discounted cash flow analysis, time-adjusted cash flows result with every transaction assumed to fall at the end of the accounting period (each year in most cases). Initial investments are considered to take place at the end of the first year of the project.

15.1.2 Project Costs

Investment costs derive from the estimate of the costs of construction/rehabilitation of the irrigation scheme (head works, conveyance and drainage system, infield works, training and institutional aspects and any other costs needed to ensure that the investments made are sustainable and achieve the estimated benefits). The costs items included depend on the type of system, but in general if total rehabilitation costs amount to more than US$ 2,500 per ha, or the total costs for new schemes exceeds US$ 5,000 per ha then it will be difficult to achieve a positive cost benefit analysis.

Prior to the investment decision, the standard procedure is to assess the viability of the proposed irrigation project through financial and economic analysis. These, together with social and environmental assessments, are used when rationing scarce development funds and deciding whether to accept or reject a project. Project analysis translates all benefits and costs of a project into monetary values. This process basically consists of the following stages:

- identifying all benefits and costs arising from the physical effects of a project;
- measuring the monetary values, where possible, of such benefits and costs;
- putting these values in current or constant monetary terms; and
- comparing the benefit and cost streams of the project through the use of the project decision criteria.

Time is critical to any irrigation project's benefits and costs, because money received at the present time is preferred over money gained in the future. The concept of the time value of money is directly incorporated into project analysis through the use of a discounted cash flow. It is essential for all project analysis to use either discounting (use of year 1 prices as the base) or compounding (projecting prices to year n) if benefit and cost streams are to be added across years - otherwise "apples" and "pears" are being added together and much of the validity of the analysis is lost.

When assessing a project, financial analysis considers only the prices for costs and benefits as given by the private market. In contrast, economic analysis is concerned with the full social opportunity costs of a project. Thus, in an economic analysis, the target groups widens from the immediate investor to society, and for critical inputs and outputs social values must be estimated and used if private and social values differ significantly. In irrigation projects, this commonly leads to major differences between financial and economic analyses regarding the treatment of such categories as capital, environmental costs and benefits, foreign exchange, market subsidies, taxes and equity issues.

Assessing project worth against alternative projects or development funding constraints requires some common rules of comparison or decision criteria. In financial and economic analysis the most commonly used criteria are the net present value, the benefit-cost ratio, the payback period and the internal rate of return of the project.

While in large government projects it is rare for the water users to be responsible for the complete costs of the projects, the relative stakes of the farmer in investment decisions are generally much higher in small farmer financed irrigation systems. Faced with the uncertainty and lack of knowledge about the outcome of the investment decisions, the water users in farmer managed projects are apt to give great weight to the financial risks that they personally must bear. Risk aversion and conservative attitude towards uncertain irrigation investments obviously is a rational and justified attitude for smallholders living near the poverty line. Therefore, a major objective of the participatory planning processes should be to create a clear understanding with the farmers of not only the potential benefits but also of the financial risks of participating in a farmer-managed and farmer funded irrigation operation.

After a project has been prepared, a critical review or an independent appraisal usually needs to be conducted. This provides an opportunity to re-examine every aspect of the project plan, in order to assess whether the proposal is appropriate and sound before large sums of money are committed to it. It will also look at whether the time frame proposed for implementation is realistic. The appraisal process builds on the plan, but it may involve gathering new information if the specialists on the appraisal team feel that some of the data are questionable or some of the assumptions faulty.

15.2 Crop Budgets and Farm income

Analyzing the financial benefits of an irrigation project involves looking at the project at two levels: the farmer level and the scheme level. At farmer level, we look at production levels, labour requirements and net income 'with' and 'without' the project. At scheme level, we look at costs incurred in constructing, operating and managing the whole scheme. Scheme-level costs are then compared with estimated income from the whole scheme (all irrigators) to assess the financial benefits of investing in irrigation.

Farm income analysis: In analyzing a project, the underlying assumption we make is that, for a farm or farming community, the objective will be maximization of the income that the families will earn as a result of participating in the project. To achieve the objective, we must analyze the resource use, the income generated by the operation of the project and the investment. This section deals with the first two aspects, while the investment aspects will be dealt with in Section 2.2. The resources used consist of land, water, labour and inputs. The tools to evaluate these resources are cropping patterns, labour requirements and crop budgets.

Cropping patterns: When an irrigation project is introduced, the area for irrigation might be taken from the participating farmers' landholdings being used for rainfed cultivation. If the farmers become full-time irrigators, they might commit all their rainfed land. This means that by switching to irrigation the income that used to come from this rainfed land is lost, and the income from irrigation is gained. In order to assess the impact of this, we have to establish what was grown on the rainfed land and look at the new cropping pattern for the irrigated area. Where the land was previously unutilized or is reclaimed, the 'without-project' situation would be zero.

The 'without-project' situation: To estimate the benefits of the project, a cropping pattern for the irrigated area is proposed. In proposing a cropping pattern, several factors have to be taken into consideration:

- The farmers' wishes and aspirations
- Marketing aspects (consumer and/or industrial)
- Government regulations
- Agronomic aspects
  - soils
  - climatic conditions
  - crop water requirements
  - rotational considerations
- Access to inputs
- Financial considerations
- Labour requirements

Farmers will have some idea of what they want to grow, stemming from their knowledge of the area and of what is especially in demand in terms of their household requirements or the market. This might or might not coincide with what is feasible, since the proposed crops should be in accordance with the agronomic conditions above. However, whatever is proposed will have to be approved by the farmers.

One of the major aspects of choosing a cropping pattern under irrigation, is to determine whether there is a market for the crops. The production structure has to fit the market, and possible markets and their supply and demand have to be determined. In doing this, it is important to look into the following elements:

- How big is the market now and what will be its size in the future?
- What sort of competition exists in the market? Do a few big suppliers or many small ones dominate it?
- How far is the market from the scheme? Are there suitable marketing channels available?
- What sort of price variations can be expected? Is the price very sensitive to supply variations?
- What sort of storage and packaging facilities are necessary to enter the market and are they available?
- Can the scheme act as a reliable and continuous supplier and thus improve the competitive position?
- Is there a specific niche that the scheme has good possibilities of exploiting?
- What are the options for hedging, i.e. delivering on contract?
- Are the farmers capable of organizing the marketing, which means organizing the harvesting, preparing and packing the produce and organizing the transport?

Though not all these questions may be answered satisfactorily, it is important that they at least are considered when the proposed cropping pattern is worked out. The larger the scheme the more crucial it is to have a clear view of exactly how the marketing is going to take place. One general rule normally applies: the safer the market the lower the price.

In choosing the crops, it should also be considered whether the most profitable ones fulfil other requirements that include:

- Reliable demand
- Local consumption potential
- Food security

Having taken all these factors into consideration, a proposed cropping pattern can be established. In some countries, government agricultural departments produce farm viability models detailing potential yields under various conditions. Where available, these data can be used to estimate potential yields for a planned scheme. In estimating yields, it is assumed that on completion and with adequate support services, after 3-5 years, farmers will obtain good yields. Whatever the crop, a learning process must be assumed as new practices and crops will take time to be adopted. Labour requirements

Lastly, the labour requirements will have to be determined in order to establish whether the farmers can provide the extra labour needed.

Labour requirements need to be calculated on a crop-by-crop basis over the cropping season to reach total requirements for the farm and to identify critical demand periods. This is generally based on labour estimates made through field interviews with data associated with various operations in the proposed scheme, which includes providing typical input costs to the farmers. This will indicate the number of labour days required for individual activities such as land preparation, manuring, planting, irrigation, etc. and also the inputs that need to be provided and the associated costs. It is important to consider whether the farm family can manage the tasks assigned to them, whether they will need to hire in labour and whether it will actually be available when needed. Poor farmers have many calls on their time, and it is essential that other off-farm activities and commitments are examined to ensure that the labour inputs can actually be realised. Average family size must be considered, as well as seasonal off farm employment.

The 'without' and 'with-project' situations must be carefully considered as farmers are good economists, and they will determine whether the proposals presented are feasible and will benefit them. In the case of rehabilitation of irrigation and drainage systems, the before and after project intervention is very important. In many cases, the systems have been allowed to deteriorate by government before hand over to communities. In these cases, it is unreasonable to expect farmers to contribute to government errors and oversight.

15.3 Gross margin analysis/Returns to Labour

Gross margin analysis: Crop budgets contain the evaluation of gross margins per hectare for the different crops. Gross margin is the income generated from a production activity and is equal to the difference between the total gross income and the total variable costs.

Yield, harvest and price: The basis for estimating the total income earnings from production are the harvest (= yield x area) and the unit price that farmers are likely to obtain, taking into account the season and the local market conditions. Multiplying the harvest and the estimated unit price gives the estimated gross income. For horticultural crops, the marketable or saleable harvest takes into account losses that might occur since it is unlikely that the entire crop can be marketed. Losses can be due to poor harvesting methods or they can occur during storage and problems in marketing (for example not providing sufficient transport and not reaching the market at the right time). The exact rate of loss will vary depending on the type of crop and the distance to market. If a crop is highly perishable and is grown in a remote area with unreliable transport facilities, then higher losses should be anticipated compared to a crop that stores well in a scheme that is favourably located in respect of transport and market.

The prices used in crop budget estimates and investment calculations can stem from suppliers of agricultural inputs, marketing boards and prices observed in local markets. Input suppliers' prices are used directly. Blend prices, which are average prices for various grades of the same product are used for crops sold to marketing boards. For freely marketed crops, major markets should be monitored closely to provide average prices for each month.

The gross income is the total value of production from the farm as an enterprise. It includes sales plus value of retained produce for consumption at home (farm) and any by-products with value, such as retentions for livestock feed. Gross income of marketed output = marketed output (quantity) x market blend price (US$/unit quantity). Gross income of retained output = output retained (quantity) x farm gate price (US$/unit quantity), where farm gate price is the value the produce would have fetched if sold locally. Allowance needs to be made for home consumption as not all of the crop will be sold. The Total gross income = gross income of marketed output + gross income of retained output.

Variable costs are the costs that can be directly allocated to a particular enterprise in a production season. These tend to change with the size of the enterprise and the scale of production. Variable costs include land preparation (hired labour or equipment), planting material (for example seed), fertilizers (both organic and inorganic), chemicals (pesticides, insecticides, herbicides), transport of inputs, interest on seasonal loan, if money for inputs is borrowed, casual labour for weeding, harvesting, etc., packing material, transport of outputs and any marketing costs (fees for market stands; personal transport for farmers to market and/or marketing fees charged by wholesalers).

The cost of household labour is not itemised but hired labour is included. The gross margin for each enterprise is assumed to be the return to family labour and capital. For planting material, fertilizers and chemicals, the rates recommended from research and extension are applied and valued at the most recently available prices. Transport expenses will vary according to quantities carried, and whether it is provided by the farmers or farmer groups or hired in. Interest on seasonal loan is calculated as a percentage of the total cost of the inputs (land preparation, seed, fertilizers, chemicals and transport of inputs to the farm).

Packing material should be included in the crop budget to an extent that is necessary to ensure that the crop reaches the market in the best state, and will include sacks for grain crops. For crops like potatoes, dry onions and carrots, which are normally sold by the pocket, an allowance for packing will have to be made.

The gross margin of an enterprise is the difference between the total gross income earnings and the total variable costs. This is then the estimated gross return to the labour and capital that a farmer has invested for a unit land area of the particular crop. The gross margin is expressed on a per hectare basis to allow comparison of different crops. The gross margin of different enterprises on the farm should be added up to give the farm margin.

Standard crop budgets or viability models for various crops are usually produced by government research and/or extension departments, and can be used to make rough estimates of enterprise performance. Adjustments need to be made to these standard crop budgets, depending on specific conditions on the ground, such as soil quality, temperatures, farmer management levels, etc.

When the crop budgets for all crops have been made, the whole plot gross margin for the irrigated area and any income foregone in the rainfed land can be estimated. This will reflect the change in cropping intensity for the before and after project situation. The gross margin of each irrigated plot multiplied by the number of plots in the scheme is used to the 'with-project' benefits of the irrigation scheme. The gross margin for the rainfed land foregone by the area occupied by the irrigation provides the 'without-project' benefits.

15.4 Operation and Maintenance Costs

These comprise the costs of running the O&M, both fixed and variable – the operating costs and the maintenance costs for keeping the I & D infrastructure in a good and workable condition. Operating costs comprise:

- Salaries and allowances of O & M Staff;
- Maintenance of buildings, offices, stores and housing (if appropriate);
- Running costs of office;
- Running costs of O&M vehicles and plant;
- Costs of special repairs;
- Running costs of irrigation and drainage pumping stations.

Maintenance costs are calculated in detail at the end of each irrigation season, to determine the routine and preventative works needed to keep the infrastructure in a condition that it can provide the agreed level of service (see section 13). The annual expenditure will reflect the original level of investment in the capital works and typical values are given below[30]. Actual costs should be determined, but these can be used as a first estimate.

[30] Guidelines for Planning irrigation and drainage investment projects, FAO Investment Centre Technical Paper 11, Rome 1996.

Table 15.1 Typical Values of Annual Maintenance

Type of Works	Annual Maintenance cost as % of Initial Capital Cost
Diversion Structure/Weir	1.5
Main canal - Lined	1.0
Buried Pipelines	0.5
Buildings	1.5
Electric Pumps	3.0
Piped Distribution Systems	1.0
Portable Pipes and Sprinklers	6.0
Tertiary Channels and Structures	1.0 – 2.0
Drains (Sub-surface)	1.5
Drains (Open)	2.0

The operating expenditure is calculated for the costs of equipment utilized in making the investment functional and would include the ones described below.

Replacement costs: These are the costs incurred to replace specific items. As an example for an irrigation scheme, the following assumptions about the replacements are made:

- All hoses and valves should be replaced every 5 years
- All sprinklers and tripods should be replaced every 10 years
- The pumping unit should be replaced every 15 years

Energy costs: These depend on the elevation of the water source relative to the elevation of the scheme, which determines whether water should be pumped in order to reach the scheme, and on the irrigation system used (surface or pressurized). In the case of an overhead or pressurized irrigation system, energy costs used in the appraisal are estimated on a per crop basis (assuming crop water requirements, pumping head and conveyance needs).

Repair and maintenance costs: These costs are usually based on assumptions which depend on the cost of the equipment utilized. Thus a percentage of the cost of equipment (normally ranging from 1.5-5%) is taken as repair and maintenance costs per year. Real costs can be used if known from other similar schemes.

Technical support: In large irrigation schemes, government may commit at least one full-time agricultural extension officer to advise farmers on their agricultural activities. The cost of this technical expertise (mainly salary) is included in the analysis of the project.

Water charges: These are the charges payable to whoever supplies water, for example the national water authority. Where water is purchased, the water charges should be indicated as a cost.

Sunk cost is the cost incurred in the past that cannot be retrieved as a residual value from an earlier project. A sunk cost has no opportunity cost, as the assets represented by the sunk cost have no alternative use. In addition, a sunk cost is therefore not included in the outflow when projects are analyzed. This can be the case if the project is a rehabilitation of a previously operated irrigation scheme, and a dam was constructed to provide water for the previous irrigation scheme. Then the dam is considered a sunk cost.

Residual value: This is the value of the asset remaining unused at the end of a project. The asset can be termed a residual asset. In project analysis the residual value is generally added to the benefit stream at the end of the project. Salvage value or scrap value are forms of residual values that refer to the estimated value of the asset at the end of the project period. In our analysis, we assume this value to be zero as the project period will be the same as the estimated lifetime of the irrigation system.

Adequate funds need to be provided to meet O&M costs otherwise a backlog of deferred maintenance will arise. If this is addressed, further deterioration, declining performance of the sector, and increasing costs for eventual rehabilitation will result. Whilst this serious problem is well known, there has been no sustained effort to redistribute resources to deal with the issue. Governments tend to remain preoccupied with its irrigation development programs, with rehabilitation needs continuously neglected and postponed.

15.5 Implementation Period

Implementation starts when the final appraisal report has been approved and when financing agreements have been concluded. It involves:

- Preparation of an action plan and budget for the project
- Mobilization of resources (human, material and management) and assigning of responsibilities
- Mobilization of farmers to participate fully in the project right from the start
- Initiation of fieldwork, for example laying out of engineering works, crop production, etc.

Project implementation must be sufficiently flexible to take into account changed circumstances, which are difficult to predict. For example, price changes may necessitate different cropping patterns or adjustments in inputs.

15.6 Benefit/Cost (B/C) ratio

The B/C ratio is the ratio between the PV of the benefit stream and the PV of the cost stream. It thus is an indication of how much the benefits exceed the costs. Dividing the sum of the PV of the benefits by the sum of the PV of the costs gives the B/C ratio. If this ratio is greater than 1, at the current discount rate, the benefits exceed the costs. This means that it would be profitable to go ahead with this project. If the ratio had been below 1, the project would not be viable. The selection criteria are thus B/C ratio > 1.

15.7 Internal Rate of Return

Internal Rate of Return (IRR) is the rate of discount at which the total discounted cash benefits expected from the project, equal the total discounted cash costs required by the investments. It is the rate that makes the NPV of the project equal to zero. The IRR can also be described as the rate of growth of an investment. This rate can be interpreted as the highest rate of interest an investor could pay, without losing money, if all the funds to finance the investment are borrowed and if the debt service (loan and accrued interest) was repaid by use of cash proceeds from the investment. The investment criterion is that the IRR should be greater than the discount rate.

The IRR can be computer generated. Excel, for example, provides the facility to calculate the IRR, using the accounting function. If no computers are available, then the calculation of IRR is done by trial and error. Two discount rates within ten percentage points need to identified. One discount rate should give a positive NPV and the other a negative NPV. The following formula is used:

IRR = ldr + [(hdr - ldr) x NPV at ldr]/[(NPV at ldr - NPV at hdr)]

Where:

IRR	=	Internal Rate of Return
Hdr	=	Higher discount rate
ldr	=	Lower discount rate
NPV	=	Net Present Value

From the financial analysis, for the proposed irrigation scheme to be viable, the IRR should exceed the cost of borrowing.

The payback period is the period it takes for annual net benefits to equal initial investment. It shows how long it takes for the project to generate benefits to cover costs incurred in the investment. It can also be calculated on undiscounted benefits and cost streams. Generally, lower payback periods are preferred although notice should be taken of the fact that payback period criterion ignores potential benefits in later years.

15.8 Financial Analysis/Economic analysis/Sensitivity analysis

A financial analysis takes the point of view of the primary stakeholders in the project, which are the investors (for example government, farmers, local authorities, NGOs, etc.) and other stakeholders. It looks at a change in income as a result of the project in domestic market prices, and in general is expressed in domestic currency. In a financial analysis, the prices used are the actual prices that stakeholders experience, whether they are free market prices or controlled prices, non-taxed or taxed. For ease of comprehension, the prices in the previous chapter have been converted to US$. In reality they should be expressed in the currency of the country.

An economic analysis takes the point of view of the society and seeks to clarify whether projects will benefit the economy as a whole. Thus, the objective of the economic analysis is not income maximization of the primary stakeholders, as is the case with the financial analysis, but maximization of benefits at the national level.

When the economic values for the project input and output have been determined, the same methods that were used in the financial investment analysis can be applied. For the economic analysis, where the point of view of the whole economy rather than that of the farmer is taken, the interest charged by the lender is not relevant. Instead, one would focus on the opportunity cost of capital. Theoretically this is the rate that would be set in an ideal capital market. The government and the Central Bank, however, regulate the capital market. As an approximation, the interest rate for long-term government bonds could be used. Another estimate for the real economic discount rate is based on the cost of borrowing money on the international capital market where it is assumed that marginal borrowing in the economy will take place. Rates set by international financing institutions, such as the World Bank (WB), International Monetary Fund (IMF) and African Development Bank (AfDB) approximate to the economic discount rate.

Rehabilitation and modernization will tend to take priority for investments over the next few years as such projects will probably result in higher internal rates of return considering the considerable sunk costs. All such schemes will need to be carefully reviewed before investments are agreed to ensure complete and realistic capital and O&M costs to enable effective operation and maintenance under the WUAs and the achievement of improved water management and efficiency and higher irrigation ratios. A key element will be the delivery of water to the farmers when they need it and at a cost that is affordable to them. For those schemes with lower irrigation ratios, there are likely to be a number of related issues that are limiting the utilization of the irrigation infrastructure. In those schemes with good irrigation ratios, farmers may request assistance for part improvement and modernization and these should be given priority particularly where water may be a constraint

Planning irrigation schemes involves projections of inputs and outputs over a period of time. There is thus a need to consider the element of uncertainty. What happens if the future developments are not as envisaged? How can the uncertainty element be taken into consideration in the financial and economic analysis? Sensitivity analysis is done to allow planners and investors to take into consideration eventualities that cannot be predetermined or are beyond the direct control of those involved in project implementation. It is done in order to protect investment decisions from risk. For most agricultural projects four major risk areas affect the viability of projects realte to unstable prices, rising cobnstrcutioon costs, delays in implementation, cost overruns, yields falling below expectations or reaching the required values several years later than anticipated.

Changes in prices are naturally of the utmost importance when one is considering the viability of an agricultural project. There is a need to test the project viability's dependence on price changes, especially the prices of the major components of the project. **Considerations should be made as to what** happens if the market is flooded with produce at the same time, or the planned markets for the produce do not materialise.

A delay in implementation means that the benefits from the project are delayed too. This can be important for the viability of the project, as the developments in the implementation period carry a relatively heavy weight in the analysis due to the time value of money.

However, when evaluating small irrigation schemes with no major construction activities, delays are unlikely to incur any great costs. Farming operations will continue until the contractors move in, and no substantial amount of money will be disbursed before the scheme has been commissioned.

If, however, major capital outlays are involved, delays are more likely to cause additional expenses as loan repayments become due, and dryland production is forfeited as long as irrigation construction is taking place.

There can be considerable uncertainty involved in the estimation of the prices of spare parts and in the estimations of the construction costs. As a result, there is a need to test the viability of the project in the event of cost overrun.

Yields may vary because of adverse weather conditions, lack of inputs, etc. Therefore, it is important to use conservative yield estimates in the analysis, except for grain maize. Grain maize is generally a well-known crop in the region for which it seems reasonable to expect normal yields. Dryland income foregone (that is treated as cost in the analysis) is estimated to be stable, which means that it is assumed that drought will not affect the dryland yields. This adds leeway to the estimates of the viability of the project.

Sensitivity analysis involves recalculating the measures of project worthiness under new assumptions and including the results in the analysis. Aspects considered are 20% lower prices, 20% - 30% cost overrun on investment, replacement, repair and maintenance costs. These are examined to test the viability of the project.

Sensitivity analysis requires a lot of information that may be costly to obtain in terms of time and resources. Some may not be available. The simple assumption on varying one variable may not hold in practice. In life, variables may change jointly. Higher input costs may be accompanied by lower demand for products. It is, however, necessary that a judgement be made in analyzing these likely effects. It is not adequate to just highlight problems. Some ways to reduce risk and uncertainty include adding physical and price contingency allowances, introducing flexibility in design and implementation, ensure that market surveys or technical studies are carried out on uncertain items before implementation, initiate benchmark surveys to determine the basis for the project, market analyses to assess marketing arrangements (possibly contracts, etc.) and pilot areas to test unproven technologies and development interventions.

15.9 References

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.16 Performance Assessment, Monitoring and Evaluation

16.1 Overview

Performance assessment is an integral component of management. In the context of irrigation and drainage systems performance, assessment is carried out at different levels by different entities. At national level, an irrigation agency might be interested in how different schemes are performing in relation to agricultural production and water use. At the on-farm level, the water users association are interested in knowing how much water they are receiving, how well they are distributing it and the level of fee recovery from water users. At the field level, water users measure the performance of the association in delivering water, and the output from their fields in terms of agricultural produce, and the cash that it generates when sold.

By measuring performance, at whatever level, those responsible for management at that level are able to assess whether performance is satisfactory, or whether it can be improved. Through an assessment of the performance (and the associated process of diagnostic analysis) the manger is able to identify areas where performance can be improved. The assessment of performance is often made in comparison to how other schemes, WUAs or farmers are performing; this comparative assessment is an integral part of the process of performance benchmarking.

Monitoring and evaluation (M&E) is a part of performance assessment, and is generally used in the context of project, rather than scheme, management[31]. Monitoring is an integral part of the management of an irrigation and drainage project, seeking to ensure that the project is on track to complete the assigned activities on time, within budget and to the quality required. Evaluation is carried out once the project has been completed as is used to assess whether the project has been successful in achieving its objectives. Information gained from evaluation of the project can then be fed back into the design and implementation of future projects.

16.2 Assessing Scheme Performance

16.2.1 Overview

Prior to establishing procedures for assessing performance, it is important to think through the various components of the process and to establish a framework for the assessment. The framework serves to define why the performance assessment is needed, what data are required, what methods of analysis will be used, who will use the information provided, etc. Without a suitable framework the performance assessment programme may fail to collect all the necessary data, and may not provide the required information and understanding.

The framework is based on a series of questions (Figure 16.1). The first stage, purpose and scope, looks at the broad scope of the performance assessment - who it is for, from whose viewpoint it is undertaken, who will carry it out, its type and extent. Once these are decided, the performance assessment programme can be designed, selecting suitable criteria for the performance assessment, performance indicators and the data that will be collected. The implementation of the planned programme follows, with data being collected, processed and analysed. The final part of the programme is to act on the information provided, with a variety of actions possible, ranging from changes to long-term goals and strategy, to improvements in day-to-day procedures for system management, operation and maintenance.

[31] Project management is time-bounded and requires that specified activities are carried out within a given time frame to deliver specific outputs.

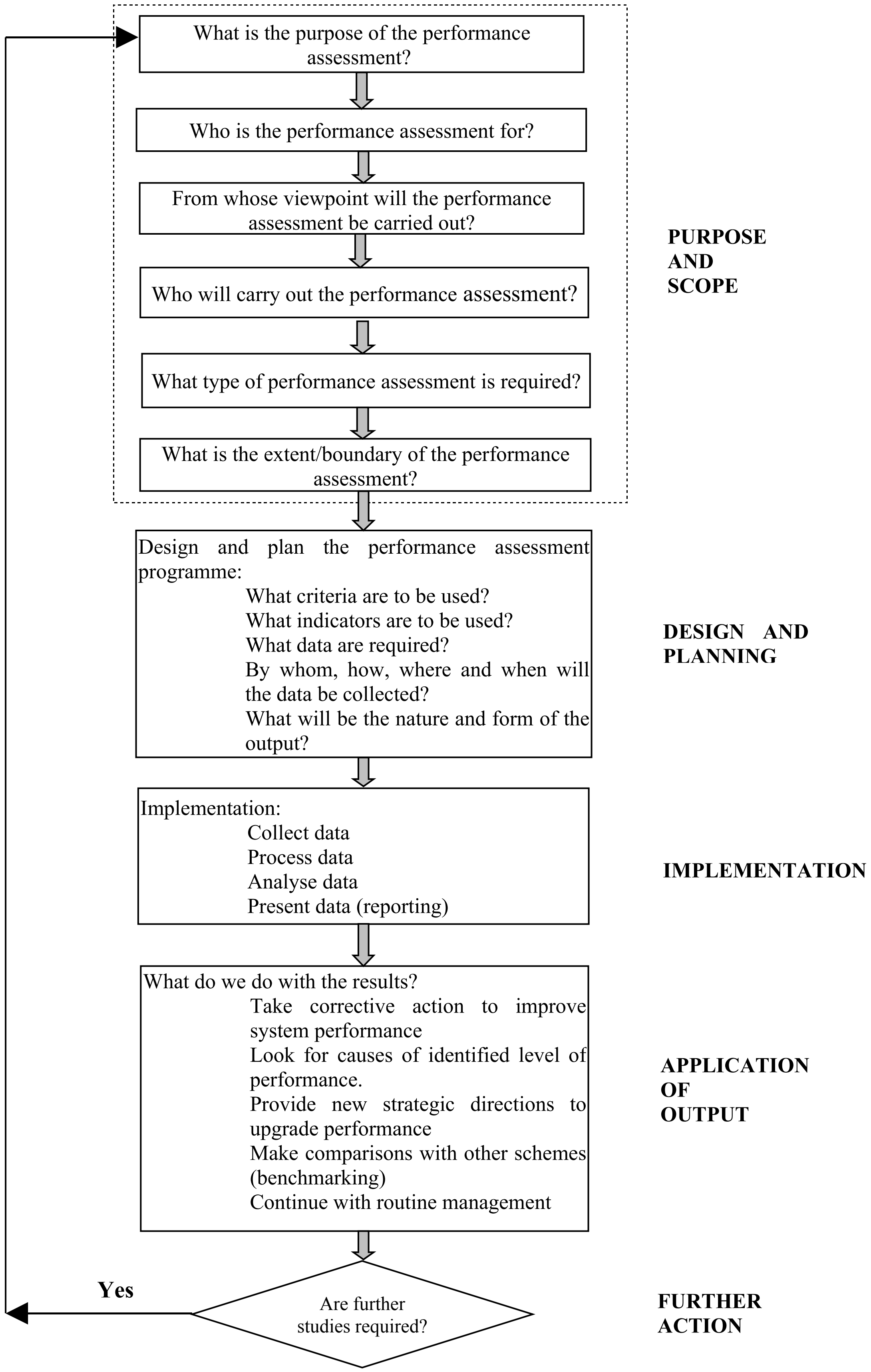

Figure 16.1 Framework for performance assessment of irrigation and drainage schemes

16.2.2 Purpose and scope

The initial part of formulating a performance assessment programme is to decide on the purpose and scope of the performance assessment. Key issues relate to who the assessment is for, from whose viewpoint, the type of assessment and the extent/boundaries. It is important that adequate time is spent on this part of the work as it structures the remaining stages.

Purpose and objectives

As with any project or task it is essential that the purpose and objectives of the performance assessment be defined at the outset.

Three levels of objective setting can be identified:

- rationale
- overall objective
- specific objectives

The *rationale* outlines the reason that a performance assessment programme is required. The *overall objective* details the overall aim of the performance assessment programme, whilst the *specific objectives* provide further detail on how the overall objective will be achieved (Table 16.1).

Table 16.1 Example of the rationale and a set of objectives for a performance assessment programme

Rationale:	Water management needs to be improved if all farmers within the scheme[32] are to obtain adequate livelihoods
Overall objective:	To identify feasible and sustainable water management practises which lead to improved crop production and thereby income for the farming community
Specific objectives:	i) Monitor water demands and allocations at all control points (primary, secondary and tertiary canal intakes) ii) Analyse current match between water supply and demand, and identify areas for improvement iii) Formulate strategy for improvement iv) Implement strategy v) Monitor and evaluate impact

Establishing the rationale and identifying the overall and specific objectives of the performance assessment programme is not always straightforward; care needs to be taken at this stage to ensure that these objectives are clearly defined.

For whom?

Who the assessment is for is closely linked to the purpose of the assessment. The performance assessment can be carried out on behalf of a variety of stakeholders. These include: government; funding agencies; irrigation and drainage service providers; irrigation and drainage system managers; farmers; research organisations.

[32] The term "irrigation and drainage system" refers to the network of irrigation and drainage channels, including structures. The term "irrigation and drainage scheme" refers to the total irrigation and drainage complex, the IandD system, the irrigated land, villages, roads, etc.

Figure 16.2 Good performance from a farmer's perspective

From whose viewpoint?

The assessment may be carried out on behalf of one stakeholder or group of stakeholders, but may be looking at performance assessment from the perspective of another stakeholder or group of stakeholders (Figure 16.2). Government may commission a performance assessment, for example, to be carried out by a research institute to study the impact of system performance on farmer livelihoods. Farmers might commission a study of the irrigation service provider, in order to ascertain if they are receiving an adequate level of service for fees paid.

By whom?

Different organisations or individuals have different capabilities in respect to performance assessment, and different types of performance assessment will require different types of organisation or individuals to carry out the assessment (Table 16.2). A scheme manager might establish a performance assessment programme using existing O&M personnel to be able to monitor and evaluate scheme performance. A government agency might employ a consultant to carry out performance assessment of a scheme with a view to further investment, whilst a university research team might carry out a research programme to identify and understand generic factors that affect system performance.

Table 16.2 Examples of for whom, from whose viewpoint and by whom performance assessment might be carried out

For whom?	From whose viewpoint?	By whom?
Scheme manager	The scheme management	Scheme manager and staff
Government	Government (return on proposed investment)	Consultant
Government	Society in general, but specifically water users	Government regulatory authority
Funding agency	Farmers (livelihood)	Consultant
Scientific community	The management of the system	Research institute/university
Farmers	Farmers	Consultant

Type

Small and Svendsen (1992) identify four different types of performance assessment, to which a fifth, diagnostic analysis, can be added:

- operational
- accountability
- intervention
- sustainability
- diagnostic analysis

The type of performance assessment is linked with the purpose; in fact Small and Svendsen refer to these categories as the rationale for performance assessment.

Operational performance assessment relates to the day-to-day, season-to-season monitoring and evaluation of scheme performance. *Accountability* performance assessment is carried out to assess the performance of those responsible for managing a scheme. *Intervention* assessment is carried out to study the performance of the scheme and, generally, to look for ways to enhance that performance. Performance assessment associated with *sustainability* looks at the longer-term resource use and impacts. *Diagnostic analysis* seeks to use performance assessment to track down the cause, or causes, of performance in order that improvements can be made or performance levels sustained.

A further requirement to define at the outset is whether the performance assessment relates to one scheme (internal analysis) or comparison between schemes (external analysis). The complexity and variety of types of irrigation and drainage scheme makes comparison between schemes difficult and problematic. Some schemes are farmer-managed, some are private estates with shareholders, some are gravity fed, some fed via pressurised pipe systems, etc. Currently, there is no definitive methodology for categorising irrigation and drainage schemes, therefore there will always be discussion as to whether one is comparing like with like. A short list of key descriptors for irrigation and drainage schemes are presented in Table 16.3. This list of descriptors can be used as a starting point to select schemes with similar key characteristics for comparison; other important characteristics can be added as necessary.

It is important to understand, however, that comparison between different types of schemes can be equally valuable, as for instance might be the case for governments in comparing the performance of privately owned estates with smallholder irrigation schemes. The two have different management objectives and processes, but their performance relative to criteria based on the efficiency and productivity of resource use (land, water, finance and, labour) would be of value in policy formulation and financial resource allocation.

Benchmarking of irrigation and drainage systems is a form of comparative (external) performance assessment that is increasingly being used (see later sections for more detail). Benchmarking seeks to compare the performance of “best practice” schemes with less well performing schemes, and to understand where the differences in performance lie. Initially performance assessment might be focussed on a comparison of output performance indicators (water delivery, crop production, etc.), followed by diagnostic analysis to understand (a) what causes the relative difference in performance, and (b) what measures can feasibly be taken to raise performance in the less well performing scheme(s).

Table 16.3 Key descriptors for irrigation and drainage schemes

Descriptor	Possible options	Explanatory notes	Example
Irrigable area	-	Defines whether the scheme is large, medium or small scale	8567 ha
Annual irrigated area	Area supplied from surface water Area supplied from groundwater	Shows the intensity of land use and balance between surface or groundwater irrigation	7267 ha 4253 ha surface 3014 ha groundwater
Climate	Arid; semi-arid; humid tropics; Mediterranean	Sets the climatic context. Influences the types of crops that can be grown	Mediterranean
Average annual rainfall (P)	-	Associated with climate, sets the climatic context and need for irrigation and/or drainage	440 mm
Average annual reference crop evapotranspiration (ET_o)	-	Associated with climate, sets the climatic context and need for irrigation.	780 mm
Water source	Storage on river; groundwater; run-of-the river; conjunctive use of surface and groundwater.	Describes the availability and reliability of irrigation water supply	Over-year storage reservoir in upper reaches. Ground- water aquifers.
Method of water abstraction	Pumped; gravity; artesian	Influences the pattern of supply and cost of irrigation water.	Gravity fed from rivers, pumped from groundwater
Water delivery infrastructure	Open channel; pipelines; lined; unlined	Influences the potential level of performance.	Open channel, lined primary and secondary canals
Type of water distribution	Demand; arranged on-demand; arranged; supply orientated	Influences the potential level of performance.	Arranged on-demand
Predominant on-farm irrigation practice	Surface: furrow, level basin, border, flood, ridge-in-basin; Overhead: rain-gun, lateral move, centre pivot; drip/trickle Sub-surface: drip	Influences the potential level of performance.	Predominantly furrow, with some sprinkler and (increasingly) drip
Major crops (with percentages of total irrigated area)	-	Sets the agricultural context. Separates out rice and non-rice schemes, monoculture from mixed cropping schemes.	Cotton (53%) Grapes (27%) Maize (17%) Other crops (3%)
Average farm size	-	Important for comparison between schemes, whether they are large estates or smallholder schemes	0.5-5 ha (20%) >5 – 20 ha (40%) >20 – 50 ha (20%) > 50 ha (20%)
Type of management	Government agency; private company; joint government agency/farmer; farmer-managed	Influences the potential level of performance.	River system – Government; Primary and secondary systems – Water users associations.

The selection of performance assessment criteria will be influenced by whether the exercise looks internally at the specific objectives of an irrigation scheme, or whether it looks to externally defined performance criteria. Different schemes will have different objectives, and different degrees to which these objectives are implicitly or explicitly stated. It may well be that when measured against its own explicitly stated objectives (for example to provide 1000 people with secure livelihoods), a scheme is deemed a success. However, when measured against an external criterion of crop productivity per unit of water used, or impact on the environment, it may not perform as well. This reinforces the point made earlier that assessment of performance is often dependent on people's perspective – irrigation is seen as beneficial by farmers, possibly less so by fishermen and downstream water users.

Extent/Boundaries

The extent of the performance assessment needs to be identified and the boundaries defined. Two primary boundaries relate to *spatial* and *temporal* dimensions. *Spatial* relates to the area or number of schemes covered (is the performance assessment limited to one secondary canal within a system, to one system, or to several systems); *temporal* relates to the duration of the assessment exercise and temporal extent (one week, one season, or several years).

Other boundaries are sometimes less clear cut, and can relate to whether the performance assessment aims to cover technical aspects alone, or whether it should include institutional and financial aspect. How much influence, for example, does the existence of a water law on the establishment of Water Users Associations have on the performance of transferred irrigation and drainage systems?

The use of the *systems approach* advocated by Small and Svendsen (1992) can add to the definition and understanding of the boundaries and extent of the performance assessment programme. The systems approach focuses on *inputs, processes, outputs* and *impacts* (Figure 16.3). Measurement of outputs (for example water delivery to tertiary unit intakes) provides information on the effectiveness of the use of inputs (water abstracted at river intake), whilst comparison of outputs against inputs provides information on the efficiency of the process of converting inputs into outputs. The process of transforming inputs into outputs has impacts down the line – the pattern of water delivery to the tertiary intake has, for example, an impact on the level of crop production attained by the farmer.

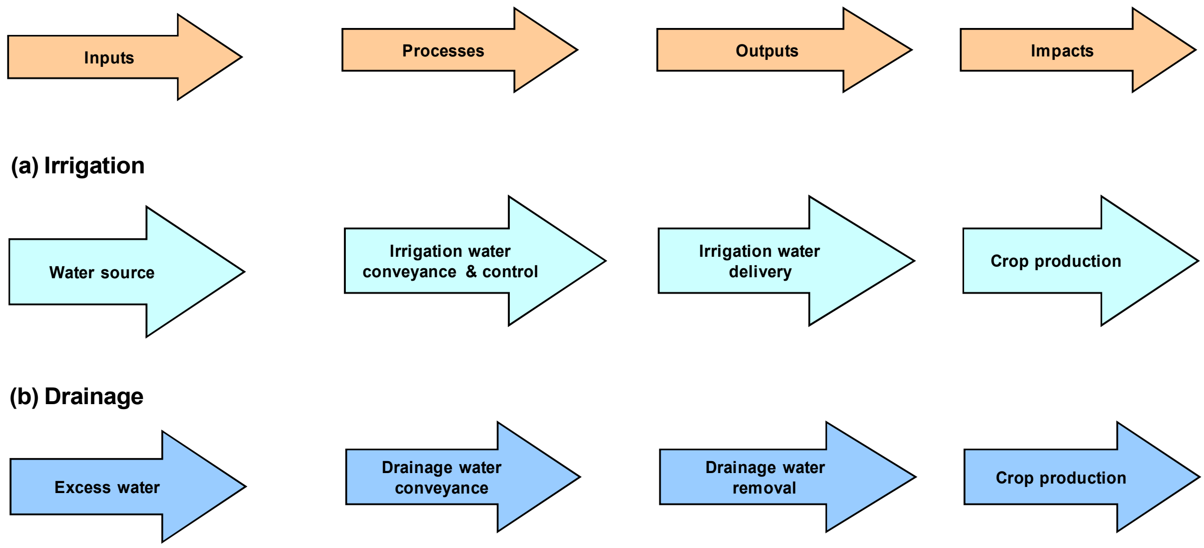

Figure 16.3 Inputs, processes, outputs and impacts in irrigation and drainage

Measurements of canal discharges will provide information on how the irrigation system (network) is performing, but tells us little about the performance of the irrigation and drainage scheme as a whole. To obtain this information, we need to collect data within the irrigated agriculture system (Figure 16.4), and the agricultural economic system to set the performance of the irrigation system in context. Caution should be excercised in relating the performance of the irrigation system (e.g. adequate and timely water supply) to that of the agricultural economic system (e.g. farmer income), as many variables intervene between the supply of the irrigation water and the money received by the farmer for the crops produced.

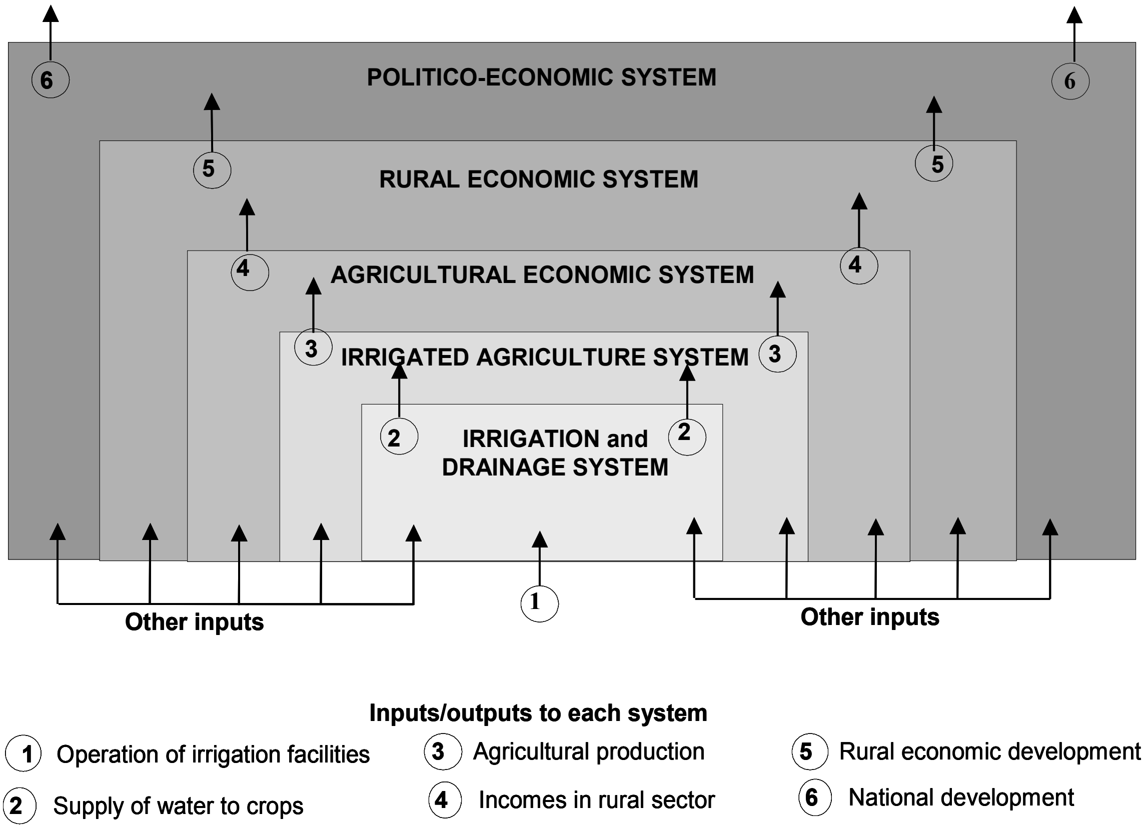

Figure 16.4 Irrigation and drainage functions in the context of nested systems

16.2.3 Design and planning of the performance assessment programme

Having specified the approach to the performance assessment programme in terms of the purpose and strategy, the performance assessment programme can be designed and an implementation programme planned. The key issues to consider are:

- What criteria are to be used?
- What performance indicators are to be used?
- What data are required?
- By whom, how, where and when will the data be collected?
- What is the required form of output?

Performance criteria and scheme objectives

In the literature the terms performance criteria, performance indicators and performance measures are used by different authors to mean different things. The following definitions are proposed in order to clarify the terms *performance criteria, objectives, performance indicators* and *targets*:

i). *Objectives* are made up of *criteria*:
"To maximise agricultural **production**"
"To ensure **equity** of water supply to all farmers"
"To optimise the **efficiency** of water distribution"

ii). *Criteria* can be measured using *performance indicators*
iii). Defined *performance indicators* identify data requirements
iv). Data can then be collected, processed and analysed
v). If *target, standards*, *reference* or *benchmark* values of performance indicators are set or known then performance can be assessed

In selection of criteria for performance assessment, it is necessary to define whether the assessment will be made against the scheme's stated objectives and criteria, or against an alternative set of performance objectives or criteria. An example of where a scheme's objectives and target values are stated is shown in Table 16.4. In this case the targets for cropped area and crop production (in terms of crop production and value) can also be monitored over time to assess the sustainability of the scheme.

Table 16.4 Example of linkage of objectives, criteria, performance indicators and targets

Objective	Criteria	Performance indicator	Target value
Maximise area harvested	Productivity	Cropping intensity	2052 ha (100%)
Maximise total crop production	Productivity	Total production	7,600 tonnes
Maximise total value of agricultural production	Productivity	Total value of production	$1,067, 238
Maximise productivity of water	Productivity	Water productivity Value of production per unit water	0.16 kg/ m^3 0.023$/ m^3
Maximise equity of water supply	Equity	Area planted/Area harvested Delivery performance ratio	1.0 standard dev. < 10%

Source: Calculations for Mogambo Irrigation Scheme, Somalia in Burton (1993)

Whilst an irrigation scheme may have stated objectives, its performance may need to be assessed against different criteria (Table 16.5). For example, a government might assess a scheme's performance in relation to the country's economic needs, or environmental sustainability and impact. Simply because these criteria are not stated in the objectives for the scheme does not mean that the scheme cannot be assessed against such externally stipulated criteria. For example, a scheme may not have stated objectives about pollution loading, but an environmental regulatory agency may have their own standards against which the scheme's performance is assessed.

Table 16.5 Criteria for good system performance according to type of person

Type of person	Possible first criterion of good system performance
Landless labourer	Increased labour demand, days of working and wages
Farmer	Delivery of an adequate, convenient, predictable and timely water supply
Irrigation engineer	Efficient delivery of water from headworks to the tertiary outlet
Agricultural economist	High and stable farm production and incomes
Economist	High internal rate of return
Political economist	Equitable distribution of benefits, especially to disadvantaged groups
Environmental scientist	Low levels of fertilizer and pesticide contamination in drainage water

In some of the literature on performance assessment, authors have stated that performance should be assessed against objectives set for a given scheme. This is an obvious starting point, but, is more difficult to apply when there are no explicitly stated objectives for the scheme.

As outlined in Murray-Rust and Snellen (1993), the setting of objectives is a crucial part of the management process, and much has been written on the subject in the context of business management. Some key points in relation to objective setting for irrigation management and performance assessment are outlined below:

i) **Explicit or implicit.** Objectives can be *explicit*, where they are clearly stated, or *implicit*, where they are assumed rather than stated. For example, an irrigation scheme might have the explicit objective of food production, but in a river flood plain an (essential) implicit objective is flood protection to prevent the irrigation scheme being inundated by flood waters. In performance assessment, it is important to identify both types of objectives.

ii) **Hierarchy of objectives.** Objectives occur at different levels within a system or systems. An hierarchy of objectives for irrigation development, identified by Sagardoy et al (1982), was, in ascending order:

- Appropriate use of water
- Appropriate use of agricultural inputs
- Remunerative selling of agricultural products
- Improvement in social facilities
- Betterment of farmers' welfare.

Each of these objectives is important at its own system level, satisfying the objectives at one level means that those at another (higher) level might also be satisfied. This hierarchy of objectives is an integral part of the *Logical Framework* project planning tool, moving from outputs to purpose to satisfy the overall goal.

iii) **Ranking or weighting of objectives.** Within a system there may be several, sometimes competing and objectives. For performance assessment these may need to be ranked or weighted and assessments made to evaluate how well individual and collective objectives are satisfied. This process is commonly termed multi-criteria analysis. An example of the weightings and rankings attached to individual objectives depending on whether the irrigation scheme is run as a State Farm or settlement scheme are presented in Table 16.6. Objectives to maximise equitable distribution of water might be favoured for a settlement scheme, whilst objectives to maximise value of production might be favoured for a State Farm.

Table 16.6 Comparison of objectives, weightings and rankings for a State Farm and a settlement scheme (Burton, 1993)

Objective	State Farm		Settlement scheme		Performance indicator	Target value
	Weighting*	Ranking*	Weighting*	Ranking*		
Maximise area harvested	6	(v)	10	(ii)	Area harvested	2052 ha (100%)
Maximise total production	10	(iv)	6	(iii)	Total production	7600 tonnes
Maximise total value of agricultural production	10	(i)	6	(iv)	Total value of production	$1,067,238
Maximise productivity of land (kg/ m^3)	10	(ii)	10	(v)	Water productivity	0.16 kg/ m^3
Maximise productivity of water ($/m^3)	10	(iii)	10	(vi)	Value of production per unit water	0.023$/ m^3

Maximise equity of water supply	0 (vi)	10 (i)	Area planted/Area harvested Delivery performance ratio	1.0 standard deviation less than 10%

* Note: For weightings 1 is low, 10 is high; for ranking (i) is highest, (vi) lowest

Performance indicators

Performance is measured through the use of indicators, for which data are collected and recorded. The analysis of the indicators then informs us on the level of performance.

The linkage between the criteria against which performance is to be measured, and the indicators that are to be used to measure attainment of those criteria, is important. Using the nested systems outlined in Figure 16.4, for example, performance criteria and indicators for the irrigation system, the agricultural system and the agricultural economic systems can be defined (Table 16.7). Note that a performance criterion, such as equity, can be defined differently depending on the system to which it relates.

Table 16.7 Examples of linkages between performance criteria and performance indicators

Criteria	Performance indicator[1]		
	Irrigation and drainage system[2]	Irrigated agriculture system[2]	Agricultural economic system[2]
Command	Water Level Ratio	-	-
Adequacy	Overall Consumed Ratio Delivery Performance Ratio	Crop production relative to family food needs	Cash value of crop production relative to defined poverty level
Equity	Overall Consumed Ratio Delivery Performance Ratio	Spatial distribution within scheme of: - crop type - crop yield - cropping intensity	Spatial distribution within scheme of farm income
Reliability	Overall Consumed Ratio Delivery Performance Ratio	Number of years crop production is adequate	Number of years income from crop production is adequate
Efficiency	Overall Consumed Ratio Field Application Ratio Outflow over Inflow Ratio	Crop yield	O&M Fraction
Productivity	-	Crop yield	Crop Gross Margin Internal Rate of Return
Profitability	-	-	Farm Profit Return on Investment (EIRR)
Sustainability	Efficacy of Infrastructure Groundwater depth Indicator Value on Salinity	Sustainability of Irrigable Area	Financial Self Sufficiency O&M Fraction Fee Collection Ratio

Notes:
1. See Table 16.9 for more detail on these indicators
2. As detailed in Figure 16.4

In some instances it is useful to consider indicators for the inputs and outputs across a number of systems, examples are presented in Table 16.8.

Table 16.8 Examples of indicators using inputs and outputs across different systems

Criteria	Indicator example	Systems covered
Productivity	Water Productivity (kg/m^3)	Irrigation system Irrigated agriculture system
Productivity	Land productivity (kg/ha)	Irrigation system Agricultural economic system

Target values may be set for these indicators, or the values obtained at a particular location or time can be compared with values of the indicator collected at other locations *(spatial variation)* or time *(temporal variation)*. Thus, values of performance indicators can be compared within or between schemes.

Data requirements

Following on from identification of the performance criteria and indicators to be used in the performance assessment programme the data needs can be identified (Table 16.9).

Table 16.9 Linking performance indicators to data requirements

Indicator	Definition	Units	Data required
Cropping intensity	Actual cropped area Irrigable area	%	Actual cropped area (ha) Irrigable area (ha)
Crop yield	Crop production Area cultivated	kg/ha	Crop production (kg) Area cultivated (ha)
Sustainability of irrigable area	Average cropped area Initial total irrigable area	-	Average cropped area (ha) Initial total irrigable area (ha)
Overall Consumed Ratio	Crop water demand – effective rainfall Volume of water supplied to command area	-	Crop water demand (mm) Effective rainfall (mm) Irrigation water supply (mm)
Delivery Performance Ratio	Actual flow of water Intended flow of water	-	Actual volume delivered (m^3) Intended/planned volume to be delivered (m^3)
Water Productivity	Yield of harvested crop Volume of supplied irrigation water	kg/m^3	Crop production (kg) Area cultivated (ha) Volume of irrigation water supplied (m^3)
Water Level Ratio	Actual water level Design water level	-	Actual water level (m) Design water level (m)
Field Application Ratio	Crop water demand – effective rainfall Volume of water delivered to the fields	-	Crop water demand (mm) Effective rainfall (mm) Irrigation water supply (mm)
Efficacy of Infrastructure	Functioning part of infrastructure Total infrastructure	-	Number of functioning structures Total number of structures
Groundwater depth	Depth to groundwater	m	Depth to groundwater (m)
Indicator Value on Salinity	Actual concentration of salinity Critical concentration of salinity	-	Actual concentration of salinity (mmhos/cm) Critical concentration of salinity (mmhos/cm)
OandM Fraction	Cost of management, operation and maintenance Total budget for sustainable MOM	-	Cost of management, operation and maintenance (MOM, $) Total budget for sustainable MOM ($)
Fee Collection Ratio	Irrigation fees collected Irrigation fees due	-	Irrigation fees collected ($) Irrigation fees due ($)

Source: Chapter 3, Bos et al, 2005

Data collection (who, how, where and when)

During the performance assessment programme design stage, it will be necessary to identify *who* will collect this data, and *how*, *where* and *when* it will be collected.

All or some of the required data may already be available, such as crop areas, or there may be a need for additional data collection procedures or special equipment to collect data (such as automatic water level recorders to gather detailed information on canal discharges day and night). Allowances will need to be made in the performance assessment budget, for the costs associated with the data collection and handling programme.

To understand the performance of an irrigation scheme it is neither necessary, nor economic or time efficient, to collect data for every location in a scheme. The performance assessment programme should be designed to take representative samples, to enable an adequate analysis to be carried out in keeping with the prescribed needs. It is, for example, common to take sample tertiary units from the head, middle and tail of irrigation systems when studying irrigation water management performance.

When the data needs have been decided a data collection schedule can then be drawn up. An example schedule for a performance assessment programme by a scheme manager is presented in Table 16.10.

Table 16.10 Example of a data collection schedule - Who, how, where and when

Data required	Units	Who	How	Where	When
Irrigable area	ha	Scheme manager	From design drawings or scheme database	In office	-
Crop production	kg	Scheme agronomist	Interviews with farmers	In selected sample tertiary units	At end of season
Actual cropped area	ha	Scheme agronomist	Data returns from farmers, and/or spot checks in field	For whole scheme but field checks made on selected sample tertiary units	During the irrigation season
Crop yield	kg/ha	Scheme agronomist	Crop cuttings	In selected sample tertiary units	At harvest time
Crop water demand	mm/day	Scheme agronomist or irrigation engineer	By calculation using standard procedures (e.g. Cropwat or Criwar)	In selected sample tertiary units	During the season
Rainfall	mm/day	Water Masters	Using rain gauge	At locations within the scheme area	Daily
Actual discharge	m^3/s	Water Masters	Reading of measuring structure gauges	At selected sample tertiary unit intakes	Daily
Actual duration of flow	hours	Water Masters	Reading of measuring structure gauges	At selected sample tertiary unit intakes	Daily
Intended discharge	m^3/s	Scheme manager	From indents submitted by farmers	In office	Each week
Intended duration	hours	Scheme manager	From indents submitted by farmers	In office	Each week
Crop market price	$/kg	Scheme agronomist	Interviews with farmers and traders	Villages and markets	At end of season

Note: The example given is for a performance assessment programme carried out by a scheme manager for the whole scheme with a view to understanding overall scheme performance

16.3 Implementation

The performance assessment programme design phase is followed by the implementation phase, covering the actual collection, processing, analysis and reporting of the data. Depending on the nature of the performance assessment programme, implementation may be over a short (1 week) or long period (several years). In all cases, it is worthwhile to process and analyse some, if not all, of the data collected as the work progresses in order to detect errors in data and take corrective action where necessary.

16.4 Application of output

The use of the information collected from a performance assessment study will vary depending on the purpose of the assessment. The use to which the results of the performance assessment are put will depend on the reason the performance assessment was carried out.

Possible actions following the conclusion of the performance assessment study might include:

- Redefining strategic objectives and/or targets
- Redefining operational objectives and/or targets
- Implementing corrective measures, for example:
  - Training of staff
  - Building new infrastructure
  - Carrying out intensive maintenance
  - Developing new scheduling procedures
  - Changing to alternative irrigation method(s)
  - Rehabilitation of the system
  - Modernisation of the system

16.5 Further action

Further studies may be required as a result of the performance assessment programme. Performance assessment is closely linked with diagnostic analysis, and it is often the case that an initial performance assessment programme identifies areas where further measurements and data collection are required, in order to identify the root causes of problems and constraints.

Where performance assessment identifies the root cause of a problem or constraint, further studies may be required to implement measures to alleviate the problem, such as, for example, field surveys for the planning and design of a drainage system to relieve waterlogging.

16.6 Performance assessment at different levels

Performance assessment can take place at different levels:

- At the sector level when assessing how irrigation and drainage is performing in comparison with the objectives set for the sector, and in comparison with other uses of water.
- At the scheme level when assessing how individual schemes are performing against their own explicitly or implicitly stated objectives, or when assessing the performance of different schemes against themselves.
- At main system level where the performance of the water delivery service is assessed, or
- At the on-farm level where the performance of the on-farm water delivery, water use and water application is assessed[33].

The purpose of assessment at these different levels, and possible indicators to be used to assess performance are briefly outlined in the following sections. It is important to note that the approach adopted here is that water delivery and water removal are taken as the primary function; other functions such as maintenance, fee recovery, and the like are subsidiary to the prime function. Fee recovery, for example, is important in order that management staff can be employed and maintenance work carried out, with the end product that water is delivered to the crops' root zone at the right time and in the right quantity to match the crops' needs.

16.6.1 Sector level

At the sector level, performance assessment is focused on the productivity of financial investment in the I&D sector and on the productivity and efficiency of water use. In many countries and river

[33] If required the on-farm level could be further sub-divided into on-farm and in-field.

basins, there is increasing pressure on the available water resources, and an increasing need to justify the use of water for agricultural use against other uses, such as for domestic, industrial, environmental, navigation use. Assessment at this level is generally carried out by government, either through the water resource agency, or by consultants.

16.6.2 Scheme level

At the scheme level, performance assessment is focused on the outputs, outcomes and impacts of the I&D scheme. Outputs will generally focus on crop production, whilst outcomes will generally focus on protecting livelihoods and financial benefits to the farming community. The interest in impacts may range from the environmental impact of the scheme to its wider impact on the rural and national economy.

Table 16.11 presents key indicators that can be used for performance assessment at this level, with indicators covering a range of domains, including agricultural production, irrigation water delivery, drainage water removal, finance, and environmental protection.

16.7 Main system level

At the main system level performance assessment is focussed on water delivery, which will depend on the management, operation and maintenance processes and procedures of the main system service provider. Table 16.12 summarises the key indicators that can be used for assessing main system water delivery performance.

Table 16.11 Key indicators for assessing the scheme level management and O&M performance

Indicators	Definition	Notes[1]
Agricultural production		
Total seasonal[2] area cropped per unit command area (Cropping intensity)	Total seasonal area cropped / Total command area of system	a
Total seasonal crop production (Tonnes)	Total seasonal crop production by crop type within command area	a
Total seasonal crop production per unit command area (crop yield, kg/ha)	Total seasonal crop production / Total command area of system	a
Total seasonal value of crop production ($)	Total seasonal value of agricultural crop production received by producers	a
Total seasonal value of crop production per unit command area ($/ha)	Total seasonal value of crop production / Total command area of system	a
Total seasonal crop production per unit water supply (kg/m^3)	Total seasonal crop production / Total seasonal volume of irrigation water supply	a
Total seasonal value of crop production per unit water consumed ($/m^3)	Total seasonal value of crop production / Total seasonal volume of crop water demand (Etc)	a
Total seasonal value of crop production per unit water supplied ($/m^3)	Total seasonal value of crop production / Total seasonal volume of irrigation water supply	a
Irrigation water delivery		
Total seasonal volume of irrigation water supply (MCM)	Total seasonal volume of water diverted or pumped for irrigation (not including diversion of internal drainage)	a
Seasonal irrigation water supply per unit command area (m^3/ha)	Total seasonal volume of irrigation water supply / Total command area of system	a
Main system water delivery efficiency	Total seasonal volume of irrigation water delivery / Total seasonal volume of irrigation water supply	b
Seasonal relative irrigation water supply	Total seasonal volume of irrigation water supply / Total seasonal volume of crop water demand	a
Water delivery capacity	Canal capacity at head of system / Peak irrigation water demand at head of system	-
Financial		
Total seasonal MOM expenditure[3] per unit command area ($/ha)	Total seasonal MOM expenditure / Total command area of system	c
Total seasonal MOM expenditure per unit irrigation water supply ($/m^3)	Total seasonal MOM expenditure / Total seasonal volume of irrigation water supply	c
Total seasonal maintenance expenditure per unit command area ($/ha)	Total seasonal maintenance expenditure / Total command area of system	c
Total seasonal maintenance expenditure fraction	Total seasonal maintenance expenditure / Total seasonal MOM expenditure	c
MOM funding ratio	Actual annual income / Budget required for sustainable MOM	d
Fee collection ratio	Irrigation (and drainage) service fees collected / Irrigation (and drainage) service fees due	d
Farm profit	Total farm income – total farm expenditure	e
Drainage water removal		
Average depth to groundwater (m)	Average seasonal depth to groundwater calculated from water table observations over the irrigation area	f
Environmental protection		
Salinity of soil water (mmhos/cm)	Electrical conductivity of soil water	f
Soil salinity (mmhos/cm)	Electrical conductivity of soil	f
Salinity of water in open drain (mmhos/cm)	Electrical conductivity of water in open drains	f
Drainage water quality: Biological (mg/litre)	Biological load of drainage water expressed as Biological Oxygen Demand (BOD)	f
Drainage water quality: Chemical (mg/litre)	Chemical load of drainage water expressed as Chemical Oxygen Demand (COD)	f

1. Location and sampling interval:
    a. Determine for total command area and individual tertiary units
    b. Discharges measured at the main canal intake and tertiary unit intakes
    c. Determine for total command area, main system only and individual Water Users Associations
    d. Determine for individual service providers (government agency or Water Users Associations)
    e. For individual water users
    f. Periodic sampling at selected locations
2. May be seasonal or annual, depending on circumstances. If there is more than one season and there are marked differences between the seasons' cropping patterns and water availability it is preferable to consider each season separately
3. Costs for irrigation water delivery and drainage water removal may be kept separate or combined; it depends if there is a separate drainage authority.

Source: Burton et al, 2007

Table 16.12 Indicators used for assessing different performance criteria related to water delivery

Criteria	Performance indicator	Definition	Notes
Reliability	Relative Water Supply	Volume of irrigation water supply / Volume of irrigation water demand	Variation of the RWS at the main canal intake and at tertiary intakes during the season indicates the level of reliability of water supply and delivery
	Delivery Performance Ratio	Volume of irrigation water supplied / Target volume of irrigation water supply	Variation of the DPR at tertiary unit intakes during the season indicates the level of reliability water delivery
Adequacy	Relative Water Supply (RWS)	Volume of irrigation water supplied / Volume of irrigation water demand	Measured at main canal intake and each tertiary unit intake. Target value = 1.0, less than 1.0 indicates water shortage
	Delivery Performance Ratio (DPR)	Volume of irrigation water supplied / Target volume of irrigation water supply	Measured at main canal intake and each tertiary unit. Target value = 1.0. If there is a water shortage the target supply may be less than the actual irrigation water demand.
Timeliness	Dependability of Irrigation Interval	Actual irrigation interval / Planned/Required irrigation interval	The planned/required interval between irrigations is either that planned (such as in a planned irrigation rotation regime) or that dictated by the crop's soil moisture status.
	Timeliness of Irrigation Water Delivery	Actual date/time of irrigation water delivery / Planned/Required date/time of irrigation water delivery	Compares the actual date and time of delivery (planned in the rotation or requested by the farmer) compared to the actual delivery date and time.
Equity	Relative Water Supply	Volume of irrigation water supply / Volume of irrigation water demand	Variation of the RWS at tertiary intakes indicates degree of equity or inequity
	Delivery Performance Ratio	Volume of irrigation water supplied / Target volume of irrigation water supply	Variation of the RWS at tertiary intakes indicates degree of equity or inequity
Efficiency	Relative Water Supply	Volume of irrigation water supply / Volume of irrigation water demand	Comparison of the RWS at the main canal intake and the tertiary unit intakes indicates the level of losses
	Overall scheme efficiency	Volume of water needed by crop / Volume of water diverted/pumped from source	Useful indicator. Relatively easy to obtain a meaningful value. Estimate crop irrigation water demand at the field (using FAO CROPWAT programme, or similar) and measure actual discharge at main canal intake.
	Main system water delivery efficiency	Volume of water delivered (to tertiary unit) / Volume of water diverted/pumped from source	Measure discharges at main canal intake and offtakes to tertiary units. Value may change due to the seasons (wet/dry), with drainage inflow possible in wet season.
	Crop production per unit water supply	Total crop production / Volume of water diverted/pumped from source	As measure of efficiency use to determine change in production per unit of water diverted at source. Useful for monoculture schemes.
Productivity	Crop production per unit water delivered	Total crop production / Volume of water delivered (to tertiary unit or field)	Increasingly important indicator. Need to be careful where there is mixed cropping.
	Value of crop production per unit water delivered	Total value of crop production / Volume of water delivered (to tertiary unit or field)	Increasingly important indicator. Use the value of crop production where there is mixed cropping.
Cost effective-ness	ISF collected to GVP ratio	Total irrigation service fee (ISF) collected / Total gross value of production (GVP)	Assesses the cost of the ISF compared to the total gross value of production. Broad indicators only as other costs are involved.
	ISF to total crop input costs ratio	Irrigation service fee (ISF) due for the crop / Total input costs for the crop	Assesses the costs of the ISF as a fraction (or percentage) of the total input costs for planting, harvesting and marketing the crop. Often found to be in the range of 4-10% of total input costs where the ISF is set at adequate levels to recover sustainable MOM costs.

Source: Adapted from Bos et al, 2005 and Malano and Burton, 2001

16.7.1 On-farm level

At the on-farm level, performance assessment is focussed on water delivery from the tertiary unit intake to the farmers' field(s), and water application by the farmer to the crops in the field. In some cases, the performance assessment can be sub-divided into the water delivery function (often carried out by the water users association), and the water application function (generally carried out by the farmer). In these cases, the assessment will look separately at the performance of the WUA, and the performance of the farmer. Output from the field may be constrained by the performance of the farmer, or the WUA, or both, and might also be constrained by the water delivery pattern in the main system.

An example of a scoring system used for assessing the performance of Water Users Associations is presented in Table 16.13. The indicators are divided into categories covering institutional, financial and technical performance of the WUA. Scores are applied by the assessment team to each of the indicators based on the achievement against stated target values[34].

One of the most detailed guides for assessing irrigation performance at field level is by Merriam and Keller (1978). A subsequent publication under the FAO Irrigation and Drainage Paper series built on this work, and provided computer models to assist in the design and evaluation of surface irrigation methods (Walker, 1989). The performance indicators are relatively straightforward (Table 16.14), assessing the water actually applied against the water required in the root zone. Measurement and determination of the value of the indicators is, however, less straightforward.

Table 16.13 Measures of in-field performance for surface irrigation

Indicator	Definition
Application uniformity:	
- Christiansen coefficient (C_u)	100 (1.0 – Σx/mn) where x = the absolute deviation from the mean application, m, and n = the number of observations
- Distribution Uniformity (DU)	$\frac{\text{Average depth infiltrated in the lowest one quarter of the area}}{\text{Average depth of water infiltrated}}$
Application efficiency (E_a)	$\frac{\text{Volume of water added to the root zone}}{\text{Volume of water applied to the field}}$
Water requirement efficiency (E_r)	$\frac{\text{Volume of water added to root zone storage}}{\text{Potential soil moisture storage volume}}$
Deep percolation efficiency (DPR)	$\frac{\text{Volume of deep percolation}}{\text{Volume of water applied to the field}}$
Tailwater ratio (TWR)	$\frac{\text{Volume of runoff}}{\text{Volume of water applied to the field}}$

Source: Walker, 1989; Merriam and Keller, 1978.

[34] Note that some of these target values are specific to this situation (Albania), they should be reviewed and adapted for other situations. Where monetary units are used it is important that the target figures are updated annually to allow for inflation.

Table 16.14 Example of Key Indicators Used to Monitor Water Users Associations performance

Water Users Association Performance Indicators				
Indicator	**Definition**	**Value**	**Scoring**	**Score**
Formation				
Area transferred to WUA	Area transferred to WUA / Total gross area serviced by the system		2 = 100% 1 = 50-99% 0 = <50%	
Membership, Representation and Accountability				
WUA membership ratio	Total number of WUA members / Total number of irrigators in service area		2 = >50% 1 = 25-50% 0 = <25%	
Annual General Meetings	Annual General Meeting held		2 = Yes 0 = No	
Annual General Meeting attendance	Number of WUA members attending AGM / Total number of WUA members		2 = >50% 1 = 30-50% 0 = <30%	
Administrative Council meetings held	Number of meetings held during the year (January-December)		2 = >5 1 = 1-5 0 = 0	
Administrative Council elections	Number of elections for members of Administrative Council held in last 2 years		2 = Yes 0 = No	
Women members of Administrative Council	Number of women members of Administrative Council		2 = 1 or more 0 = None	
Area irrigated				
First irrigation crop area ratio (of total service area)	Total annual recorded (first) irrigation crop area / Total gross area serviced by the system		2 = >50% 1 = 30-50% 0 = <30%	
Crop audit correction factor	Reported area of first irrigation / Crop area measured from crop area audit survey		2 = >90% 1 = 75-90% 0 = <75%	
Financial				
Employment of Accountant	Accountant employed and duration of employment		2 = Yes, >4 months 1 = Yes, <4 months 0 = None	
ISF collection per hectare of service area	Total ISF collected / Total gross area serviced by the system * Adjusted to current values		2 = >1800* Lek/ha 1 = 1000-1800 Lek/ha 0 = <1000 Lek/ha	
ISF collection as percent of target	Total ISF collected / Target total annual Irrigation Service Fees		2 = >90% 1 = 60-90% 0 = <60%	
ISF collection per hectare irrigated	Total ISF collected / Total annual irrigated crop area * Adjusted to current values		2 = >2500* Lek/ha 1 = 1000-2500 Lek/ha 0 = <1000 Lek/ha	
Financial Audit of WUA	Level of approval of WUA financial affairs by independent auditors		2 = Accounts approved 1 = No audit undertaken 0 = Accounts qualified/rejected	
Operation				
Area managed by Water Masters	Total gross area serviced by the system / Number of Water Masters employed by WUA		2 = < 250 ha 1 = > 250 ha 0 = No Water Masters	
Degree of flow measurement	Level of flow measurement at the head of the system (either primary canal or secondary canals)		2 = Full water measurement record 1 = Some water measurement 0 = No measurement	
Maintenance				
Annual maintenance planning	Extent of annual maintenance planning, costing and implementation *Note: The inspection plan must be reviewed and scored by the PMU staff.*		2 = Inspection undertaken and detailed plan produced 1 = Maintenance plan produced without proper inspection 0 = No plan produced.	
Maintenance expenditure per unit of total service area	Maintenance cost / Total gross area serviced by the system * Adjusted to current values		2 = >1000* Lek/ha 1 = 500-1000 Lek/ha 0 = <500 Lek/ha	
Maintenance expenditure to revenue ratio	Maintenance expenditure / Gross revenue collected		2 = >70% 1 = 40-70% 0 = <40%	
Total Score	Sum of scores for performance indicators. Top scores indicate Water Users Association than need no further support.		2 = >32 1 = 20-32 0 = <20	

Notes: 1 US$ = 140 Lek (2002)
Source: Halcrow, 2002.

16.8 Benchmarking Performance

16.8.1 What is benchmarking?

Benchmarking originated in the corporate business sector as a means for companies to gauge, and subsequently improve, their performance relative to key competitors. By studying key competitors' outputs, and the processes used to achieve those outputs, many organisations have been able to adopt best management practices and enhance their own performance (Box 16.1). In some cases, organisations have done so well that they have, in turn, become the organisation that others use as a benchmark.

> **Box 16.1 Definition**
>
> Benchmarking can be defined as:
> *"A systematic process for securing continual improvement through comparison with relevant and achievable internal or external norms and standards"*
> *Source: (Malano and Burton, 2001):*

There are many reasons why organisations may be interested in the benchmarking activity. The private sector is primarily driven by a desire to improve return on investment or return to shareholders; in the public sector the aim is to improve the effectiveness and efficiency of the organisation and the level of service provision. In the irrigation and drainage sector, service providers are responding to a variety of drivers, including:

- Increasing competition for water, both within the irrigated agriculture sector, and from other sectors;
- Increasing demand on the irrigation sector to produce more food for growing populations. Coupled with the pressure on available water resources, this results in the "more crop per drop" initiative promoted by the International Water Management Institute (IWMI) and the Food and Agriculture Organisation (FAO);
- Growing pressure to effect cost savings whilst increasing the productivity and efficiency of resource use;
- Turnover and privatisation of irrigation and drainage schemes to water users, leading to more transparent and accountable (to users) management practices;
- Increasing interest by the wider community in productive and efficient water resource use and the protection of aquatic environments;
- Increasing need for accountability to both government and water users in respect of water resource use and price paid for water.

Different drivers will apply in different situations, it is important at the outset of a benchmarking programme to identify the key drivers that are forcing change within the irrigation and drainage sector.

Benchmarking is about moving from one level of performance to another (Figure 16.5). It is about changing the way in which systems are managed, and about raising the expectations of all parties as to the level of achievable performance. It is a change management process that requires identification of shortcomings, and then acceptance by key stakeholders of the need, and pathways for achieving the identified goals. Benchmarking is part of a strategic planning process which asks and answers such questions as: *"Where are we now?", "Where do we want to be?",* and *"How do we get there?"*

Benchmarking uses performance assessment procedures to identify levels of performance and will use MandE procedures to see how actions taken to close identified performance gaps are progressing.

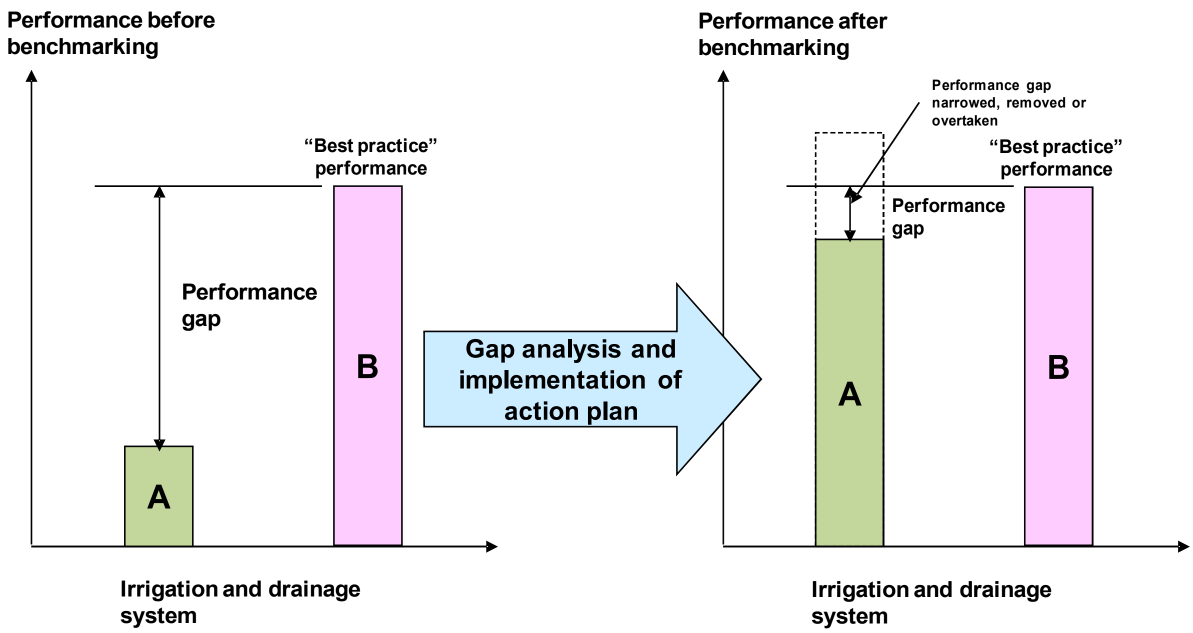

Figure 16.5 Benchmarking - comparative performance against best practice

16.8.2 Benchmarking stages

There are six key stages to benchmarking as shown in Figure 16.6:

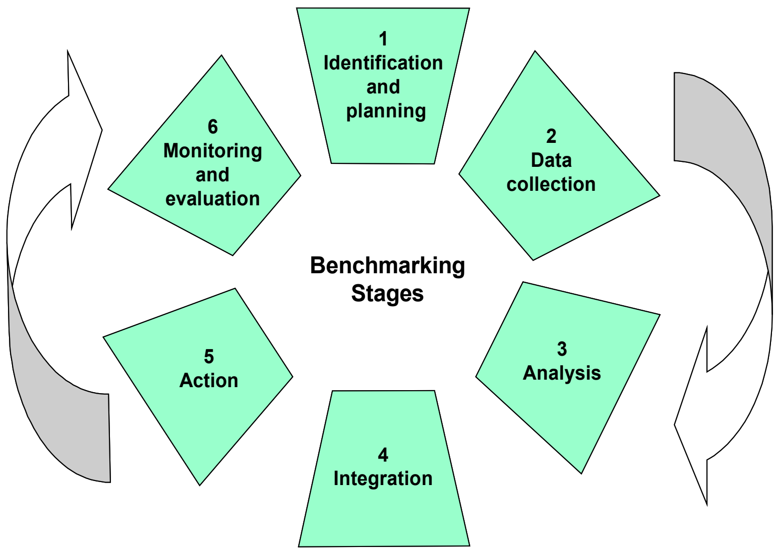

Figure 16.6 Benchmarking stages (Malano et al, 2004; Burton et al, 2005)

Stage 1 - Identification and planning

This stage identifies:

- The objectives and boundaries of the benchmarking programme
- Who the benchmarking is for
- The key processes
- The related performance indicators
- The data requirements.

It is important from the onslaught, to identify the objectives and boundaries of the benchmarking exercise. Is the objective to improve the efficiency and productivity of water alone, or irrigated farming as a whole? Is the benchmarking for the individual farmer, the service provider, the regulator or government? Having decided on these key issues, it is necessary to identify the processes involved within the identified boundaries and the related performance indicators and data needs.

Box 16.2 Descriptors for irrigation and drainage schemes

- Irrigable area
- Drained area
- Annual irrigated area
- Climate
- Water resources availability
- Water source
- Average annual rainfall
- Average annual reference crop potential evapotranspiration (ET_o)
- Method of water abstraction
- Water delivery infrastructure
- Type of water distribution
- Type of drainage
- Predominant on-farm irrigation method
- Major crops (with percentages of total irrigated area)
- Average farm size
- Type of irrigation system management
- Type of drainage system management

Source: Malano and Burton 2001.

A key part of the process is to identify successful organisations or irrigation and drainage systems with similar processes. Use of key descriptors (Box 16.2) enables similar systems and processes to be identified and enables meaningful comparison to take place. For example, the water use on a rice scheme will be significantly different from that on a cotton scheme.

In identifying the key processes (Figure 16.7) the following questions can be asked:

- What are the objectives of the enterprise?
- How is success measured? What are the outputs and desired outcomes?
- What are the processes that contribute to the attainment of these outputs and outcomes?
- How can these processes be measured?

It is also important to consider the impact of the key processes; the consequences of water abstraction from rivers, and pollution from agricultural drainage water are key considerations in this respect.

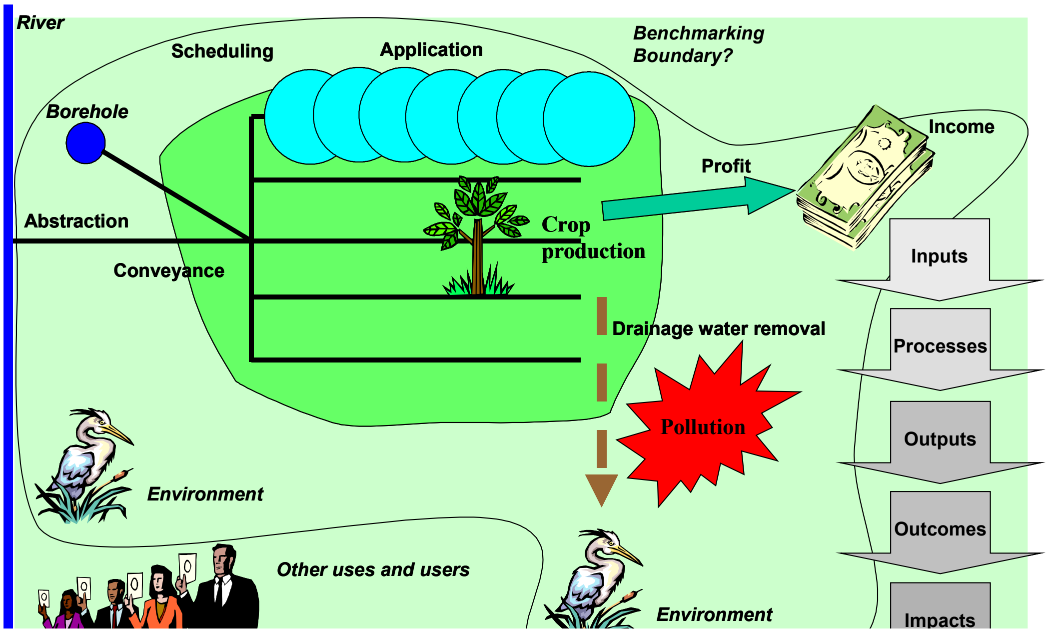

Figure 16.7 Identification of key processes

Possible key processes and indicators include:

- Irrigation water abstraction, conveyance and application
  - Volume of water abstracted for irrigation
  - Irrigation water abstraction per unit area
  - Relative irrigation water supply (abstraction/demand)
- Crop production
  - Irrigated area
  - Cropping intensity
  - Crop yield
  - Value of crop production per unit area
  - Value of crop production per unit water abstracted
- Business processes
  - Cash flow (investment vs returns)
  - Total annual income
  - Annual profit
- Environmental impact
  - Waste water quality (biological/chemical content)
  - Minimum flow levels in river

Stage 2 - Data collection

Data are collected and the value of performance indicators determined. The data collection programme will identify what data are to be collected, by whom, how frequently, where, and how accurate the data need to be. These data are for the system under review and the benchmark system(s), and will include input, process, output, outcome and impact performance indicators. Additional data may have to be collected for the benchmarking exercise beyond those already collected for day-to-day system management, operation, and maintenance.

Stage 3 - Analysis

Data are analysed and the performance gap(s) identified in the key processes (Figure 16.8). The analysis also identifies the cause of the performance gap, and the action(s) to close the gap. Recommendations are formulated from the options available, and then reviewed, and refined. Further data collection may be required for diagnostic analysis where additional information and understanding are required to identify root causes of the performance gap. This can be either the beneficial causes of the better performing system(s) or the constraining causes of the less well performing systems.

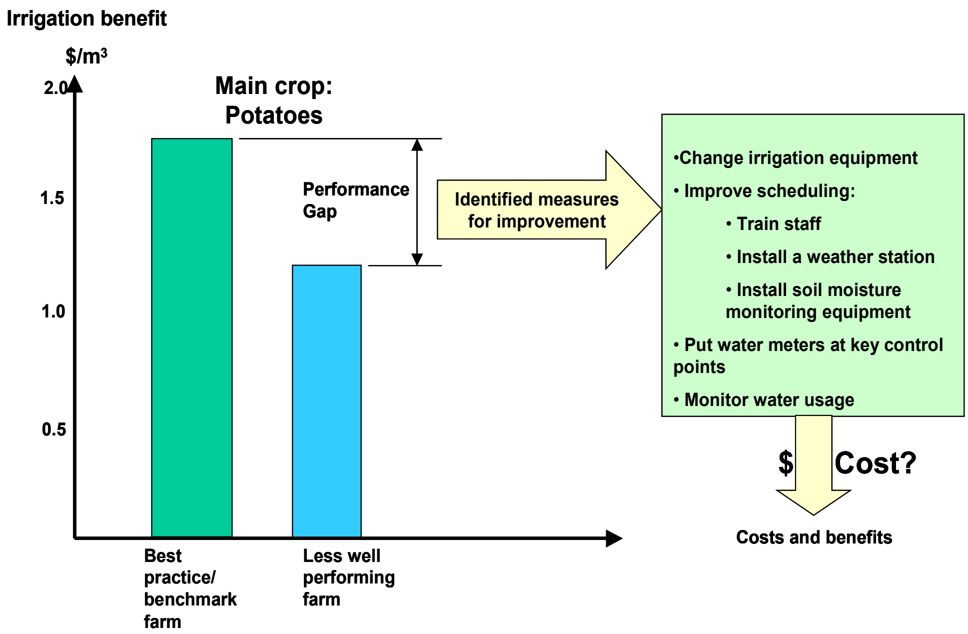

Figure 16.8 Identification and costing of measures to close the performance gap

Stage 4 Integration

The action plan developed from the analysis phase, must be integrated into the operational processes and procedures of the organisation, in order to bring about the desired change. It is crucial that those responsible for benchmarking have the power within the organisation to bring about change. Benchmarking programmes often fail at this stage, leaving those involved disillusioned with the process, and with the performance of the organisation.

The process of adapting the new processes and procedures is often termed as "internal marketing", and leads to the development of a sense of ownership and support by key personnel for the benchmarking process. Training is a key element of this process.

Stage 5 Action

Once acceptance of the new processes and procedures has been gained, they can be put into place to bring about the desired change. Leadership by senior management plays a key role in ensuring that the action plan is implemented successfully. Careful monitoring of the process is required at this stage to ensure that desired targets are being achieved, and that corrective action, where necessary, is taken in time.

Stage 6 Monitoring and evaluation

The success of benchmarking is marked by the continuing measurement of the organisation's performance, against the target norms and standards established during the analysis and integration stages. These targets are, however, changing over time, and continual updating and revision of the targets is necessary to maintain best practices and relative performance.

Figure 16.6 shows a cyclical programme of activities, though there may be a break of some years between one benchmarking exercise and another. During this period, the lessons learnt from the benchmarking programme are implemented, monitored and evaluated, with refinements being made as experience is gained with implementing the new processes and procedures. As mentioned previously, it has been the case with some organisations that they have so improved their performance that they have become the benchmark.

16.8.3 Example of benchmarking in Australia

The Australian National Committee of Irrigation and Drainage (ANCID) was one of the first organisations to implement a benchmarking programme in the irrigation and drainage sector. It began in 1998 with 33 schemes managed by irrigation service providers, and now has over 40 schemes in the programme, covering some 75% of the irrigation water provider business in Australia. The total business distributes 18,000 GL of water annually, providing water for some 2 million ha, and generating an annual business turnover of A$200 million (US$ 162 million) from a production base of some A$7 billion (US$ 5.7 billion) (Alexander and Potter, 2004). The crops grown include rice, maize, grape vines, cotton, sugar cane, pasture, citrus and vegetables.

The benchmarking programme used 65 performance indicators:

- System operation (12 No.)
- Business processes (25 No.)
- Financial management (14 No.)
- Environmental management (14 No.)

These indicators have been formulated to fit with the "triple bottom line" approach adopted by the industry, measuring performance in economic, environmental and social dimensions.

A key feature of the Australian benchmarking programme is the "three tier" reporting of data to protect commercial confidentiality. Tier 1 collects data on general irrigation water provision ("Who we are"), Tier 2 collects data on performance ("How we interact"), and Tier 3 collects data on confidential internal business performance benchmarking ("How we improve"). The data are collected each year using a standard questionnaire, each contributor indicating what data can and cannot be released. The data are analysed and the report made available to all contributors, with anonymous data presented for others to compare their performance with. If a contributor wishes to obtain more information on the confidential data they write to ANCID who forward their request on to the relevant contributor.

Figure 16.9 presents examples of the performance indicators used. As can be seen there is a wide range in the values of each of the indicators, this is due to individual differences between the systems (the crop types, method of irrigation, lined/unlined canals, etc.). This highlights the importance of using the system descriptors (Box 10.3) to categorise systems to enable comparison of like with like.

The achievements of the benchmarking programme in Australia are summarised as (Alexander and Potter, 2004):

- Allowing comparison of the performance of irrigation water providers relative to each other, both at the domestic and international level;
- Providing a more progressive and accountable image of the irrigation sector;
- Monitoring the uptake and impact of modern technology;
- Improvement in record keeping and performance analysis by service providers;

- Availability of objective and reliable data across a substantial part of the irrigation industry;
- Adoption by businesses of the ANCID benchmarking approach and formulation of their own inter-business benchmarking systems;
- More confident setting by business managers of targets for water delivery efficiency, operation, health and safety and resource use.

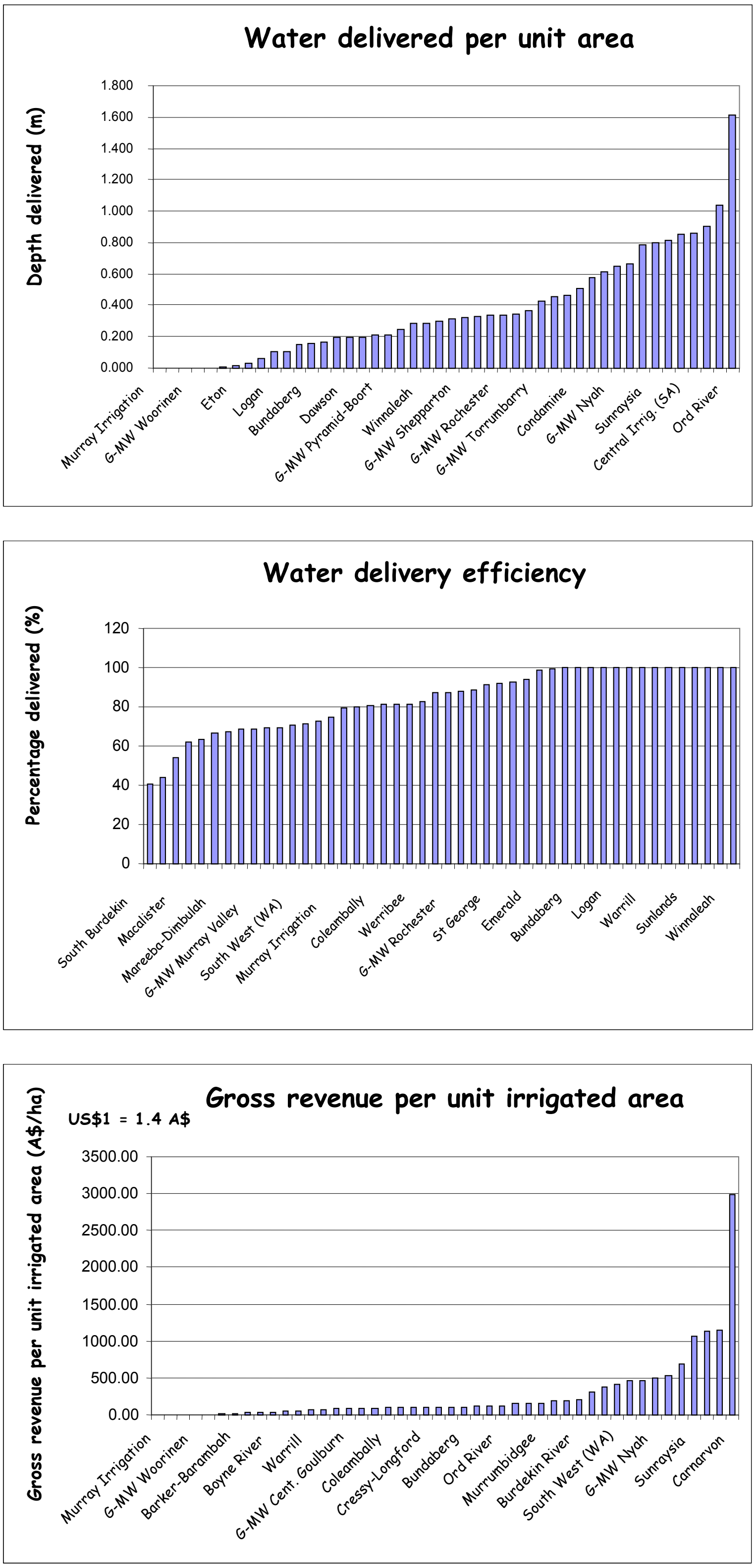

Figure 16.9 Examples of performance data plots from the Australian benchmarking programme

16.8.4 Example of benchmarking in Egypt

The following sections outline the procedures followed for implementing a benchmarking programme in Egypt in the irrigation and drainage sector between May 2004 to September 2005 (World Bank, 2005a; 2005b). Using the framework outlined above the key components of the benchmarking programme are outlined below:

i) Drivers of the benchmarking process
The key driver for benchmarking was the government's interest in institutional reform, to facilitate improvements in service delivery in the public sector. Part of this process was the need to measure and assess performance, and to raise the performance of less well performing systems.

ii) Objectives of benchmarking programme
The overall objective of the benchmarking programme was to sustain and increase agricultural production, whilst:

a. Improving the efficiency and productivity of water use, thus reducing the amount of water diverted for irrigation;
b. Minimising the cost of irrigation water delivery, and drainage water removal, consistent with providing reliable, timely and adequate irrigation water supplies and drainage water removal, and sustainable levels of system maintenance;
c. Sustaining soil fertility and the crop growth environment through effective drainage water removal and drainage system maintenance.

iii) Boundaries
The main processes to benchmark were identified as:

- Irrigation water delivery
- Drainage water removal
- Maintenance of infrastructure
- Environmental protection (through management of water quality).

The physical boundary was identified as the branch canals (Table 16.15, Figure 16.10). Branch Canals were chosen as suitable management units to benchmark, as:

- They are the lowest management unit run by the Irrigation Service;
- They are at the front end of service delivery to the client (the farmers);
- They are discrete management units, with measurable inputs, outputs and processes;
- Water delivery and drainage water removal processes in the Branch Canal command area are strongly influenced by how these processes are managed;
- Improvements in the management processes at this level can have a marked impact on crop production (output performance);
- Branch Canals in a given locality have similar basic features, allowing meaningful comparisons in performance;
- Data collection is feasible.

Table 16.15 Summary details of Branch Canals selected for benchmarking

Branch canal	Main canal	Governorate	District	Area (fed)
Besentway	**El-Mahmoudia**	**Beheira**	**Abu Homos**	**5500**
Zawyet Naim	**El-Mahmoudia**	**Beheira**	**Abu Homos**	**2350**
El-Baidda	**El-Mahmoudia**	**Beheira**	**Kafr El-Dawar**	**5600**
Daqalt	**Mit Yazaid**	**Kafr El Sheikh**	**Kafr El Sheikh**	**5200**
Sanhour El-Kadeema	**Mit Yazaid**	**Kafr El Sheikh**	**Desouk**	**5640**
Nesheel	**Mit Yazaid**	**Gharbia**	**West Mahala**	**3630**

iv) Programme
The programme established for benchmarking is summarised in Table 16.16.

Table 16.16 Programme for benchmarking performance in the I&D sector

No.	Activity	Example/Explanation
1.	Identify the objectives of the total process	• Increased agricultural production • Improved efficiency and productivity of water use • Minimising costs whilst maintaining adequate operation and maintenance standards • Sustain soil fertility and crop growth environment
2.	Identify the key **outputs**	• Irrigation water delivery • Drainage water removal • Crop production
3.	Identify performance indicators for measurement of outputs	• Crop production (in kg and LE) • Crop production (in kg and LE) per unit area • Crop production (in kg and LE) per unit water supply
4.	Collect data for output indicators and benchmark performance against comparable units	• Crop type, area, yield, input costs, market price, water supplied
5.	Quantify the gap in output performance	This may be between total crop production on branch canals, or between total crop production within mesqas
6.	Identify the key **processes** that contribute to the output performance	• Irrigation water delivery (reliability, timeliness and adequacy) • Drainage water removal (timeliness, adequacy, soil water quality) • Maintenance of IandD system
7.	Identify performance indicators for these key processes	• Seasonal relative irrigation water supply (supply/demand) • Seasonal irrigation water supply per unit area (m^3/ha) • Main system water delivery efficiency • Pumping hours and discharge per unit area for mesqas in the head , middle and tail reaches • Seasonal average depth to groundwater (m) • Seasonal soil and drainage water quality • Cost of irrigation water delivery and drainage water removal
8.	Collect data for these process indicators and assess and benchmark process performance against comparable processes	• Compare performance of the following indicators between branch canals and mesqas: ➢ Branch Canal water delivery efficiencies ➢ Relative irrigation water supply ➢ Mesqa pumping hours per unit area ➢ Irrigation water supplies per unit area ➢ Average depths to groundwater ➢ Groundwater and soil quality
9.	Identify the gaps in process performance	This may be between Branch Canals or between mesqas on a Branch Canal
10.	Identify the key factors that influence this performance, and propose remedies.	• Tail end mesqas, for example, may be getting less water per unit area than head-end mesqas. • Groundwater levels and soil salinity levels may be high, thus reducing crop yields
11.	Prepare an Action Plan for introduction and implementation of the proposals.	The Action Plan might require senior management to take action, and/or for WUA representatives, or others, to take action. Need to specify who is involved, what resources are required (time, people, finances), and the programme for implementation
12.	Gain acceptance of the Action Plan by key stakeholders	• Agreement from senior managers within irrigation and drainage agencies • Agreement between WUAs on a Branch Canal
13.	Implement the Action Plan	• Disseminate the details of the Action Plan widely to explain what is being done • Leadership will be required by key stakeholders to ensure Action Plan is implemented properly • Make step-by-step improvements
14.	Monitor implementation and degree of change effected	Monitoring data fed back to all key stakeholders, including senior management and to WUA representatives
15.	Evaluate implementation and degree of change on completion	Senior management and WUA representatives to assess the change in performance as a result of implementing the Action Plan.

v) Performance indicators

The indicators related to water delivery and removal, agricultural crop production and environmental protection for the four related processes are detailed in Table 16.10. There are 30 indicators identified, which require 24 sets of data.

vi) Data collection

Figure 16.10 shows the location of data collection within the branch canal command area. Table 16.18 summarises where the data was collected, by whom and with what frequency.

Table 16.10 Benchmarking processes and indicators

Objective/desired output	Output indicators	Process indicators	Definition
Agricultural crop production	Total seasonal area cropped per unit command area (Cropping intensity)		Total area cropped seasonally / Total command area of system
	Total seasonal crop production (Tonnes)		Total seasonal crop production by crop type within command area
	Total seasonal value of crop production (LE)		Total seasonal value of agricultural crop production received by producers
	Total seasonal crop production per unit command area (crop yield, kg/feddan)		Total seasonal crop production / Total command area of system
	Total seasonal value of crop production per unit command area (LE/feddan)		Total seasonal value of crop production / Total command area of system
	Total seasonal crop production per unit water supply (kg/m^3)		Total seasonal crop production / Total seasonal volume of irrigation water supply
	Total seasonal value of crop production per unit water consumed (LE/m^3)		Total seasonal value of crop production / Total seasonal volume of crop water demand (Etc)
	Total seasonal value of crop production per unit water supplied (LE/m^3)		Total seasonal value of crop production / Total seasonal volume of irrigation water supply
Processes			
Irrigation water delivery		Total seasonal volume of irrigation water supply (MCM)	Total seasonal volume of water diverted or pumped for irrigation (not including diversion of internal drainage)
		Seasonal irrigation water supply per unit command area (m^3/feddan)	Total seasonal volume of irrigation water supply / Total command area of system
		Main system water delivery efficiency	Total seasonal volume of irrigation water delivery / Total seasonal volume of irrigation water supply
		Seasonal relative irrigation water supply	Total seasonal volume of irrigation water supply / Total seasonal volume of crop water demand
		Water delivery capacity	Canal capacity at head of system / Peak irrigation water demand at head of system

Irrigation MOM finance and staffing levels		Total seasonal MOM cost for irrigation water delivery per unit command area (LE/feddan)	Total seasonal MOM cost for irrigation water delivery Total command area of system
		Total seasonal MOM cost for irrigation water delivery per unit irrigation water supply (LE/m^3)	Total seasonal MOM cost for irrigation water delivery Total seasonal volume of irrigation water supply
		Total seasonal maintenance expenditure for irrigation water delivery per unit command area (LE/feddan)	Total seasonal maintenance expenditure for irrigation water delivery Total command area of system
		Total seasonal maintenance expenditure fraction for irrigation water delivery (LE/feddan)	Total seasonal maintenance expenditure for irrigation water delivery Total seasonal MOM cost for irrigation water delivery
		Total cost per person employed on water delivery (LE/person)	Total cost of personnel engaged in irrigation water delivery Total number of personnel engaged in irrigation water delivery
		Command area per unit irrigation staff (feddan/person)	Total command area of system Total number of personnel engaged in irrigation water delivery
Drainage water removal		Average depth to groundwater (m)	Average seasonal depth to groundwater calculated from water table observations over the irrigation area
Drainage MOM finance and staffing levels		Total seasonal MOM cost for drainage water removal per unit command area (LE/feddan)	Total seasonal MOM cost for drainage water removal Total command area of system
		Total seasonal MOM cost for drainage water removal per unit drainage water removal (LE/m^3)	Total seasonal MOM cost for drainage water removal Total seasonal volume of drainage water removed
		Total seasonal maintenance expenditure for drainage water removal per unit command area (LE/feddan)	Total seasonal maintenance expenditure for drainage water removal Total command area of system
		Total seasonal maintenance expenditure fraction for drainage water removal (LE/feddan)	Total seasonal maintenance expenditure for drainage water removal Total seasonal MOM cost for drainage water removal
		Total cost per person employed on drainage water removal (LE/person)	Total cost of personnel engaged in drainage water removal Total number of personnel engaged in drainage water removal
		Command area per unit of drainage staff (feddan/person)	Total command area of system Total number of personnel engaged in drainage water removal
Environmental protection		Salinity of soil water (mmhos/cm)	Electrical conductivity of soil water
		Soil salinity (mmhos/cm)	Electrical conductivity of soil
		Salinity of water in open drain (mmhos/cm)	Electrical conductivity of water in open drains
		Drainage water quality: Biological (mg/litre)	Biological load of drainage water expressed as Biological Oxygen Demand (BOD)
		Drainage water quality: Chemical (mg/litre)	Chemical load of drainage water expressed as Chemical Oxygen Demand (COD)

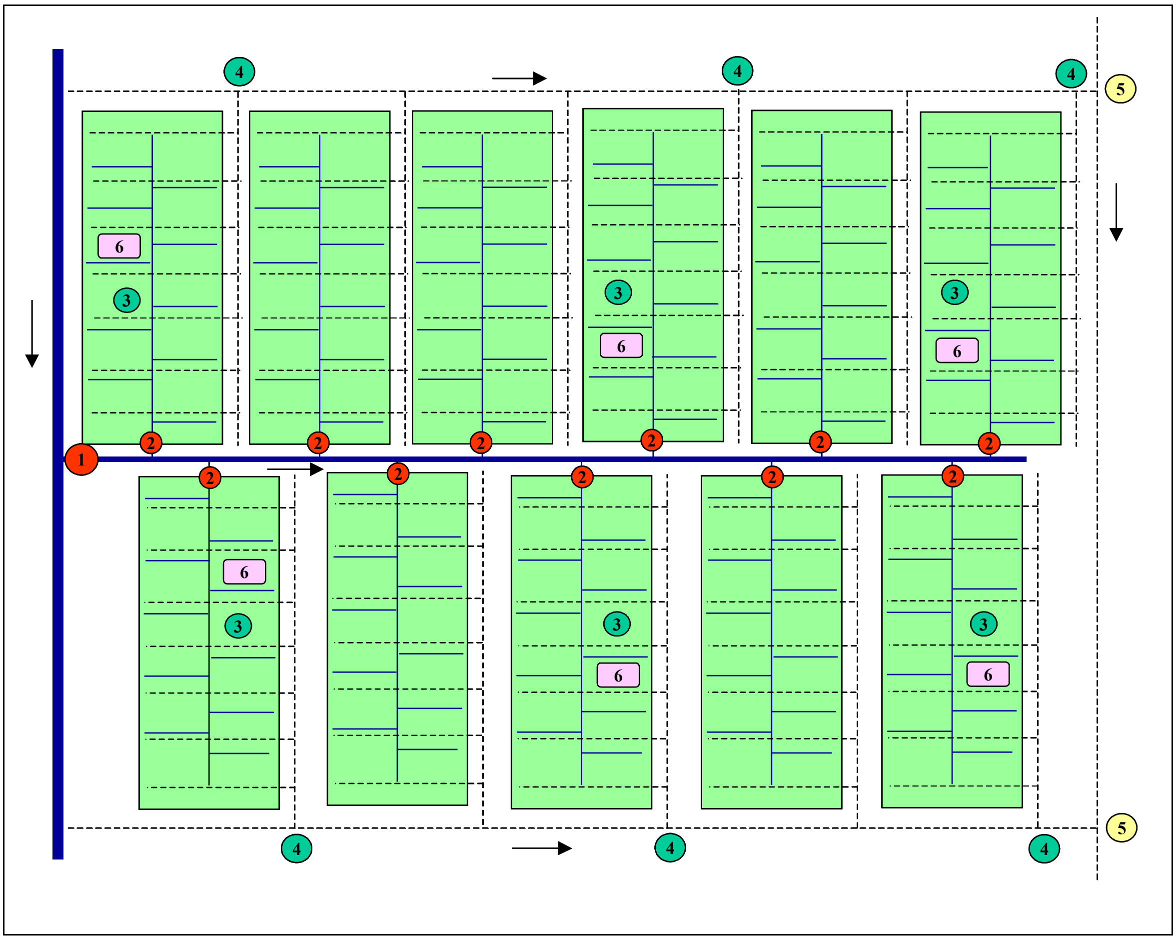

Figure 16.10 Location of data collection *(see Table 16.18 for further details)*

Table 16.12 Data requirements for benchmarking

Map loc-ation	Location	Data collected	Units	By whom collected	How collected	Frequency of collection	Period collected	Remarks
1	Branch canal intake	Discharge entering branch canal: • Flow depth • Gate opening • Discharge • Duration of flow	 m m m^3/s hrs, mins	Irrigation Service District staff IIS staff	Measurement	Daily	Season	Level data recorded daily by Irrigation Service staff. On two systems water level and gate opening data collected by WMRI under contract to IIP, using automatic water level recorders.
1	Branch canal intake	• Water quality	mmhos/cm	IIS staff	Measurement	Once per month	Season	Data regularly collected for two canals by WMRI
1a	Branch canal tail escape	Discharge leaving branch canal: • Flow depth • Discharge • Duration of flow	 m m^3/s hrs, mins	IIS staff	Measurement	Daily	Season	Data regularly collected for two canals by WMRI
2	Mesqa intake	Discharge delivered to mesqa: • Pumping hours • Pumping head (intake, delivery) • Fuel consumed	 hrs m litres	Pump operator	Measurement	Hourly	Season	Data collected by WUA for all mesqas for charging and cost calculation purposes
3	Selected mesqas (2 head, 2 middle, two tail)	Groundwater and soil data: • Depth to groundwater • Salinity of groundwater (EC) • Soil salinity at 40 cm depth	 m mmhos/cm mmhos/cm	EPADP staff		10-12 times per season Once/season	Season	12 piezometers installed in each branch canal command.
4	Selected mesqas (outfalls to selected mesqas 2 head, 2 middle, two tail)	Drainage water levels: • Number of days collector outlet submerged during season	m	Drainage service field staff	Measurement	Periodically	Season	EPADP field staff will monitor selected collector drain outfalls during the season and record the number of days they are submerged
5	Secondary drain outfall	Drainage water level and flow: • Drainage water level • Discharge	 m m^3/s	Drainage service field staff	Measurement	Daily (water level) Monthly	Season	WMRI are monitoring drainage water quality on a regular basis for two of the systems

		• Water quality (EC)	mmhos/cm	EPADP staff		(water quality)		
6	Selected mesqas along branch canal (10 head, 10 middle, 10 tail)	Command and crop areas: • Command area For a typical 10 ha sample area: • Crop type • Crop area • Crop duration • Crop production (bags) • Weight of bags (by crop type) • Crop market price • Cost of production	ha - ha days bags kgs LE LE	WUA IIS staff	Interviews with farmers. From agricultural cooperatives and Ministry of Agriculture	Once per season	Season	Simple crop data collection procedures need to be tested with WUAs to ascertain whether reliable crop data can be obtained for comparison between WUAs. These can be cross checked with data collected from other sources (crop cuttings by Ministry of Agriculture, data collected by agricultural cooperatives, etc.)
6	Selected mesqas along branch canal (10 head, 10 middle, 10 tail)	Water user satisfaction survey: • Satisfaction with water delivery • Satisfaction with drainage removal • Problems/constraints	- - -	IIS staff	Survey	2 times per season (mid-season and just after harvest)	Season	
7	District irrigation system	Irrigation Directorate MOM expenditure and staffing: • Total command area • Total annual MOM expenditure (salaries, office costs, operation, maintenance, etc.) • Total annual *planned* maintenance expenditure on canal systems • Total annual *actual* maintenance expenditure on canal systems • Total number of staff • Total cost of staff	ha LE LE No. LE	District Irrigation Engineer	Office records	Seasonally	Season	These data are available at the Directorate level. If possible they should be broken down to Branch Canal command areas, if possible. If not the Directorate level data can be used as they are representative of the average annual MOM expenditure and maintenance expenditure. Historic data can also be analysed for comparative purposes and trend analysis.
8	District drainage system	Drainage Directorate MOM expenditure and staffing: • Total command area	ha	District Drainage Engineer	Office records	Annually	Season	These data are available at the Directorate level. If possible they should be broken down to

		• Total annual MOM expenditure (salaries, office costs, operation, maintenance, etc.) • Total annual *planned* maintenance expenditure on drainage systems • Total annual *actual* maintenance expenditure on drainage systems • Total number of staff • Total cost of staff	LE LE No. LE					Branch Canal command areas, if possible. If not the Directorate level data can be used as they are representative of the average annual MOM expenditure and maintenance expenditure. Historic data can also be analysed for comparative purposes and trend analysis.
9	Branch canal and mesqas	Complaints: • Number of complaints • Nature of complaint • Action taken	No. - -	District Irrigation Engineer	Office records	Each season	Season	
9	Branch canal collector drain and secondary drains	Complaints: • Number of complaints • Nature of complaint • Action taken	No. - -	District Drainage Engineer	Office records	Each season	Season	

The results of the benchmarking programme are presented in Table 16.19. The table shows the indicators chosen and their values for the six branch canals. In the table, the “best” values have been highlighted in gold, whilst critical values are highlighted in red and areas for concern in yellow. Some of the indicators have not been given highlights, as these are indicative indicators and it is not possible to judge them one against another. This is the case for example with the Total Seasonal Crop Water Demand (at field), and the Total Seasonal Irrigation Water Supply per Unit Command Area, where the value depends on the cropping pattern within the Branch Canal – there is no one “best” figure here but the value does serve to show the relative scale of supply to, and demand by, each Branch Canal. The Seasonal Relative Irrigation Water Supply is then the prime indicator linking the supply and demand.

From this benchmarking study it was concluded that:

- The process was valuable in identifying the performance in key management units (the Branch Canal). Comparing the performance of similar management units enabled best practice and suitable performance targets to be identified, identified gaps in performance and provided (some) answers to the root causes of these performance gaps;
- Diagnostic analysis is a fundamental part of benchmarking. Analysis of the initial set of performance indicators led on to further data collection and interviews with water users to identify the root causes of poor levels of performance;
- The value of comparative performance assessment and establishing benchmarks for selected performance indicators cannot be over-emphasised; it provides real targets against which less well performing systems can be judged;
- Involvement of the water users in the process through discussions and questionnaires is an essential part of the benchmarking process;
- Due to the varying levels of performance across a range of indicators it is not always possible to identify one “best practice” system. In some cases the irrigation water delivery performance was good, but the drainage performance was poor, and vice versa. Nevertheless, individual, achievable targets are obtained to use as benchmarks;
- If benchmarking is to be adopted on a wider scale as a management tool there should be greater involvement with the system managers, the District Irrigation and Drainage Engineers in the process, and the water users. These key stakeholders must be engaged in the process at the outset, and the analysis and findings shared with them at all stages;
- In future developments a GIS would be a useful tool used to process, analyse and present the data.

Table 16.19 Summary performance table for irrigation and drainage – Egypt, Winter 2004-5

Description	Units	Branch Canal					
		Besentway	Zawiet Naim	El- Baidda	Daqalt	KadeemaSanhour El-	Nesheel
Irrigation							
Total seasonal value of crop production per unit command area	LE/feddan	2,676	2,684	**2,935**	2,419	2,730	2,886
Total seasonal value of crop production per unit water supply	LE/m^3	0.88	0.82	1.28	0.68	**3.23**	2.62
Total seasonal volume of crop water demand (at field)	m^3/feddan	2,236	2,352	2,226	1,828	2,155	2,326
Total seasonal irrigation water supply per unit command area	m^3/feddan	3,024	3,289	2,286	3,577	846	1,110
Total seasonal irrigation water delivery per unit command area	m^3/feddan	1,340	2,037	1,339	1,587	574	N/a
Main system water delivery efficiency	%	44%	**62%**	59%	44%	68%	N/a
Seasonal relative irrigation water supply	-	0.60	**0.87**	0.60	**0.87**	0.41	N/a
Total seasonal MOM costs for irrigation water delivery per unit command area	LE/feddan	18.43	18.43	18.43	20.00	20.00	20.00
Total seasonal MOM costs for irrigation water delivery per unit irrigation water supply	LE/m^3	0.012	0.011	0.016	0.011	0.031	0.036
Total seasonal maintenance expenditure for irrigation water delivery per unit command area	LE/feddan	13.47	13.47	13.47	10.00	10.00	10.00
Total annual maintenance expenditure fraction for irrigation water delivery	-	0.73	0.73	0.73	0.50	0.50	0.50
Total cost per person employed on water delivery	LE/person	3,902	3,902	3,902	3,750	3,750	3,750
Irrigation command area per unit staff	Feddan/ person	393	393	393	375	375	375
Head:Tail mesqa pumping hours ratio	-	1.06	1.03	N/a	0.66	0.88	N/a
Drainage							
Groundwater level (depth to)	m	0.80	0.58	0.82	0.75	0.58	0.95
Groundwater salinity	Mmhos/cm	2.2	3.0	2.1	2.0	3.2	6.1
Soil salinity	Mmhos/cm	0.8	0.7	1.1	2.8	3.9	3.5
Farmer questionnaire							
Irrigation problems:							
- Very severe	Counts	-	-	-	-	-	-
- Severe	Counts	-	-	-	-	1	3
- Mild	Counts	2	7	0	0	18	2
Drainage problems:							
- Severe	Counts	-	-	-	-	-	1
- Mild	Counts	-	-	-	5	-	3
- Little	Counts	-	1	-	14	1	2
Legend		Best		Critical		Area of	

		value		value		concern	

LE – Egyptian pounds 1 US$ = 5.78 LE

16.9 Monitoring and evaluation[35]

16.9.1 Purpose and definition

Monitoring and evaluation (M&E) are distinct but related activities, as can be seen from the definitions provided below (OECD, 2002; Casley and Kumar, 1987):

Monitoring is the continuous collection of data on specified indicators to assess for a development intervention (project, programme or policy), its *implementation* in relation to activity schedules and expenditure of allocated funds, and its *progress and achievements* in relation to its objectives.

Evaluation is the periodic assessment of the *design, implementation, outcomes and impact* of a development intervention. It should assess the relevance and achievement of objectives, implementation performance in terms of *effectiveness* and *efficiency*, and the *nature, distribution* and *sustainability* of impacts.

The linkage between monitoring and evaluation takes various forms:

- Monitoring can raise issues for evaluation, whilst evaluation results can indicate where new processes or activities need to be monitored;
- Monitoring and evaluation are used together by managers to identify and then diagnose problem areas;
- Monitoring and evaluation often use the same data, but use these data in different ways

Monitoring compares actual progress with that planned for a project, and provides managers and others with regular updates on the progress made towards the final outputs and outcomes of the project. Good monitoring is dependent on an effective management information system (MIS), the design and implementation of which is one of the first tasks when implementing a project.

Evaluation can take place either during project implementation or at the end. Project managers will need to evaluate the progress of a project and establish why targets are, or are not, being met. Formal evaluations may be required, such as are carried out by funding agencies, for mid-term or final reviews to establish project progress and achievements against the stated targets. Mid-term evaluations can be important in identifying problem areas and measures to address such problems in good time. Ex-post evaluations can be carried out some while after completion of the project in order to measure the full impacts of the project; in the case of an irrigation rehabilitation project for example this may be 2-3 years after completion of the physical works.

16.9.2 Definition of terms used in monitoring and evaluation

There are a number of terms used in M & E which have specific meanings, these are explained in Table 16.20 below:

[35] This section has been adapted from "A toolkit for monitoring and evaluation of agricultural water management projects" written by the author in association with Laurence Smith and Julienne Roux for the Agriculture and Rural Development Division in the World Bank.

Table 16.20 Terms used in M & E

Term	Explanation
Higher level development objectives:	The longer-term objective, change of state or improved situation to which achievement of the **project development objective(s)** is intended to contribute. Sometimes referred to as the higher level development goal.
Project development objective:	The combination of one or more project component **outcomes** which make up the physical, financial, institutional, social, environmental or other development changes which the project is designed and expected to achieve.
Outcomes:	The effects of project components in terms of observable change in performance, behaviour or status of resources.
Outputs:	The products, capital goods and services resulting from a development intervention and which are necessary for the achievement of **project component outcomes**.
Activities:	The actions taken by project implementers that deliver the **outputs** by using the **inputs** provided.
Inputs:	The human, and material resources financed by the project.

16.9.3 M & E Framework

There are two widely used frameworks for monitoring and evaluation (M&E):

- The Logical Framework, and
- The Results Framework.

These two frameworks are related but different in their focus. The logical framework is more focussed on M&E of project activities and outputs, the results framework is more focussed on outcomes and impacts.

Both the frameworks rely on the "causal chain", the hierarchy of links between inputs-activities-outputs-outcomes as shown in Figure 16.11 and 16.12. The funding of inputs (means) enable activities (ends) to be carried out, which in turn enables outputs to be achieved leading to attainment of desired outcomes and objectives. At all levels, there are "necessary conditions" which need to be satisfied, for example that there are sufficient skilled labour to convert the activities into the required outputs, or that other factors in the national economy enable the desired outputs of the project (e.g. rehabilitated and functioning irrigation and drainage system), to be converted into desired outcomes (e.g. increased crop production through improved water supply and other inputs), or objectives (e.g. improved livelihoods through selling of surplus crop production). Whilst the rehabilitation of the physical components of the irrigation and drainage system might be within the control of the project, the expected increases in crop production and farmer livelihoods are not, as these depend on resources and actions outside the control of the project. If at the project design stage key necessary conditions are not in place, then measures may be taken to include additional activities within the project which will satisfy these conditions (for example including a component to provide farm machinery where this is required but not available).

Figure 16.11 Logical hierarchy for project design

Means-ends chain	*equals*	Logical project design	*subject to*	Required conditions being in place
End		Higher level development objectives		
↑		↑		necessary conditions
end (means)		Project development objective(s)		
↑		↑		necessary conditions
end (means)		Project component outcomes		
↑		↑		necessary conditions
end (means)		Outputs		
↑		↑		necessary conditions
end (means)		Activities		
↑		↑		necessary conditions
Means		Inputs		

Thus:

- **IF** inputs are provided, **THEN** activities can take place;
- **IF** activities are successfully completed, **THEN** planned outputs should result;
- **IF** outputs are used as intended, **THEN** the project component outcomes should be realised;
- **IF** the outcomes are achieved, **THEN** the project development objective(s) (PDO) should be achieved; and
- **IF** the PDO is achieved then the expected contribution should be made to higher level developmental objectives.

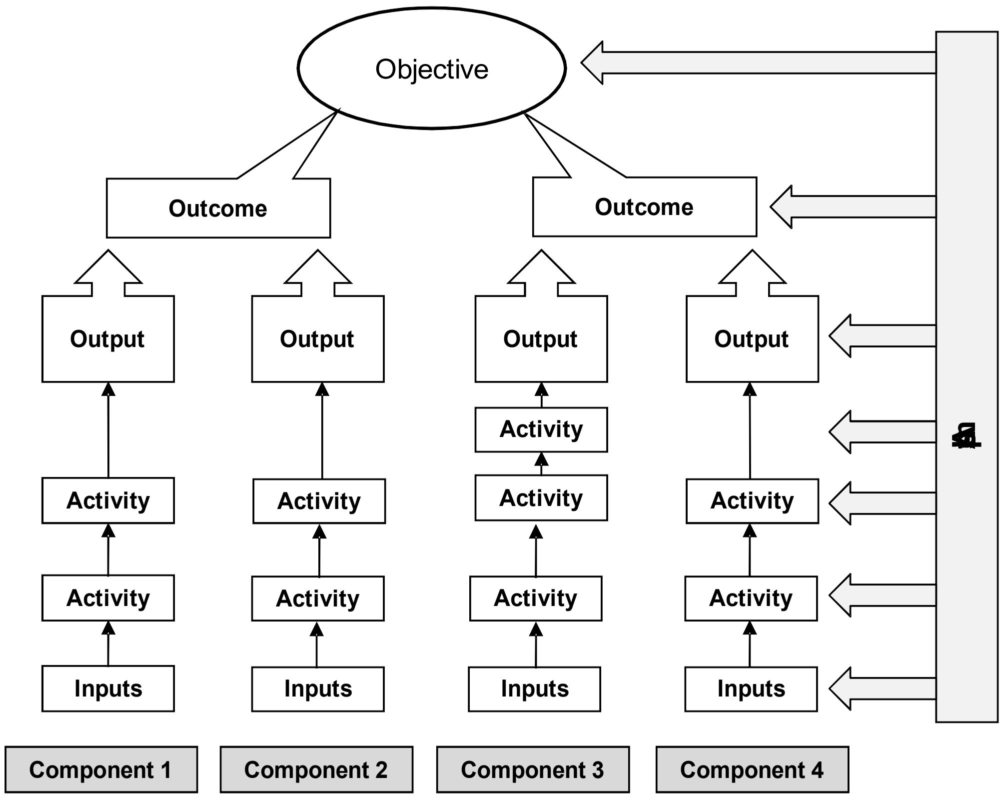

Figure 16.12 Logical hierarchy of multiple project components

Project monitoring can be usefully divided into results monitoring and implementation monitoring, as shown in Figure 16.13. Implementation monitoring is more suited to project managers who are focussed on achieving the required outputs from the various inputs and activities, whilst results monitoring is suited to senior project managers such as development agency task team leaders or supervising government personnel who are more interested in the long-term impacts of the project on society and the target beneficiaries.

For evaluation there are five commonly used criteria for assessing the performance of a project:

Impact The effect of the project on its wider environment, and its contribution to the wider policy, sector or Country Assistance Strategy development objectives.

Relevance The appropriateness of project objectives to the problems intended to be addressed, and to the physical and policy environment within which the project operates.

Effectiveness How well the outputs contributed to the achievement of project component outcomes and the overall Project Development Objective(s), and how well assumed external conditions contributed to project achievements.

Efficiency Whether project outputs have been achieved at reasonable cost, i.e. how well inputs have been used in activities and converted into outputs.

Sustainability The likelihood that benefits produced by the project continue to flow after external funding has ended.

The role of these five criteria in relation to the project logic and types of indicator are shown in the last two columns of Figure 16.13.

Project logic	Types of indicator	*Focus of M&E*	Characteristics	Evaluation criteria	
Objectives	**Impact**	*Results monitoring*	Long-term widespread improvement in society	Relevance and impact	Sustainability
Outcomes	**Outcome**		Intermediate effects for beneficiaries		
Outputs	**Output**	*Implementation monitoring*	Capital goods, products and services produced	Effectiveness and efficiency	
Activities	**Process**		Tasks undertaken to transform inputs to outputs		
Inputs	**Input**		Human and material resources		

Figure 16.13 A logical structure for project monitoring and evaluation

16.9.4 The Logical Framework

The logical framework was developed in the 1960s as a tool to improve project planning and implementation, and has been adopted by a number of development agencies including the World Bank as a project planning and management tool. At the core of the process is the *logical framework matrix* (Table 16.21) which is used to summarise the thinking that has occurred in the planning of the project based on problem and stakeholder analysis. The matrix comprises four columns and six rows which show:

- The hierarchy of project objectives (the causal chain or project logic);
- The indicators and sources of data to show how the project and its results will be monitored and evaluated;
- The assumptions and risks faced at each level showing the necessary external conditions that need to be satisfied if the next level up is to be achieved.

Table 16.21 Structure of the logical framework matrix

Project logic	**Indicators**	**Sources of verification**	**Assumptions and risks**
Higher level development objective(s): the longer-term objective(s), change of state or improved situation to which achievement of the **project development objective(s)** is intended to contribute.	How the objective(s) is to be measured; specified in terms of quality, quantity and timeframe.	Data sources that exist or that can be provided cost-effectively through the completion of surveys or other forms of data collection.	If the PDO(s) is achieved, what conditions beyond the project's direct control need to be in place to ensure the expected contribution to the higher level development objectives?
Project development objective(s) (PDO): the combination of one or more **project component outcomes** which make up the physical, financial, institutional, social, environmental or other development changes which the project is designed and expected to achieve.	How the PDO(s) is to be measured in terms of its quality, quantity and timeframe.	Details of data sources, how the data will be collected, by whom and when.	If the project component outcomes are achieved, what conditions beyond the project's direct control need to be in place to achieve the PDO(s)?
Project component outcomes: the effects of project components in terms of observable change in performance, behaviour or status of resources.	Specification of how each project component outcome is to be measured in terms of its quality, quantity and timeframe.	Details of data sources, how the data will be collected, by whom and when.	If the outputs are produced, what conditions beyond the project's direct control need to be in place to achieve the project component outcomes?
Outputs: the products, capital goods and services resulting from a development intervention and which are necessary for the achievement of **project component outcomes**.	How the outputs are to be measured in terms of their quality, quantity and timeframe .	Details of data sources, how the data will be collected, by whom and when.	If the activities are completed what conditions beyond the project's direct control need to be in place to produce the outputs?
Activities: the actions taken by project implementers that deliver the **outputs** by using the **inputs** provided. *(this level is not specified in some versions of LFA)*	*(a summary of the activities and resources may be included in this cell)*	(a *summary of the costs and budget may be provided in this cell)*	If the inputs are provided in full and on time what conditions beyond the project's direct control need to be in place to ensure completion of the activities?
Inputs: the human, and material resources financed by the project.			What preconditions are necessary for input provision and project commencement?

Note: The terminology used in the matrix may vary from that used by some organizations.

Source: Burton et al, 2007.

The stages followed in project planning contributing to the logical framework analysis are outlined in Box 16.3, whilst the sections below summarise the steps that are followed in formulating the logical framework matrix:

Box 16.3 Stages of project planning

Analysis stage
- Stakeholder analysis – identifying and characterising key stakeholders and assessing their capacity
- Problem analysis – identifying key problems, constraints and opportunities; determining cause and effect relationships
- Objective analysis – developing solutions from the identified problems; identifying means to ends relationships
- Strategy analysis – identifying different strategies to achieve solutions; selecting the most appropriate strategy

Planning stage
- Developing logical framework matrix – defining the project structure, testing its internal logic and risks, formulating measurable indicators of achievement
- Activity scheduling – determining the sequence and dependency of activities; estimating their duration and assigning responsibility
- Resource scheduling – from the activity schedule, developing input schedules and a budget.

Source: European Commission, 2004.

Identification of the Target Group: The first step is to identify the target group that the project intends to benefit, influence or change the behaviour of. The choice of the target group influences the approach of the project, the level of technology employed and the institutional and organisational arrangements that are required. Issues of status, access to resources, caste, ethnic status, gender, occupation/form of livelihood need to be considered and specified where appropriate.

Setting objectives: An objective states the desired state that is to be achieved through implementation of the project. There are three key objectives – the higher level development objective (or goal), the project development objective (PDO), and the intermediate objectives identified for each project outcome. The PDO needs to specify the changes that can be expected in the target group, organisation or location if the project is completed successfully, and must be a specific statement whose achievement can be verified. It is important that the PDO is realistic, and does not overstate the aims of the project (e.g. a rehabilitation project will improve irrigation water delivery and thereby agricultural production. Its impact on poverty eradication is less clear cut, though this might be the higher level objective in association with other interventions).

Identifying project outputs: Outputs are the result of the conversion of project inputs through the various project activities, and are a precondition for achievement of the project objectives. Importantly the achievement of the specified outputs is within the control of the project management, for which they should be held accountable. It is important that outputs are: identified; quantified (in terms of quantity, quality, time and place); realistic and feasible within the resources available. Often there are several outputs contributing to the achievement of the PDO, it is important that the causal chain linking these outputs to achievement of the PDO is clearly identified.

Defining activities*:* An activity converts project inputs into output(s) over a specified timeframe. Activities need to be carefully specified, such that their implementation progress can be measured and verified in terms of quantity, time and place. It should be clear who is responsible for implementation of each activity, and that all activities required to achieve a specified output are included in the project. Likewise not activity should be specified which does not contribute to a project output.

Identifying inputs: Inputs are the goods, personnel, services and other resources required for carrying out project activities. It is important to look at the planning stage at the inputs required for a project; these will include the purpose and type (personnel, equipment, materials, vehicles, etc.), the quantity required, duration, timing, cost and availability.

Assessing external conditions: assumptions and risks: The logical framework approach requires that proper attention is given to the environment within which the project is set, and the assumptions and risks related to implement the project within this environment. False assumptions or failure to adequately take account of inherent risks has led to the failure of far too many projects. By considering assumptions and risks at the project design stage, proper assessment can be made of their impact on the project outcome, and, where feasible, action taken to mitigate or remove them.

16.9.5 The Results Framework

The results framework is a simplified version of the logical framework with a focus on the Project Development Objective(s) (PDO) and the intermediate outcomes (results) expected from the implementation of each project component.

The results framework comprises:

- A statement of the project development objective, outcome indicators and the use of the indicators (Table 16.22);
- A table showing the intermediate results, results indicators and the use of these indicators in results monitoring (Table 16.23);
- For both the outcome indicators and intermediate results indicators a table showing the indicators, the target values for each year of the project, and details of the data collection and reporting to include the frequency of measurement and types of report, the data collection instruments and who is responsible for data collection (Table 16.24).

It is important that the project development objective is clear and concise, and that it identifies the change in status to be brought about by the project. In the agricultural water management sector, this change in status is usually expressed in terms of technology, agricultural productivity and value of agricultural production contributing to an increase in farmer income. The PDO should make clear:

- Who are the beneficiaries and where they are located;
- What problem will have been addressed by the project;
- What will the nature and scale of the change brought about by the project.

It is important that the PDO is expressed at the right level, that it is not set at too high a level (e.g. to reduce poverty in the rural sector) or too low a level (e.g. at activity level, such as to rehabilitate the physical infrastructure). The PDO should be realistic in terms of what it can achieve given its focus, resources, and duration, it should be measurable and should summarise the achievements of the project as a whole, rather than reiterate the individual component outputs or outcomes.

It should be clear from the results table how the individual components of the project link together to achieve the project development objective. This can be shown through the intermediate results and results indicators stated in Table 16.18, with an explanation of how the results indicators will be used to monitor the progress of the project. This table is supported by Table 16.19 which specifies the annual targets, data collection, reporting and dissemination arrangements which will enable management to track and report on project progress.

Selection and specification of the indicators at the various levels is important; it may take several iterations until they are finalised. These indicators should measure and summarise the results of the work carried out, and it should be clear by whom the data will be collected and where they will be reported.

Table 16.22 Example of a Results Framework with PDO and outcome indicators

PDO	Outcome Indicators	Use of Outcome Information
To improve irrigation and drainage service delivery and land and water management for the benefit of sustainable increases in productivity in irrigated agriculture.	Water distribution by main system service providers to WUAs in 80 percent of the irrigation area matches the irrigation water demands. Water distribution by WUAs to farmers in 80 percent of the rehabilitated systems closely matching the irrigation water demands. Collection rates by WUAs at least 80 percent of total assessed fees after establishment of WUAs. Number of farmers in sub-project areas more knowledgeable and applying recommended irrigated agricultural practices. Increase in average crop yields in sub-project areas after completion of rehabilitation works.	Given the small increase in yields assumed and many other contributing factors, it will be difficult to assess quantifiable livelihood benefits to farmers which are attributable to the project. Not attempted under the project. Given other contributory factors than water supply, yield increases may be difficult to both measure and attribute to the project. .

Source: World Bank

Table 16.23 Example of results table with intermediate results and indicators

Intermediate Results	Results Indicators	Use of Results Monitoring
Component 1: Rehabilitation and Modernization of Irrigation and Drainage Systems		
(1.1) Irrigators in 10 sub-project area command areas are provided with an improved, more manageable water supply through the rehabilitation of on- and off-farm works.	Number of systems with the ability to supply controlled and measured volumes of water to match water users' requests. Number of systems with ability to manage and control groundwater levels within acceptable ranges.	Results to be based on a system-by-system basis taking account of the phasing of the physical works.
Component 2: Sustainable Management, Operation and Maintenance of Irrigation and Drainage Systems		
(2.1) WUAs formed and functioning effectively in sub-project areas.	Number of WUA Support Units functioning effectively and providing adequate levels of training and support to WUAs. Number of WUAs setting ISF rates which match sustainable MOM needs based on asset management assessments.	Assess changing nature of Support Unit's role over the project period. A leading indicator of understanding and acceptance of need for sustainable MOM, in particular system maintenance.
(2.2) Main system service delivery functioning effectively.	Number of main system service providers who are following updated procedures for preparation of seasonal water allocation plans and achieving target values for actual against planned delivery. Number of WUAs receiving irrigation water supplies which closely match irrigation demands throughout the irrigation season Annual maintenance expenditure on main system at least 80 percent of levels of expenditure assessed by maintenance studies.	Assesses the ability to plan water allocations to closely match demand and thereby conserve water supplies. Assesses the capability to manage and operate the main system to provide reliable, timely, adequate and equitable water supply. Assesses the level of adoption of the maintenance studies, and the commitment to sustainable MOM for the main system.
(2.3) On-farm service delivery functioning effectively	90 percent of water users in each WUA receiving irrigation water supplies which match their requests.	Assesses the WUA management's capability in operating the system.
Component 3: Agricultural Development		
(3.1) Capacity of farmers and farm managers strengthened.	Number of farms who have successful and continued access to external technical and financial services through the Farmer Service Centers (FSC). Number of independent and well-functioning Farmer Service Centers.	Identify target group and establish regular monitoring program with statistically based sampling procedures. Need to prepare Level of Service Agreements for each FSC against which to measure performance.

Intermediate Results	Results Indicators	Use of Results Monitoring
(3.2) Farm mechanization improved.	Number of farmers requesting farm machinery. Number of WUAs requesting maintenance machinery.	

Source: World Bank

Table 16.24 Arrangements for results monitoring

		Target Values						Data Collection and Reporting		
Indicators	**Base-line**	**YR1**	**YR2**	**YR3**	**YR4**	**YR5**	**YR6**	**Frequency and Reports**	**Data Collection Instruments**	**Responsibility for Data Collection**
Outcome Indicators										
Water distribution by main system service providers to WUAs in 80 percent of the irrigation area in sub-project areas matching irrigation water demands (Number of systems and area in ha).	0	0	0	0	0	2 / 8,000	7 / 46,000	Annually from YR5 as rehabilitation completed. Quarterly and Annual Reports; Implementation Completion Report (YR6)	General project monitoring. Water demand and supply data from main system service providers. Baseline (YR1) and impact survey (YR6).	Project M&E team. WUA Support Unit staff. Main system service providers' staff. Baseline and impact study contractor.
Water distribution by WUAs to farmers in 80 percent of the rehabilitated systems closely matching the irrigation water demands (Number of WUAs and area in ha).	0	0	0	0	0	4 / 8,000	20 / 46,000	Annually from YR5 as rehabilitation completed. Quarterly and Annual Reports; Implementation Completion Report (YR6)	General project monitoring. WUA records. Baseline (YR1) and impact survey (YR6).	Project M&E team. WUA Support Unit staff. Baseline and impact study contractor.
Collection rates by WUAs at least 80 percent of total assessed fees (based on agreed annual budgets for MOM) after establishment of WUAs (Number of WUAs).	0	0	25	40	55	60	60	Annually from YR2 following formation of WUAs. Quarterly and Annual Reports; Implementation Completion Report (YR6)	General project monitoring. Baseline (YR1) and impact survey (YR6).	Project M&E team WUA Support Unit staff. Baseline and impact study contractor.
Number of farmers in sub-project areas more knowledgeable and applying recommended irrigated agricultural practices (Number of farmers).	0	0	0	1,500	2,000	3,000	5,000	Annually from YR3 onwards as farmer training completed. Quarterly and Annual Reports; Implementation Completion Report (YR6)	General project monitoring. Baseline (YR1) and impact survey (YR6).	Project M&E team WUA Support Unit staff. Baseline and impact study contractor.
Increase in crop yields in sub-project areas after completion of rehabilitation works (percentage).	0	0	0	0	0	10 (cotton) 15 (rice) 15 (wheat) 10 (beet)	20 (cotton) 30 (rice) 30 (wheat) 25 (beet)	Annually from YR5 as rehabilitation completed. Quarterly and Annual Reports; Implementation Completion Report (YR6)	General project monitoring. Baseline (YR1) and impact survey (YR6).	Project M&E team WUA Support Unit staff. Baseline and impact study contractor.

Source: World Bank

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.17 Project Implementation

17.1 Contract Documents

As contracting practice evolves, there is a growing awareness of the need to refine the basic documents on which it rests - the bidding documents and the contract itself - to ensure that the facility owner gets the work on time, to specification, and within budget; and the contractor realizes his expectation of profit, which is the primary reason for his being in business. Contractors who succeed have learned to manage risk and maximize profit taking, often in conditions of almost suicidal competition. However, for every contractor who succeeds, many are victims of poor planning, poor budgeting, and poor resource management. The failed contractors are a measure of the industry's inefficiency, and their failures affect the facility owner and his expectation of results from the economic asset that was under construction.

Worldwide, the industry has a poor reputation for coping with risk. On the contractor’s side, many excellent craftsmen and engineers attempt to become entrepreneurs, usually with little or no knowledge of good management practice; contractors' ranks are also graced by those lured by the "fast buck" which construction conjures up for many. On the owner's side, minimizing cost is often the absolute goal, regardless of market realities; impossibly low prices are accepted in bids and contracts of adhesion are foisted on contractors, often with clauses that give the owner all the rights and the contractor all the obligations. A fairer meeting of the minds will lead to a more harmonious contractual relationship and the achievement of the contract goals.

There are various types of contracts ranging from simple individual works, through complicated individual works to larger combined contracts that include a full range of construction works. Although the detailed specifications are simplified, in some cases the principles set out in the CMM will still apply. It is important therefore that the supervision team is made fully aware of the type and details of the specifications that apply to their particular contract, and that they are fully conversant with them. It would therefore be advisable that these are translated into local languages.

Community contributions are required in almost all projects, and in most cases this will relate to funds and not non-monetary contributions. However, in the case of the latter, it is essential that the division between the contractor and the community is clearly defined, and that the output of one is not dependant on the input of the other.

An important part of preparing contract documents is to ensure that all the parties fully understand their rights and obligations that arise from the contract. Language has often been a problem: contracts have tended to be written in tortuous legalese that has in itself been the cause of misinterpretations and disputes. There is a balance between the simplification of the language in which contracts are written and the clarification of the meanings, so that both parties can understand clearly the intent of the clauses. It is important that attempts to impose contractors to ruinously tight pricing are avoided, with attempts made to elicit bids that are closer to realistic prices, allowing adequate financial resources for construction, as well as a fair return for the contractor's efforts.

The quality of bidding and contract documents is critical to the successful implementation of the project. Risks must be property defined, and the remedies associated with those risks spelled out, in a way that enables the contractor to put his best bid forward. The owner must also be protected against irresponsibly low bids that later result in an excess of claims and controversy. Apart from insisting on clarity of the contract terms, the owner should also carry out a close scrutiny of the bidder's credentials and the responsiveness of his bid. These are the best safeguards for a timely completion of work within budget.

The International Federation of Consulting Engineers (FIDIC) has standardised much of the documentation and procedures required for all aspects of contract preparation, management, supervision and conflict resolution. The FIDIC web site (http://www.fidic.org) is a source of useful information, and should be consulted when preparing contract guides and standard documentation for a particular country. Countries like Ethiopia are well advanced in the use of contractors, but instead of standardising their contract procedures, specifications etc, they require each consultant to repeat the work (and be paid for) which was already accomplished. Each contract will have aspects that are specific to the location and types of work, but the vast majority will form or can be adopted from standard documents. In the following sections, the main aspect to be considered are presented, but contract management and supervision is a large subject in itself, and requires Engineers who are trained in the details to ensure that contract prepared are tight enough, to ensure that what has been intended actually gets built and that when problems arise, ambiguities are avoided.

17.2 Preparation of Tender Documents

The execution of construction works goes through three distinct stages. These are:

- Phase 1 - Design and Preparation of Tender Documents
- Phase 2 - Tendering up to and including the Award of Contract
- Phase 3 - Construction and Supervision

Standard documents and procedures for the first two Phases are well completed in many countries, and the processes are well understood by the main government organisations and engineering institutions. Phase 3 is in many cases not well completed, as staff is not well trained in the interpretation of specifications and also in monitoring closely the performance of contractors. They know well what is expected of them, but many will only do what they have to, and if they know that supervisors are not closely monitoring their work, they will cut corners. It is therefore essential that countries prepare standard Contract Management Manual and a Construction Supervision Manual. This will deal with all aspects to be encountered during implementation, and staff at all levels should be trained in the use of this manual to ensure good performance, quality control and sustainability of interventions.

The process up to award of contract includes the preparation of supporting data for the contract documents:

- Standard Designs and Drawings.
- Standard Bills of Quantities;
- Standard Specifications;
- Standard Contract Data;

17.3 Procurement

Qualification for contractors needs to be carefully undertaken to ensure that minimum standards for staff numbers and qualifications, basic survey and testing equipment and basic construction equipment are met. Many contractors say that they have all that is required to carry out a contract, but in practice they do not often have the relevant experience, staff and equipment. This affects the quality of delivery at the work sites. The bidding documents state the minimum requirements for the qualification of the contractors. These should be modified for the country concerned and the type and level of contract, but they must not be over modified to compromise on quality of the completed items. Sufficiently detailed requirements must be included to ensure that contractors have a minimum number of professional staff, experience of the works to be undertaken, surveying and field testing equipment and basic construction equipment. What they will not necessarily have is an understanding of the required level of workmanship that will be needed, and the level of quality control necessary to achieve this. If the contractors feel that they are not going to be closely supervised, then they will cut corners. The key aspect from the government view point will be the regular and thorough checking of the field work as it goes through its various stages. It is not an option to expect the contractor when given a drawing to build it as the designer intended with no site supervision.

17.4 Instructions to tenderers

The instructions to tenderers provide the basis upon which bids are submitted. These are comprehensive and cover the following but do not form part of the contract:

- General (Scope of Bid; Source of Funds; Eligible Bidders; Qualification of the Bidder; Site visit; other general details)
- Bidding Documents (Content; Clarification; Amendment;)
- Preparation of Bids (Bid Prices; Validity; format and signing)
- Submission of Bids (Sealing and Marking; Deadline for Submission; Modification and Withdrawal of Bids)
- Bid Opening and Evaluation (Process; Clarification; Examination of Bids and Determination of Responsiveness; Correction of Errors; Evaluation and Comparison of Bids)
- Award of Contract (Process; Notification; Advance Payment; Adjudicator; Corrupt or Fraudulent Practices)

17.5 Documents Forming a Contract

Once the evaluation of the tenders has been completed and a preferred contractor selected, formal contracts for the works are completed. The following documents form a contract:

- A letter of acceptance;
- A completed contract agreement and conditions of contract;
- The completed bid form;
- The completed bill of quantities or price schedule;
- The technical specifications and drawings;
- A programme for undertaking the works giving total contract duration, maintenance and defect period and estimated completion date.

Normally, the instructions to bidders and other parts of the bid submission do not form part of the contract but in the event of a dispute, they do provide the basis on which the contract was bid and awarded and this will be included as supporting documentation.

17.6 Conditions of contract

The Conditions of Contract have been divided into the following sections:

- A - General
- B - Time Control
- C - Quality Control
- D - Cost Control
- E - Finishing the Contract

The "*General*" section of the Conditions of Contract provides many clauses covering basic definitions and regulation of generally applicable procedures and formats. Those general items that require further specification are referred to in the Contract Data. A particularly important clause in this section is Clause covering Engineer's Decisions. This provides the authority to decide matters between the Employer and the Contractor *in the role representing the Employer*. This authority is given to the Engineer by the Employer in all matters, except in some cases where outside funders are involved with respect to adjusting the unit rates from changes in quantities, if thereby the initial Contract Prices is exceeded by more than 15% and termination of the Contract.

Other more specific clauses include:

- Start Date
- Intended Completion Date
- Appointment of Regional Manager
- Sub-Contracting
- Employer's Approval for certain communications having cost consequences or other
- significant consequences to the execution of the Contract
- Possession of Site
- Access to the Site
- Instructions
- Disputes

17.7 Transition from Instructions to Bidders to Conditions of Contract

Once both Contractor and Employer have signed the Contract Agreement, this constitutes a binding contract between the Employer and the Contractor. After this and the payment of the 10% advance payment in accordance with the Conditions of Contract, the transition from "Instructions to Bidders" to "Conditions of Contract" will have been completed and the latter will govern all subsequent activities. It should be noted that security or guarantee are normally required for an advance payment less than or equal to 10%. The Advance Payment may only be used for payment of Equipment, Plant, Materials and mobilization expenses required specifically for the execution of the Contract. The process is illustrated in Figure 17.1 below.

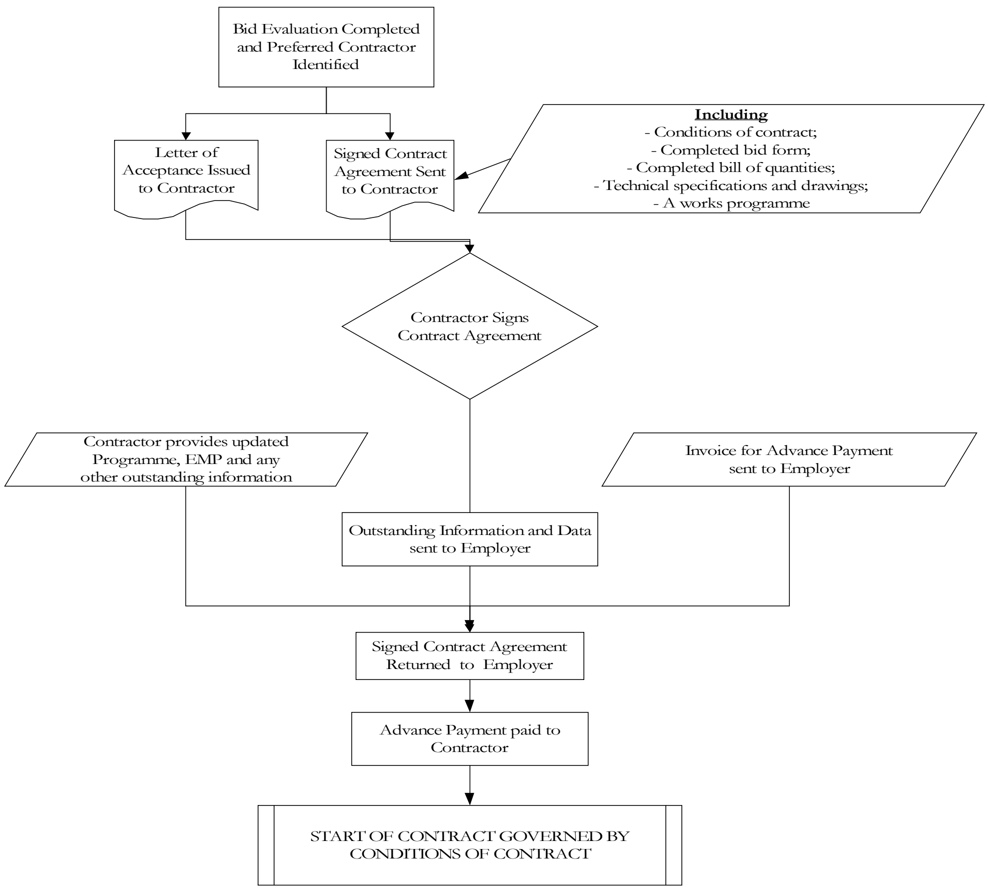

Figure 17.1 Processes from Bid Evaluation to Start of Contract

17.8 Contract Management

17.8.1 What is Construction Management?

Construction Management aims ensure that the stipulated processes are followed and that work proceeds on time, to specification and within budget allocated. To do this, it provides a set of mechanisms for monitoring progress of contract implementation to ensure that it abides by the stipulated standards, procedures and planned procurement timetable. The aim of the Construction Management Manual (CMM) is to develop a set of administrative procedures for the project that will assist the Employer (Government) in monitoring and addressing cost, schedule, technical design and procurement timetable. Any system of procedures has to be flexible to accommodate changes with time and to facilitate regular review and updating by the Employer (Government).

In most cases, Construction Management has two distinct components. The first is contract administration that ensures that the procedures required for contract management are clearly defined and systems put in place to monitor and control them. The second is the supervision of site construction works to ensure that works are built or rehabilitated as intended and that quality control is maintained. These two aspects should be dealt with separately in the Manual, mainly as many of the contract administration aspects are carried out by the different organisations. Site supervision often falls to Regional or District Offices but often executed by separate Construction supervision staff, who travel widely and comprise Construction Engineers and Construction supervisors.

17.8.2 The Need for Construction Management

Contract administration is a major function of the supervisory staff. The definitions in the General Conditions of Contract include the Engineer as someone authorized by the Administrator to represent him in the execution of the contract. Administrative functions which form part of the overall supervision activity include:

- Approval of sub-contractors
- Ensure that the contractors take reasonable measures to ensure the safety of their employees
- Ensure that the contractor uses sufficient and competent supervisory staff
- Receive and review bonds, insurances and other administrative documents required under the contract
- Receive and review the contractors' statistical reports

The largest component of the expenditure for irrigation rehabilitation or new construction is normally for civil works. During the project period, a number of construction contracts are normally undertaken and the organisation must therefore have the capacity to manage a wide range of scenarios at different stages of development, from planning to handover, and guidance in long term operation and maintenance. Effective construction supervision and management is essential to ensure the works are constructed to the required standards, on time and within budget. This work will require a substantial number of staff together with standard procedures for the administration. The tasks include the following:

- Contract administration;
- Review of contractors' submittals;
- Checking of locations, levels and dimensions of the works under construction;
- Inspection of construction activities;
- Coordination with water users during construction activities and ensuring timely delivery of any inputs;
- Inspection and testing of materials on site;
- Off-site laboratory testing where necessary and possible;

- Verification of progress payment requests;
- Determination of final quantities;
- Preparation of monthly progress reports;
- Maintenance of progress records and preparation of progress reports; and
- Contract acceptance and handover to the water users.

17.8.3 Responsibility for Construction Management

Staff assigned to work on project construction is responsible for the management of the construction contracts, often with the guidance and assistance of a Technical Assistance team comprising National and International staff. This TA team usually works as the Project Coordination Unit (PCU) within Government and is responsible for the technical and administrative aspects of the project. For the construction management, they are responsible for all technical and administrative aspects including ensuring timely payment of contractors in accordance with the documentation prepared by the construction management team. A separate Monitoring and Evaluation (M&E) Unit will need to be established and although they do not have any administrative responsibility for the management of construction works, they will be tasked with monitoring the effectiveness and efficiency of the overall construction supervision process as well as the impact of the works.

17.8.4 When Does Contract Management Start?

Construction Management overlaps with the tender process, as it ensures the smooth transition from the contractual arrangements to the physical starting of the construction works. A Construction Supervision task starts from the moment of Award of Contract and ends with the issuance of the Completion Certificate. Once the Contract is awarded, there are a number of requirements that are usually set out in the Instructions to Bidders, which the contractor must fulfil before the Conditions of Contract start to govern supervision tasks.

Once the tenders have been evaluated and the lowest evaluated bid has been established and approved by the Employer (and Donor if relevant), the Employer notifies the successful bidder by the Letter of Acceptance. The letter of acceptance states the Contract Price for which the contractor will construct the Works. The Letter of Acceptance does not form a binding contract between the Employer and the Contractor until both parties have signed the Contract Agreement and the Contractor has submitted additional information and guarantees that may be required under the particular contract.

The Contract Management Manual (CMM) needs to be produced to formalise the Contract Management of individual projects, and aims at providing the basis for supervision and control of all levels of projects to ensure that all Districts/ Regions follow the same procedures. It is also designed to provide the basis for a National standard rather than just a project standard, to encourage other agencies and projects working with the same authorities to adopt a unified approach. The CMM material will provide a guide for the Senior Technical staff and should be used as the basis for training. It is not intended as a field document to be carried by the site supervision staff as these staff will be working in the local language, and will work from field supervision manual/guidelines that will be developed out of this main CMM manual by their technical line managers. It must be treated as a dynamic process that develops as specific needs change.

There are different levels of staff and knowledge working on projects, and all need to take advantage of the material provided in the Contract Management Manual. The target group for the CMM is the line managers and higher level technical staff as it is their responsibility to provide suitable guidance and training material for the staff under their command/influence. These managers and advisors will therefore need to translate and adapt the contents to meet the specific needs of the lower level regional and field supervision staff and the size of contract to be supervised.

Documentation already in use will need to be integrated into any standards provided, as it is essential that all parts of one country are working in the same direction and providing the same quality of data and support documentation.

17.9 Construction Programming

During the preparation of the Bid, the Contractor is required to develop a tentative programme for the works that takes account of the Employers requirements and the contractors understanding of the conditions. This programme also indicates the deployment of resources, although in most cases these are not shown in detail at the tendering stage.

17.9.1 Programme to be submitted

Under the conditions of contract, the Contractor is required to prepare an updated program that acknowledges the **Start Date** and the **Intended Completion Date** that have been fixed in the signed agreement. The Contractor is also required to provide in writing, a general description of the arrangements and methods that he proposes to adopt for the execution of the Works for the Engineer's information, whenever requested to do so. This programme is aimed at providing the Engineer and the Employer with a simple tool by which to monitor the actual progress of the contract. The programme has to be submitted within the time specified in the Contract Data, and needs to show the sequence and a detailed work plan for the site activities and the duration of activities required to implement the contract. This includes the general methods, arrangements, order and timing for all the activities in the Works and will provide a basis for monitoring the Contractor's performance.

The programme is usually presented as a bar chart, but also includes general method statements, site plans and a cash flow forecast. The contracts manager should review the programme carefully before giving his approval. Anything can be put on a piece of paper, but the review should carefully analyse whether the activities in the programme are complete, whether they can start at the indicated times, whether the resources are sufficient to actually finish a task within the time presented, etc. Most importantly, the programme should show that the Works will be completed at the Intended Completion Date. A number of software packages that allow monitoring of project progress are available and MS-Project is one that is relatively easy to use. However, bar-charts and PERT-CPM diagrams can also be made manually and this may suit some smaller contractors. Any variations to the Works must be incorporated in the updated programmes that are required periodically under the conditions of contract. These programmes are submitted and discussed at the regular site and supervision meetings.

Some contractors engaged by projects on small works contracts may not be too familiar with how to prepare these and what to include. They may need some help in preparing the data in a format that is useful for the project to check and control. They should use the CPM techniques that relate to the timing of each activity to the other construction activities, and determine the impact of delays and unscheduled inputs on other related activities.

17.9.2 Programme Compilation

The data and information provided by the contractors in their tenders is generally based upon the bills of quantities presented in the contract documents, and geared towards payment for work carried out. In many cases, it is difficult to relate these to the actual works to be carried out as all quantities under the same heading, such as concrete class B, may be grouped together under the major sub-heading. Thus it is not possible to see when and in what sequence the particular individual work components will be carried out. When preparing the planned duration of the work items, these need to take account of:

- Estimates of the output from contractors' equipment;

- The build up of the contract unit rates (e.g. inputs such as labour and other materials that make up the unit rate);
- The scope and requirements of the work considering the quantities to be covered, the various locations and work sites and the time scales to be met;
- General estimates of work outputs.
- The total effective number of working days that will be possible (considering breaks for the rainy season/winter closure each year; periods of high river flows due to snow melt and upper catchment runoff that may limit access to river sites and will prevent work);
- The number and type of different locations that may up the contract site (for example, each individual structure on an irrigation or drainage canal should be shown on the programme with planned start and completion dates);
- Possible conflict between machinery owned by the contractor when they are to be deployed at several different locations under the same contract.

Certain basic work has to be completed before the main construction works can be started, and this includes the clearance and preparation of the site and the provision of coffer dams and diversion channels for river and irrigation canal works. Where large volumes of concrete, masonry or gabion works are to be undertaken, considerable quantities of material will need to be stock piled on site prior to the start of construction. It is important that when these programmes are checked, that assumed outputs are verified against actual equipment capacities and deployment and labour availability plans. It is essential that lists of labour, equipment and stockpiled material are thus constantly monitored.

17.10 Construction Supervision Activities

The main objective of all activities of the Construction Supervision Team is the successful completion of the Project:

- ❒ in accordance with the signed Contract paying particular attention to specifications and design details;
- ❒ within the contractual Time for Completion (as specified in the contractors programme);
- ❒ Within the budget of the Project (including the WB provisions for price and physical contingencies).

On a difficult and involved project of prolonged duration this requires a well structured supervisory organisation consisting of sufficient highly qualified and suitably trained/experienced technical and administrative staff to monitor the works and collect, process, file and maintain the large amount of information required to achieve the above objectives.

The main activities of the supervisory body to achieve these objectives comprise the following:

- to approve the Contractors Method of Work;
- to monitor Contractor's progress to maintain the Programme of the Works;
- to check and verify the compliance of the Works with the Contract Specifications and Drawings;
- to measure completed parts of the Works and to check and verify Contractor's applications for progress payment;
- to conduct checks, surveys and inspections for the acceptance of the Works;
- to collect all necessary information that may be required to refuse any improper claim of the Contractor for extension of time and for extra payment.

In order to facilitate the difficult and complicated tasks of the supervisory organisation, various check lists, forms and procedures need to be prepared including the following:

- an Organization Chart of a form which is specific for the Project showing responsibility levels of those involved;
- detailed task description, outlining the specific tasks and responsibilities of individual team members;
- a reporting system including examples of standard report forms to be used;
- supervision manuals for various parts of the Works.

17.10.1 Construction Supervision Functions

For the fulfilment of the tasks of construction supervision, two types of aides are required to assist the supervising organisation. These comprise:

a) **Standard Forms** that are required for the communication between the Engineer and the Contractor. These will form part of the Administration of the Contract.

b) **Site Check Forms and Flow Charts** to assist the site supervisors and technical staff to ensure that they have covered all of their tasks adequately and that they have remembered to check all relevant details.

17.10.2 Administration of Construction Activities

Construction supervision involves the administration of the construction work to ensure that it is undertaken in an efficient and economical manner consistent with the overall objectives of the project. Administrative functions include ensuring that construction activities being undertaken by different parties are coordinated and that possible conflicts are identified and resolved. A further related function is to ensure that obligations of the employer, such as provision of access and right of way, are fulfilled. However, supervision staff should not be directly involved in such activities, except to coordinate with the employer, as represented by the project management office.

17.10.3 Control of Quality

Control of quality is one of the major functions of construction supervision, and is a key activity that will ensure that the finished product will perform as expected. This activity includes checking of position, elevation and dimensions, checking and approval of construction materials, reviewing and approving construction methods, watching over construction activities and workmanship and testing and checking of the finished product. Overall quality control is therefore a fundamental part of the supervision process, for which testing is a supporting and subsidiary activity.

17.10.4 Conformance to Specifications

To effectively check Contractor's compliance with the Contract Specifications, it is imperative that all staff are fully familiar with all conditions and specifications related to their part of the Project (Technical Specifications and Bills of Quantities). To facilitate the use of the CMM manuals and the related Contract documents, all these documents are translated by an Engineer into the local language used by site supervision staff.

At the first level, the checking will be the duty of the site Construction Supervisors who act under the responsibility of and in accordance with instructions given by the Construction Engineers which are passed down from the Regional/District Managers. Using the standard forms provided in the manual, they will report their findings to their respective Construction Engineer who will take appropriate measures if any improper work is found. After referral to the Regional/District Manager, this will take the form of a written Instruction which is issued by the Regional Engineer to the Contractor. This clearly states the nature of the deviation and instructs him to remove and re-execute any work not in accordance with the Specifications within the time limit which should be stated in the Instructions. It must be remembered that the role of the Construction Supervisor is to test and examine any materials to be used for workmanship employed in connection with the Works. He has no authority to relieve the Contractor of any of his duties or obligations neither under the Contract nor to order any work involving delay or any extra payment by the Employer or to make any variation of or in the Works. His/her assignment is to draw the Contractors attention to errors that arise and if no action is taken to refer these to the responsible Engineer.

17.10.5 Construction Materials

The checking and approving of construction materials for use in the works is a fundamental part of the supervision process. Requirements for materials are normally set out in the standard specifications, but these often refer in turn to other local or international standards. Copies of all standards referred to must therefore be available for reference. It is important to agree on the sources and types of material that the contractors will use prior to the start of works. Procedures for obtaining, using and placement of these materials must also be agreed.

17.10.6 Measurement of Work

Unless the work is a lump sum fixed price contract, for which the price to be paid has been agreed in advance, then it is necessary to measure and record the actual work which has been carried out, in order to facilitate payment under the contract. Measurement does not need to be a continuous activity, and can be undertaken to coincide with certain stages of construction after which the measurement will not be feasible. Measurement of quantities should be determined through the difference between basic sets of data, not the accumulation of reported daily accomplishment.

17.11 Contract Measurement and Variations

Final acceptance and approval of works by all parties is a critical aspect of the rehabilitation process. At local level it is recommended that representatives from the benefiting/contributing communities are included in the training of field supervisors. This will ensure that they understand the need for quality control and the aspects that need to be examined and regularly checked. It will also enable the beneficiaries to raise points that they are concerned about during construction, before the works are completed and when there is still time to make adjustments and improvements. By the time completion is reached, all concerned should be both familiar with the works and also the problems experienced on a particular site involving the relevant contractor. A number of issues should be considered when preparing contract supervision so that staff are fully equipped and trained to undertake the work:

- Many staff are well versed in the theories of quality of materials and construction, but few have a real understanding of the need for controlling this in the field and how to do this;
- Staffs at HQ level are often aware of the generality of specifications, but many will not be completely familiar with the details;
- The same staff do not often relate specification details to work quality in the field although they will be familiar with the documents;
- Quality control at field level is often very weak as staff do not have testing equipment or know how to carry it out at field level;
- Initial setting out and checking of TBMs is often not done systematically and the use of profile boards, boning rods and other simple tools are not utilised;
- Contractors do not mobilise a minimum of construction equipment to site;
- Supervision staff provided by both Contractors and projects at site level are of too low a standard.

It is essential that minimum and basic levels of testing and quality control are included. This should be coupled with a detailed programme of field level training (both formal and on-the-job) that targets quality delivery at field level and that provides a support of staff and mechanisms to deliver this. This must focus on all staff levels and link the input to output delivery at each level. The biggest single challenge is the adaptation of office produced designs to field levels and conditions and the subsequent adjustment of designs and design details to meet these field conditions.

17.11.1 Quality Management

The sustainability of interventions rests on ensuring that the works are built according to the technical specifications and designs set out in the contract documents. There are some aspects that are dealt with on site - the detailed inspection aspects - and other aspects that relate to contract administration, and these are dealt with in the Engineer’s office. These utilise the reports and data from the field and then convert them into formal documents that are transmitted to the contractor.

The basis for assessing the quality of the works is the Technical Specifications and the contractors’ interpretation of the same. Project specifications are normally developed from International Standards (FIDIC) and are unambiguous, specifying the testing norms to which materials or works must comply. They are linked in with standard bills of quantities and drawings, and assume that the contractor knows what is required and has shown that they have competence in performing similar works. Much rests with the capacity and experience of the contractor’s site staff and the checks and balances carried out by the supervision team. Should problems arise, then the Construction Engineers and Construction supervisors will report on them to the **Engineer** who will take the appropriate action.

17.11.2 Variation Orders

In the execution of the civil works contracts, it will be necessary for the Engineer to issue a number of variation orders to modify the works. This may cover the form, quality or quantity of the Works or any part thereof and is in accordance with the Conditions of Contract. These variation orders can cause significant cost overruns of the contract price if they are not closely controlled and monitored. An approval procedure for the Variation Orders needs to be established and if funds required exceed existing approvals, they will automatically trigger an application for additional funds to be available for the contract payments.

Variation Orders **must** be issued when Site Instructions may lead to Omission or Addition of Payments in relation to the original estimated quantities of the Bill of Quantities. This will be when:

- New items and new agreed rates have to be introduced;
- Existing items of the Bill of Quantities can be omitted;
- Payments shall be made for which Provisional Sums have been allocated;
- Payments shall be made against daily rates (if allowed under the contract);
- Variations in constructions shall be made, for which existing items (with existing rates) can be applied.

Variation Orders are the means by which the Engineer changes the extent or nature or programme of the works. They are a formal instruction to the contractor that invariably has a cost implication. Variation Orders are usually presented with a particular bill of quantities that shows the cost of the work to be omitted from and the cost of work to be added to the final contract price. Therefore the Variation Order contains an estimate of the net effect on the contract price and the anticipated effect on the time for the completion of the contract.

Variations may require the Contractor to any of the following:

- Increase or decrease the quantity of any work included in the Contract;
- Omit any such work (but not if the omitted work is to be carried out by the Employer or by another contractor);

- Change the character or quality or kind of any such work;
- Change the levels, lines, position and dimensions of any part of the Works;
- Execute additional work of any kind necessary for the completion of the Works;
- Change specified sequence or timing of construction of any part of Works.

If the Engineer intends to make modifications to the designs, he should always do this taking into consideration the original design criteria. Provided that where the issue of an instruction to vary the Works is necessitated by some default of or breach of contract by the Contractor or for which he is responsible, any additional cost attributable to such default will be borne by the Contractor. Variations should only be calculated on standard Measurement Sheets that detail the calculation of quantities and amounts of all Variation Orders. They must always indicate whether the Variation has any effect on the time allowed for the performance of the Contract or a change in contract price. The result of these calculations is then applied in the Payment Certificates. If the Contract does not contain any rates or prices applicable to the varied work, the Engineer may request the Contractor to submit a quotation, within 7 days, in the form of new rates for the relevant items of work, for carrying out the Variation. Should the Engineer consider that the Contractor's quotation for the Variation is not reasonable, he may order the Variation and change the Contract Price based on his own forecast of the effects of the Variation on the Contractor's costs.

17.12 Completion

Depending on the type and size of the contract, there are two categories of Completion:

- Sections of the Works
- Whole Works

Completion should not be confused with completion of all contractual obligations at the end of the Defects Liability Period. The issue of completion certificates precedes that of the Defect Liability Certificate as on receipt of the completion certificate, the contract enters the Defect Liability period.

17.12.1 Certificate of Completion

When the whole of the Works have been substantially completed and have satisfactorily passed any Tests on Completion prescribed by the Contract, the Contractor may give a notice to that effect to the Engineer, with a copy to the Employer, accompanied by a written undertaking to finish with due expedition any outstanding work during the Defects Liability Period. Such notice and undertaking shall be deemed to be a request by the Contractor for the Engineer to issue a **Certificate of Completion** in respect of the Works. The Engineer shall, within 21 days of the date of delivery of such notice, either issue to the Contractor, with a copy to the Employer, a **Certificate of Completion**, stating the date on which, in his opinion, the Works were substantially completed in accordance with the Contract, or give instructions in writing to the Contractor specifying all the work which, in the Engineer's opinion, is required to be done by the Contractor before the issue of such Certificate. The Engineer shall also notify the Contractor of any defects in the Works affecting substantial completion that may appear after such instructions and before completion of the Works specified therein. The Contractor shall be entitled to receive such **Certificate of Completion** within 21 days of completion, to the satisfaction of the Engineer, of the Works so specified and remedying any defects so notified.

The Engineer will decide whether of not the Works have been completed. He may consider that the bulk of the work has in fact been finished, but there are a number of issues and remaining works that either derive from defects or could be reasonably dealt with during the Defects Liability Period. An integral part of this Certificate is thus the *List of Defects*. This list normally is the result of an inspection of the relevant Section of the Works performed jointly by representatives of the Employer, the Engineer, the Contractor and often a representative from the beneficiaries. The objective is to ascertain whether the relevant Works have indeed been completed and if so whether still any Defects

Key Reference: *Irrigation Manual, Module 5, Irrigation Pumping Plant, Developed by Andreas P. SAVVA and Karen FRENKEN, Water Resources Development and Management Officers, FAO Sub-Regional Office for East and Southern Africa, Harare, 2002.*

The Water Team of FAO's Sub-regional Office for East and Southern Africa in Harare, Zimbabwe, has developed an Irrigational Manual for irrigation practitioners, resulting from several years of field work and training of irrigation engineers in the sub-region. It deals with the planning, development, monitoring and evaluation of irrigated agriculture with farmer participation. It consist of 14 Modules, regrouped in five volumes (Volume 1: Modules 1-6; Volume 2: Module 7; Volume 3: Module 8; Volume 4: Module 9; Volume 5: Modules 10-14), with an emphasis on engineering, agronomic and economic aspects of smallholder irrigation, but it also introduces the irrigation engineers to social, health and environmental aspects of irrigation development, thus providing a bridge between the various disciplines involved in irrigation development. For on-line reading, click one of the following:

Module: 5,

http://www.fao.org/landandwater/training.stm#irrigman

need to be corrected by the Contractor during the Defects Liability Period of the Works. In any case the Contractor shall provide an undertaking that he will correct the Defects with due expedition.

This second part of the manual deals specifically with the interpretation of the contract documents in the realization of the works. The duties of all those involved in supervising the construction works and administering PROJECTS contracts are set out in Part A of the Manual. This Part B of the Manual is intended to function as a guide for all site supervision staff on how PROJECTS construction contracts will be supervised in the field and monitored. It draws upon the binding contract documents (explained in Part A, Section 3) and should therefore be read in conjunction with the relevant contract documents for the scheme/works under construction.

17.13 References

FIDIC Contracts and Agreements. http://www1.fidic.org/resources/contracts/ FIDIC supplies its contracts and agreements as collection that can be downloaded, or received on a CD or by email. FIDIC has long been renowned for its standard forms of contract for use between employers and contractors on international construction projects, in particular:

- Conditions of Contract for Works of Civil Engineering Construction: The Red Book (1987)
- Conditions of Contract for Electrical and Mechanical Works including Erection on Site: The Yellow Book (1987)
- Conditions of Contract for Design-Build and Turnkey: The Orange Book (1995)

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Key References:

Anderson. Ian McAllister. 2005. Construction Management and Construction Supervision Manual, Ministry of Energy & Water/ FAO, Emergency Irrigation Rehabilitation Project, Kabul, Afghanistan.

This is a detailed practical manual that contains all of the requirements for both a Contract Management Manual and a Construction Supervision Manual.

Irrigation Manual, Module 12 Irrigation Pumping Plant, Developed by Andreas P. SAVVA and Karen FRENKEN, Water Resources Development and Management Officers, FAO Sub-Regional Office for East and Southern Africa, Harare, 2002.

The Water Team of FAO's Sub-regional Office for East and Southern Africa in Harare, Zimbabwe, has developed an Irrigational Manual for irrigation practitioners, resulting from several years of field work and training of irrigation engineers in the sub-region. It deals with the planning, development, monitoring and evaluation of irrigated agriculture with farmer participation. It consist of 14 Modules, regrouped in five volumes (Volume 1: Modules 1-6; Volume 2: Module 7; Volume 3: Module 8; Volume 4: Module 9; Volume 5: Modules 10-14), with an emphasis on engineering, agronomic and economic aspects of smallholder irrigation, but it also introduces the irrigation engineers to social, health and environmental aspects of irrigation development, thus providing a bridge between the various disciplines involved in irrigation development. For on-line reading, click one of the following:

Module: 12,
http://www.fao.org/landandwater/training.stm#irrigman

.18 Training

18.1 Approach

The objective of the current document is to prepare guidelines for the application of the described and documented best practices in Community Based Small Scale Irrigation within the Nile Basin countries. The " *outputs of the envisaged work will be used to inform partners and stakeholders from Ministries of Agriculture, Ministries of Water and Irrigation, Technical Advisory Committee (TAC), SAPs, representatives of NGO, World Bank, donors and Nile Secretariat. Most of all, however, the products (in various forms) will be used to inform and guide beneficiaries and/or practitioners at community and household levels so that proper use of the practices will eventually contribute to efficient use of water in the sector and ultimately to increased availability of water".*

These guidelines do not aim to answer all questions, but to present an outline of the issues to be considered to guide the practitioners and to direct them to additional resources from which they can answer more detailed questions.

Training has always been included in some manner in irrigation projects within all Nile Basin countries, and the projects have been used to produce guidelines and manuals that formed the basis of the training of staff and technicians. However, it is only recently that the software aspects have been given sufficient attention, and there is now the need to upgrade and complete the training and supporting material to ensure that a fully balanced approach is provided. Much of the training and production of manuals have only taken place during project implementation, when funds and resources are readily available. Once these projects have finished, so has the training and use and upgrading of the manuals and guidelines. If sustainability of community based small scale irrigation is to be improved along with improved productivity, a much longer-term commitment to training at all levels is essential.

Training in small scale irrigation must be mainstreamed, and all countries need to develop and complete policies to guide CBSSI, and to provide the appropriate enabling environment. In many cases training materials exist, but not at all levels from senior professional down to the farmers. Practical training materials need to be prepared for all levels in all countries and this need to be sufficient to enable exponents to plan, build, operate and maintain them. In addition, training institutions must be involved in this exercise as they have good experience in preparing appropriate and targeted training material (such as the Soil Water Management Research Group (SWMRG), Sokoine University of Agriculture in Tanzania). Coupled with this, curricula of universities and colleges must include more comprehensive material on small scale community based irrigation and have suitable material available with exchanges with other universities, colleges and field sites. Under this part of EWUAP, attempts have been made to collect and make available such information and this is expected to be invaluable in kick starting the process.

18.2 Target Users

Appropriate guidelines for the implementation and application of most of the described and documented best practices have been included in this document. The guidelines aim to provide information on the processes to be followed, and that need to be taken into consideration when planning and implementing CBSSI projects. They have been written with the intention of providing senior professionals in each Nile Basin country with sufficient information to enable them to produce practical guidelines for their own target groups on the implementation of CBSSI schemes. Links and references are provided to documents and manuals that can assist the reader with detailed construction and execution. By definition, following a guideline is never mandatory, but the guidelines form an essential part of the larger process of governance. Guidelines may be issued by and used by any organization (governmental or private) to ensure that all practitioners are made fully aware of the aspects that they need to take into consideration and to improve quality and sustainability.

18.3 Training Materials Available

The Food and Agriculture Organisation of the United Nations has been at the forefront of efforts to improve the quality of work and interventions at field level[36]. In this respect they have produced very useful and comprehensive training materials. There are many useful documents contained on the relevant web site (http://www.fao.org/landandwater/training.stm) and readers should consult this before embarking on their own documents. The materials available include *Training on Modernization of Irrigation Systems* (http://www.watercontrol.org/training/training.htm) as well as specific guidelines and manuals for training of practitioners to *On-farm water management*, *farmer Field Schools* (ftp://ftp.fao.org/agl/agll/docs/ffsfm_zim.pdf, *Capacity Development for Water in Agriculture* (http://www.fao.org/ag/agl/cdwa/)

Training and capacity building are identified as key elements in developing the skills, knowledge and means to define, plan and implement the action programmes in integrated water resources development for agriculture. In support to the global challenge, the ICID Working Group on Capacity building, Training and Education, and the Water Resources, Development and Management Service of FAO (AGLW) have jointly undertaken the compilation of information about training and educational institutions worldwide and established a web based database with various education and training courses in irrigation, drainage and flood control (http://www.fao.org/landandwater/cdwa/).

AGLW has developed and put together a package of training material for the development and implementation of a Participatory Training & Extension Programme in Farmers' Water Management also available through a dedicated web site: http://www.fao.org/ag/agl/aglw/farmerwatertraining/default.htm Through a participatory approach in extension, technical staff and other stakeholders put farmers in charge of water management at field and scheme level, promote the adoption of appropriate technologies and establish the necessary local capacity to put farmers in charge of water development and management.

18.3.1 Irrigation Water Management Training Manuals

This is a series of training manuals on subjects related to irrigation prepared by FAO in cooperation with ILRI, Wageningen. The manuals are intended for use by field assistants in agricultural extension services and irrigation technicians at the village and district level, who want to increase their ability to deal with farm-level irrigation issues. They contain material that is intended to provide support for irrigation training courses and to facilitate their conduct. They do not represent a complete course in themselves, but instructors may find it helpful to use those sections that are relevant to the specific irrigation conditions under discussion. The material may also be useful to individual students who want to review a particular subject without a teacher:

1. Introduction to irrigation, 1985 (http://www.fao.org/docrep/R4082E/R4082E00.htm)

The manual contains an introductory discussion of irrigation topics that are dealt with in greater detail in the subsequent elements of the series: it brings together explanatory notes on concepts, terms, methods and calculations that are basic to the discussion of the subject matter.

2. Elements of topographic surveying, 1985. http://www.fao.org/docrep/R7021E/R7021E00.htm

[36] The Water Resources, Development and Management Service of FAO offers technical assistance to country members in the design and implementation of on-farm irrigation systems, as well as in the identification and adaptation of irrigation techniques.

This manual describes elementary surveying equipment and provides examples of their application. It thus guides field assistants and irrigation technicians in setting out straight lines, measuring distances, setting out right angles and perpendicular lines, calculating surface areas, setting out horizontal lines, slopes and contour lines and measuring differences in elevation

3. Irrigation water needs, 1986. http://www.fao.org/docrep/S2022E/S2022E00.htm

The volume has been divided into two parts. Part I, "Principles of irrigation water needs", describes how the water need of grass relates to the water needs of the crops actually grown on an irrigation scheme. Lastly it indicates how the irrigation water needs can be estimated for various crops, taking into account the effective rainfall. Part II, "Determination of irrigation water needs", provides in a fairly simple manner methods to calculate the topics described in Part I

4. Irrigation scheduling, 1989. http://www.fao.org/docrep/T7202E/T7202E00.htm

The manual describes briefly the influence of water shortages on the yield of various crops. It provides some simple methods to determine the irrigation schedule of field crops and paddy rice

5. Irrigation methods, 1988. http://www.fao.org/docrep/S8684E/S8684E00.htm

The manual delineates the basin, furrow, border, sprinkler and drip irrigation methods. One chapter is devoted to the choice of an appropriate irrigation method. Several annexes are included providing the reader with additional information.

6. Scheme irrigation water needs and supply, 1992. http://www.fao.org/docrep/U5835E/U5835E00.htm

The manual describes various kinds of water sources for irrigation and discusses, in short, factors affecting the availability of water for irrigation as well as methods of tapping water. It provides information on how to estimate the irrigation needs of a scheme. It also includes how to determine the scheme irrigation need for rice-based cropping patterns and discusses how to match the calculated scheme irrigation need with the available supply of irrigation water.

7. Canals, 1992 (PDF format, size = 7 651KB). ftp://ftp.fao.org/agl/aglw/fwm/Manual7.pdf

The manual explains the functioning and construction of a canal network and describes the basic principles of water flow in small canals. It considers the elements that affect canal capacity. Furthermore it deals with maintenance aspects of a canal network and describes in detail some important technical problems that commonly arise in connection with small canals, and provides practical guidance in dealing with them.

8. Structures for water control and distribution, 1993 (PDF format, size = 8 075 KB). ftp://ftp.fao.org/agl/aglw/fwm/Manual8.pdf

This manual presents some common open channel structures that can be found in small irrigation schemes and in small units of larger schemes. In addition, it presents different types of structures for flow measurement and for the protection of the canals. Common technical problems that are encountered in operation of structures as well as the necessity of maintenance and repair works are discussed. The consequence of minor scheme extension for existing structures is also discussed.

9. Drainage of irrigated lands, 1996 (PDF format, size = 4 122 KB). ftp://ftp.fao.org/agl/aglw/fwm/Manual9.pdf

This manual discusses the need for drainage in irrigated areas, focusing on drainage at the farm level. It reviews the systems that are available to drain irrigated lands and explains which factors of soils and hydrology influence drainage. The manual touches briefly upon the design, construction, operation and management of field drainage systems.

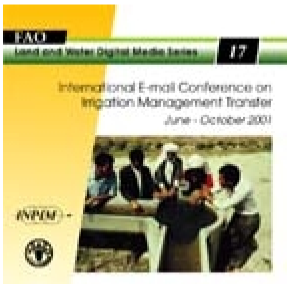
10. Irrigation scheme operation and maintenance, 1996 (PDF format, size = 1 303 KB) ftp://ftp.fao.org/agl/aglw/fwm/Manual9.pdf

This manual presents some of the difficulties confronting irrigation organizations in undertaking their duties and provides some suggestions for resolving them. The paper then discusses the methods of operating an irrigation network and the working principles involved. Maintenance tasks are discussed using the maintenance of a motorcycle as a reference for the corresponding activities in an irrigation scheme. Finally, reference is made to the need for having an effective financial control whereby the management of the system has enough resources to undertake the operation and maintenance tasks. The manual is addressed to small- and medium-scale schemes and assumes that the management organization is already in place.

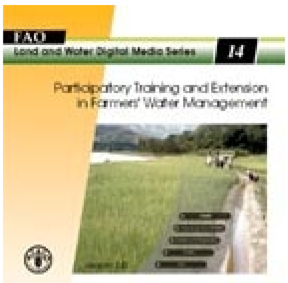
- Small-scale pumped irrigation: energy and cost, 1992 (PDF format, size = 3 098 KB). ftp://ftp.fao.org/agl/aglw/fwm/SmallScalePumpedIrrigation.pdf

This manual is about reducing the costs involved in small-scale pumped irrigation schemes. Too often, schemes are designed and constructed with little or no attention to operating costs, with the end result being that some schemes are cheap to install but very costly to run. Simple examples are used to show how this can be avoided, and how true comparisons can be made between different designs.

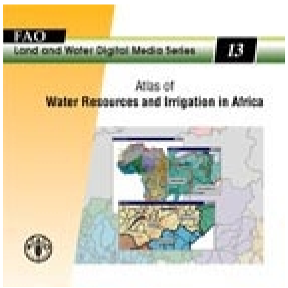
Additional material is available in the FAO Land and Water Digital Media Series (http://www.fao.org/ag/agL/lwdms.stm):



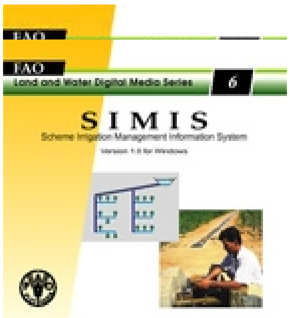
 # 17 - International E-mail Conference on Irrigation Management Transfer This CD-ROM contains all information and documents posted on the Conference Web Site. It includes all interventions made by the participants of the international E-mail Conference on Irrigation Management Transfer organized from June to October 2001 by the Land and Water Development Division of FAO and the International Network on Participatory Irrigation Management (INPIM), with the support of the Ford Foundation. The purpose of the e-mail conference was to provide a global forum to identify and share key issues and lessons gained from experiences around the world on transferring the management of irrigation.



 # 14 -Participatory Training and Extension in Farmers' Water Management This CD-ROM provides guidelines, procedures and relevant material for the development of a participatory training and extension programme for technical staff, extension workers and other stakeholders, to assist farmers to take charge of water management at field and scheme level and adopt, in a sustainable manner appropriate water technologies. The programme is particularly relevant to irrigation management transfer programmes, to assist water users' associations in the operation and maintenance of the farmers' irrigation systems, and to smallholder irrigation programmes to give guidance to farmers in adopting efficient water control technologies..



 # 13 - Atlas of Water Resources and Irrigation in Africa The Land and Water Development Division of FAO is developing a global information system of water and agriculture, with the objective to provide users with comprehensive information on the state of agricultural water management across the world. The system will help in assessing the role of irrigation in global food production and the relation between irrigation and water scarcity. Moreover, the system combines classical country-based statistics on all aspects of agricultural water management (water resources and use, irrigation, drainage, etc.), known as AQUASTAT, and a set of maps, data and models combined through a Geographical Information System (GIS). Africa is the first continent for which the information system has been completed.



 # 12 - Irrigation Guidelines on CD-ROM The objective of this CD-ROM is to present a collection of irrigation guidelines for small- to medium-scale irrigation schemes (up to 1 000 ha). The aim is not solely to present existing irrigation guidelines on a CD-ROM, but to use the interactive potential of this medium to assist the user in extracting information and data from the guidelines for specific purposes. A menu-driven media tool for easy orientation on the subject and for a wide range of applications has been developed for a variety of potential users.

 # 6 - SIMIS - Scheme Irrigation Management Information System SIMIS (Scheme Irrigation Management Information System) is a decision support system aimed at assisting the managers and staff of irrigation systems in their daily tasks. A SIMIS project stores information about climate, soils, crops, irrigation network, land tenure, land use and the maintenance needs of an irrigation scheme. SIMIS processes information to provide crop water requirements and estimate irrigation needs at farm and canal level. By interacting with the user it generates water delivery schedules for different modalities of water distribution (proportional, rotational and semi-demand) and seasonal irrigation plans. SIMIS also provides support on accounting, calculating water fees, maintenance control and performance indicators.

18.3.2 Participatory Groundwater Management

More than 2 billion people worldwide depend on groundwater for their daily water supply. Major agricultural economies (North China, South Asia, North Africa/Middle East) depend on groundwater. This has in many areas come at a price: falling groundwater tables and deteriorating groundwater quality. In many places, participatory groundwater management has a possible important role to play to address these issues - alongside other measures. To bring together the scattered experience and to equip persons keen to promote participatory groundwater management, this training kit has been prepared.

The training kit (MetaMeta. 2008) consists of 8 main modules, which are complemented by additional modules, exercises and reference material. One can browse to the subject of their interest and explore what there is - most files are pps (PowerPoint) files which can be downloaded, but the entire training kit is also available on cd-rom. One can order this - free of charge - at info@metameta.nl. Alternatively, the eight modules of the training kit have been made available in pdf-format. One can download them from www.groundwatermanagement.org.