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Auditing and planning modernization
The MASSMUS Approach

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by

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Acknowledgements

The Mapping Systems and Services for Multiple Uses of Water Services (MASSMUS) methodology is a special module that addresses multiple uses of water. It is part of Mapping Systems and Services for Canal Operation Techniques (MASSCOTE), developed by the Food and Agriculture Organization of the United Nations (FAO), it has been in use since 2000 for the auditing of medium to large irrigation systems, and for planning modernization of their operation and management. MASSMUS was developed based on a set of studies, the main ones are:

Seminal works on the Kirindi Oya Irrigation Settlement Project (KOISP) in Sri Lanka carried out in the 1990s by the International Water Management Institute (IWMI).

Numerous Rapid Appraisal Procedures (RAPs) carried out by FAO since 2000 in Asia to evaluate irrigation system performance and to identify constraints and opportunities for improvement.

Numerous MASSCOTE studies conducted by FAO, since 2006 in Asia, the Middle East, North Africa and Central Asia.

Significant contribution made at the World Water Forum 5, Istanbul 2009, together with the MUS Group Network, which yielded important clarifications on the concepts and practical approaches of MUS systems.

Field studies on multiple uses of water conducted by FAO in 2009 and 2010 in Karnataka (India), Viet Nam and China where the MASSMUS methodology was refined and finalized.

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Foreword

'Water is life!' Hardly any speech about water is written that does not stress this fact, of course this cannot be contradicted. We need water for many areas of our lives including food, livelihoods, the environment, domestic use and industry.

In the water world there is no better illustration of the concept that 'water is life' than the multiple uses of water that is practiced widely in all types of water infrastructures. One single use of water is not enough to sustain life; water use needs to be multi-faceted. It happens along natural water systems and constructed infrastructure, where people use water for many different purposes. In irrigated command areas (CA) people use water primarily for crops and for many other uses. It is the same for domestic water systems where gardening and small businesses develop where there is access to water.

The full recognition of this particular dimension is a paradigm shift that FAO, together with other partners in the MUS Group, has been promoting FAO believes that MUS is an opportunity at the local level to increase water productivity and reduce water scarcity by allowing water to serve different purposes. MUS provides an occasion for people to benefit from various water services at the same time without having to wait for the costly construction of several separate infrastructures.

It is also an important opportunity for management agencies, which are often constrained by paucity of means and difficulties acquiring appropriate funding to properly maintain infrastructure. Consideration of all uses of water, and all water users, permits management agencies to share costs among many users; thus considerably reducing the unit cost per user.

Against the background of increasing water scarcity, there is no other way than to dramatically increase water productivity in all sectors so as to cope with population growth. In the context of the financial crisis and limited funding, MUS is an opportunity that cannot be ignored. For many it is simply too costly to construct several single use infrastructures and single service agencies. The way forward is to embrace MUS, which represents a paradigm shift in policy.

These guidelines were developed based on long experience acquired by FAO during auditing and planning modernization of irrigation management. They are presented to those wishing to understand the MUS concept and wanting to carry out specific assessments on water use in their own systems.

Pasquale Steduto

Deputy Director,
Land and Water Division

MASSMUS Prologue

The use of water is essentially multiple and people live in environments supported by water. These two fundamentals seem to be straightforward common sense; in fact, the patterns of water management are not included. The inheritance of the 'silo' approach has mostly led to clear-cut sectoral approaches in the water sector where water agencies are mainly organized around a single use of water. What has been observed, however, and noted throughout rural and urban areas is that multiple uses of water within a water infrastructure command area is more common than single use.

Multiple uses of water may be the result of a multipurpose scheme's design, or more frequently arises from local practices. Most water systems are run on the principle of 'non exclusion': once built it is almost impossible to prevent local people from using the water for any needs for which they have no alternative. Not having any other water source people living near the irrigation infrastructure will use the water for their animals, bathing, domestic use, the environment and fishing..

Those involved in irrigation have progressively recognized that MUS is widespread. For instance in China and India, the two countries with the largest irrigation command area: MUS is mostly related to multipurpose systems in China, whereas in India MUS is both planned for and locally practiced.

The recognition of MUS is obviously the first important step in dealing with it, but then one needs to know how to go about it, how to assess its importance and how to improve water management for the benefits of all users and uses. This is where methodology such as MASSMUS is critical for proposing a framework to tackle MUS in a water system.

On behalf of the International Commission on Irrigation and Drainage (ICID), I am pleased to welcome the publication of the FAO MASSMUS methodology. This complements the well-known MASSCOTE approach, which is widely used for auditing and planning modernization.

Engineers in China and elsewhere have already used the MASSMUS approach. It has proved effective in enlarging the concepts and improving the effectiveness of water management. I invite the reader of this MASSMUS publication to discover this new perspective.

Dr. Gao

President of the International Commission on Irrigation and Drainage (ICID)

List of acronyms and symbols

CA	Command area
CACG	Compagnie des Coteaux de Gascogne
CCA	Cultivable command area
ES	Ecosystem service
ET	Evapotranspiration
ETc	Crop evapotranspiration
ETo	Potential evapotranspiration or reference evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GIAHS	Globally Important Agricultural Heritage System
GCA	Gross command area
IAM-BARI	Institute Agro-Mediterranean of Bari, Italy
ICID	International Commission on Irrigation and Drainage
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IRC	International Water and Sanitation Centre, The Hague, The Netherlands
ITRC	Irrigation Training and Research Centre (California Polytechnic University)
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
JMP	WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation
Kc	Crop coefficient (used to convert ETo in Etc)
KNNL	Karnataka Neeravari Nigam Limited (Irrigation Company)
KOISP	Kirindi Oya Irrigation Settlement Project (Sri Lanka)
LPCD	Litres per Capita per Day (India)
LPG	Liquified petroleum gas

MASSCOTE	Mapping Systems and Services for Canal Operation Techniques
MASSLIS	Mapping System and Services for Lift Irrigation System
MASSMUS	Mapping Systems and Services for Multiple Uses of Water Services
MDG	Millennium Development Goals
MCM	Million cubic metres
MEA	Millennium Ecosystem Assessment
M&E	Monitoring and evaluation
MOM	Management operation and maintenance
MPR	Matched precipitation rate
MUS	Multiple uses of water services
NCA	Net command area (irrigable)
NRLW	Water Service of the Land and Water Development Division of FAO
O&M	Operations and maintenance
OFC	Other field crop
RAP	Rapid appraisal procedure
RAP-MUS	Rapid Appraisal Procedure for a MUS system
SCADA	Supervisory Control and Data Acquisition
SCP	Société du Canal de Provence
SOM	Service Oriented Management
UNICEF	United Nations Children's Fund
WHO	World Health Organization
WUA	Water user association
WWF5	Fifth World Water Forum

Introduction to the auditing of multiple services systems

As part of its intervention to improve irrigation system management, the Food and Agriculture Organization of the United Nations (FAO) recently developed a methodology called Mapping System and Services for Canal Operation Techniques (MASSCOTE). Since its early stages, more than 30 systems worldwide have been audited using the MASSCOTE methodology.

MASSCOTE integrates and complements tools such as the rapid appraisal procedure (RAP) and benchmarking to enable a complete sequence of diagnosis of external and internal performance indicators, and the design of practical solutions for improved management and operation of the system. Initially MASSCOTE was developed, tested and applied to large irrigation canal systems where gravity was used for supply and distribution.

The central purpose of MASSCOTE is to introduce a culture of service approach to the business of irrigation management. Therefore, it is of no surprise if the practice of multiple uses was considered from the start of MASSCOTE when the discussion focuses on service.

The **service oriented management (SOM) approach** is at the heart of MASSCOTE. Applied to large irrigation systems, as part of an irrigation modernization strategy, SOM clearly reveals the various uses and users 'beyond the crop' and beyond the farmers. In medium and large irrigation systems the concept of multiple uses of water, which was previously neglected or even rejected, has gained momentum during the last decade as a result of introducing a SOM approach. The need to improve service to users, and to progressively balance the account for operation and management, has led managers to carefully conduct censuses on uses and users and ultimately on the people who will potentially pay for the services.

Drastic revision of the notion of services and users has resulted and irrigation managers are keener to face the reality of their multi-sector business. They are progressively abandoning some of the theoretical 'fiction' on which irrigation infrastructure was developed such as 'imposed cropping pattern', 'single use', etc. MUS, in irrigation systems, is clearly the result of the **'principle of reality'** and **'service oriented management'**.

Agriculture demand is in itself multi-service

Irrigation systems were originally built to supply water to farmers, usually assuming a uniform cropping pattern. Often, however, after years of irrigation practice, the agriculture situation has changed and cropping patterns have diversified; therefore the demand for service is no longer homogeneous.

The demands of an organic farming community, growing vegetables and flowers, will be very different from the demands of uniform rice-based smallholder systems, which are again quite unlike large cotton or sugar-cane estates. Their irrigation requirements will not only be different in terms of all performance variables, but their water demands will be based on considerable differences that include irrigation techniques, labour requirements, economic returns, vulnerability to service failures, bargaining power, status, gender divisions. Crop–water requirements for the different crops and varieties will be the basis of any irrigation service demand, but they are not the only rationale for farmers' irrigation strategies. Another typical differentiation of service is met in the rice-based system where, in some areas and some seasons, farmers grow diversified crops. In this case, services should be very different in terms of frequency and quantity.

Beyond agriculture uses

Beyond water for crops, irrigation projects are seen within the larger context of basin water management in regards to both the qualitative and quantitative aspects of water. Moreover, also within a canal system, farmers and other inhabitants in the area may use 'irrigation water' for many other purposes. Furthermore, the demands on the operator include issues in the sphere of mitigation of possible negative side effects of irrigation, e.g. salinization, waterlogging and the spread of vector-borne diseases. All these issues place more or less stringent requirements on the chosen mode of operation.

Managers need to consider, several services and/or externalities within a canal system including:

- domestic water supply to villages;
- groundwater recharge;
- streams and water bodies for fishing activities;
- water supply for livestock;
- environmental needs/impacts (groundwater recharge, waterlogging, salinity, and drainage and return flow from the CA to natural streams);
- recreational needs;
- health and sanitation.

Energy production is sometimes another important use of water in multiple-use reservoirs. The routing and scheduling of water demands to generate energy is most often at the main inflow point to the project. However, in some cases, it may be within the system itself.

An analysis of 30 large irrigation systems, investigated by FAO between 2004 and 2009 using a MASSCOTE approach, shows that many contribute to uses of water beyond the crop. Only two out of 30 appear to be single use systems. The analysis and results of discussions with partners engaged in MUS projects revealed that a specific approach to multiple uses/services should be further developed and incorporated as a specific module into the MASSCOTE approach.

The purpose of this document

This document presents the conceptual and practical approaches proposed for auditing multiple services in large irrigation systems in a way that is similar to how MASSCOTE was developed for the gravity canal irrigation system. It is called MASSMUS, which stands for Mapping System and Services for Multiple Uses of Water Services.

The same spirit prevails in this new module, namely that of providing a step-by-step progressive process that starts with a rapid appraisal procedure (RAP), then proceeds with further steps related to capacity, water balance, cost and development of a vision, and the design of interventions to modernize the management set up and operation techniques. Some adaptation to the specific function and constraints, inputs and outputs for MUS has been made where necessary.

An important aspect of the MASSMUS approach for auditing water services to irrigation systems is the reference for benefits, which is associated to each type of service. Generally references for irrigated agriculture are clear and reliable: yields and water entering the command area (CA) and water used by crops during evapotranspiration are reasonably well known. The benefits of irrigation are often taken to be the monetary value of the total yield throughout the CA.

Inversely, for many other uses of water, data for: i) extending uses; and ii) references linked to its benefits is often lacking or inaccurate, meaning experts are forced to work without good data, often using references taken from elsewhere. This cannot be circumvented at the initial stage of a more systematic approach to MUS systems.

This document presents the basic background for MUS and the progressive steps used in the MASSMUS methodology for auditing irrigation systems. As a companion to this document a worksheet RAP-MUS (rapid appraisal procedure for multiple uses of water) is needed to carry out the first important step in the process. The RAP-MUS worksheet may be downloaded from the FAO website.

The RAP-MUS worksheet is adapted from the classical RAP by incorporating methodological elements pertaining to the various water services reported. Special attention has been given in the RAP-MUS to the references available for MUS, it contains tables where various reference data can be selected and inserted. The initial worksheet was developed using whatever is known and consolidated for MUS references at the time of release.

The references database in the worksheet is designed to be evolutional and should progressively incorporate new reference elements. Practitioners are encouraged to enrich and adapt the references using their own data in their own context. Readers are encouraged to check the latest version of the RAP-MUS worksheet on the FAO website, because it is regularly updated with incoming references from field MASSMUS studies.

The present document is in two parts. Part One introduces the MASSMUS methodology:

Chapter 1 presents the framework for Multiple Services.

Chapter 2 describes the MASSMUS process step-by-step.

Part Two contains Chapters 3 to 17 that analyse various water services against the same MASSMUS grid:

Chapter 3 – Agriculture users – Irrigation

Chapter 4 – Agriculture users – Livestock

Chapter 5 – Aquaculture

Chapter 6 – Domestic water

Chapter 7 – Small industry and business

Chapter 8 – Homestead gardens

Chapter 9 – Perennial natural vegetation

1. Conceptual framework for multiple water services

The term multiple-use of water is increasingly used in the water sector but often refers to different approaches and levels of scale where multiple uses take place, or originate in different sectoral backgrounds. This Chapter provides an overview of different definitions of water services, of MUS systems and the various contexts in which MUS is practiced and, finally, how MUS fits into larger-scale integrated water resources management (IWRM).

MUS: a river of multiple contributors

The recognition of MUS results from a convergence of three different approaches that have progressively revealed and highlighted the existence and extent of multiple uses of water. These approaches are livelihood, ecosystem services and water services management (domestic water or irrigation water).

The livelihood approach reveals how people (the poor and vulnerable in particular) can benefit by using water from the same infrastructure in multiple ways to satisfy their basic needs. Multiple uses of the same infrastructure in this way results in huge financial benefits when compared to what would be required to meet these needs by other means (van Koppen *et al*., 2006 and Renwick *et al*., 2007).

The domestic water sector has a long history of use by individuals and local communities for uses other than domestic purposes, particularly for production. The incremental benefits versus costs show that there are real advantages to such practices (Renwick *et al*., 2007).

The ecosystem services approach has been integral to revealing the high value of multiple uses (positive externalities) of water services, particularly because it highlights the consequences if the service were to disappear. A good example of this approach is the ecosystem services provided by paddy rice cultivation in Asia and other parts of the world. The multiple values of paddy cultivation, such as flood control, cooling effect, support to environment, have been (re)discovered and documented when this agriculture practice came under threat solely because of rice economics. Today, agriculture and wetlands prominently underlies the importance of ecosystem services (FAO, 2008).

Historically, the irrigation sector approach to modernization at field level has triggered clarification of the case for multiple uses of water associated with traditional surface irrigation techniques. For instance, in the south of France modernization of irrigation techniques at field level in the 1970s and 1980s was based on the shift to sprinkler or drip irrigation, which resulted in dramatically improving the efficiency of water application and effectively cut off groundwater recharge and the source of water for many other uses during the dry summer period, including domestic supply to towns. This recognition led, in the 1980s, to specific modernization programmes to maintain a high proportion of surface irrigation at field level to avoid depletion of groundwater, which is highly dependent on deep percolation from irrigated fields (Renault, 1988) and which is the sole source of domestic water for some towns during summer.

Historically, the concept of multi-purpose water infrastructures sharing the same reservoir or the same canal has been another important theme of MUS practice.

Recently, the concept of 'service oriented management' (SOM) has been introduced, which is central to the FAO approach to modernize management of large irrigation systems. This has revealed the importance of the various uses and users 'beyond the crop' and beyond the farmers. As a result of SOM, the concept of multiple uses of water in medium and large irrigation systems, which was neglected or even rejected, has gained momentum over the past decade. The need to improve service to users, and to progressively balance the account for operation and management, has led managers to survey more carefully uses and users and ultimately the people who will eventually pay for the services.

A FRAMEWORK FOR APPROACHES AND SCALES

It is important to recognize that multiple uses take place at different levels.

The lowest level is the **household or homestead level** where people harvest water, gathered from several sources for different uses around or near the homestead, including domestic use, and for small-scale production such as backyard gardens, livestock and micro-enterprises.

The **water system level** is at the level of a certain infrastructure such as a water distribution scheme or aquatic ecosystem. These schemes are often designed with a specific use in mind, for example, field crop irrigation or domestic supply. Users may actually engage in multiple-uses at the household level, as seen above, but other uses and functions may be built in at the scheme level. For example, an irrigation canal may also fill village reservoirs for domestic supply, or provide water for fish habitats. In large complex systems, such as some canal systems in South Asia, or paddy irrigation schemes in Southeast Asia, there may be a wide-range of these uses and functions at the scheme level.

At the **catchment or river basin level**, multiple uses of water occur in upper catchments down to estuaries and coastal wetlands, where different schemes and users take and discharge water for multiple purposes. Typically, large dams have been built to serve multiple functions including flood protection, urban water supply, hydropower and irrigation.

As a practice, MUS approaches may have different entry points and thus we can distinguish:

- Community based MUS
- Domestic MUS
- Irrigation MUS

However, beyond the diversity of scales and approaches MUS shares some key issues that were thoroughly discussed at an international workshop in Leiden 2010 (MUS, 2010).

The same central concepts of MUS apply at each scale (household, community and large-scale system) and are defined as a:

Demand approach – focusing on the needs, the practices of people, and their livelihoods; and

Service oriented management (SOM) strategy.

BOX 1.1

Acknowledge the widespread practice of multiple uses and functions in water systems

Historically people, communities, and water managers have used constructed delivery systems or natural water systems deliberately for more than a single use. In many rural and urban areas, domestic water networks are used for small-scale productive activities. Similarly, irrigation systems are often de facto providing large amounts of water within their command areas that facilitate access to water for many other uses through recharge of surface streams and groundwater. Last, aquatic systems (wetlands including rice-based systems) provide many important productive and ecosystem services to nearby populations. Under appropriate stakeholder management processes, the practice of multiple uses and functions can prove to be sustainable and very efficient for the community.

Source: WWF5 Istanbul Water Guide (2009) Item No. 52

BOX 1.2

Recognize the multiple benefits of multiple uses and functions of water services including for the most vulnerable users.

Multiple use systems can provide more vulnerable users with low cost services for water for domestic use, agriculture (irrigation, rainfed), homesteads, gardens, water for cattle, habitats for fish and other aquatic resources and rural enterprise water supplies. The same infrastructure may be used for these services as well as for hydroelectric power and, in some cases, to aid inland waterway navigation.

Multiple use systems consider and support important cultural values and functions essential for local well-being and livelihoods and may provide ecological benefits including flood control, groundwater recharge, water harvesting, water purification and biodiversity conservation. Diversification of water sources and of productive activities is instrumental in increasing the resilience of local communities and management of global shocks and risks that may be caused by climate or market crisis.

Source: WWF5 Istanbul Water Guide (2009) Item No. 53

The same model with different problematic aspects

A MUS approach aims to reconcile the uses, the users and the water resources at each scale. This is the triangle model shown in Figure 1.1, which applies to household, community and water system.

The problematic aspects at each scale will vary depending on the sector (see Figure 1.2).

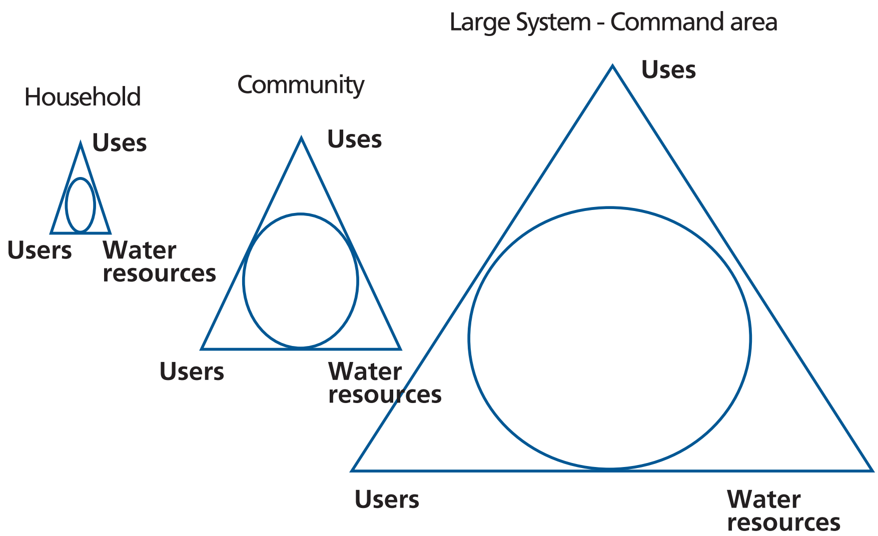
In the **domestic sector** the intervention comprises use of the community territory and beyond (natural resources) to capture, treat and pipe water to households in the community. In a nutshell the key issue for domestic MUS is to increase the size of the pipe to allow other than domestic uses of water (domestic-plus).

For **community-based projects**, the issue is to diversify the connection between the sources and households within the community's territory. This intervention focuses on having many small pipes to provide various services as illustrated in Figure 1.2.

For **irrigation projects,** the MUS approach comprises mastering the various water flows within the command area as a result of introducing canal water or of irrigation practice at field level, on the basis of which other uses strive. If the irrigation system is small, then the MUS approach will be strongly linked to a community-based approach. If the system is large, then the MUS approach will be independent. Ultimately, a comprehensive MUS approach for irrigation must combine household, community and system approaches.

The main conclusion of this conceptual review is that all approaches are necessary to carry out a comprehensive MUS approach. Within an irrigation command area, community and household levels need to be handled properly to understand the management issues for irrigation water in relation to other uses of water.

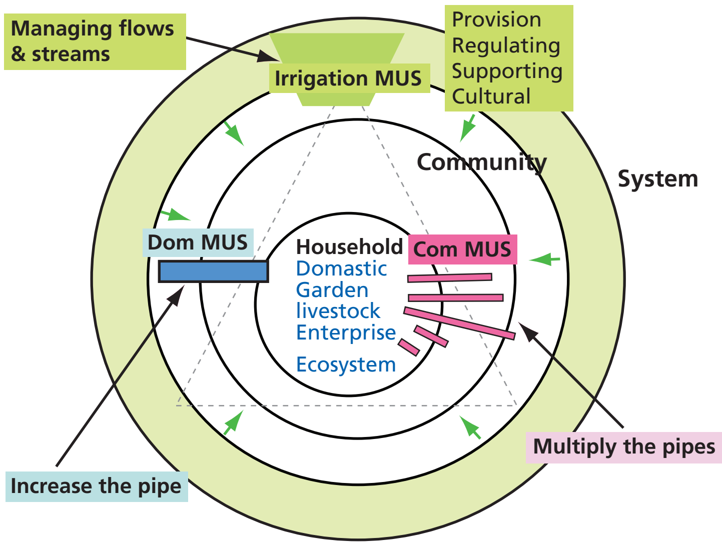
FIGURE 1.1
The same MUS conceptual model at various scales



MUS in large rainfed systems

Are MUS on large systems only related to irrigation? This is a valid question. MUS is not limited to large irrigation systems for agriculture. Although the FAO–MASSCOTE and MASSMUS programmes focus on modernization of large irrigation systems and, as such, the tools and methods developed consider only large irrigation systems, any large agriculture/rural domain is eligible for MUS interventions regardless of the density of irrigation in terms of spatial expansion and time.

FIGURE 1.2
Illustrating the integration and complementarities of the MUS approaches



An ecosystem service approach can be carried out with a similar conceptual approach of uses, users and sources to large rainfed systems. Obviously, for rainfed systems the capture of rainfall and harvesting is a dominant component but not the only one. A complete approach to the ecosystem services can be carried out for a dry or rainfed agriculture system (Lange, 2010).

In practice they are very different but conceptually rainfed and irrigated systems can be grouped broadly in MUS large-scale agrisystems. Irrigated systems are often mixed: rainfed during the wet season and irrigated during the dry season.

WATER MANAGEMENT FOR MUS AND IWRM

Many newcomers to the MUS approach often ask about the difference between Integrated Water Resources Management (IWRM) and MUS, which is a valid question. IWRM addresses two key elements of water management through the promotion of water sharing among the stakeholders or through the implementation of allocation mechanisms between the different sectors. MUS also addresses water sharing among stakeholders and, in this respect, overlaps IWRM. However, the scales and methodologies used by IWRM and MUS differ. IWRM focuses on the basin level and aims to convey general principles of water sharing through advocacy actions and mechanisms. On the other hand, MUS tends to focus on local practices and aims to make these practices more effective and equitable on a larger scale.

The multiple-use approach mainly applies to the household, community and system levels. One can of course talk about management arrangements at the catchment or basin scale to ensure water can be provided for multiple uses to different users, however this is known as IWRM or integrated catchments. IWRM is often understood as governance and management for dealing with competing water sectors at the basin or catchment scale. MUS is an approach to providing multiple use of water services at the system level and down, where IWRM provides an approach to coordination at the catchment scale. See Figure 1.3 and Box 1.3 for further clarification of MUS *versus* IWRM.

BOX 1.3

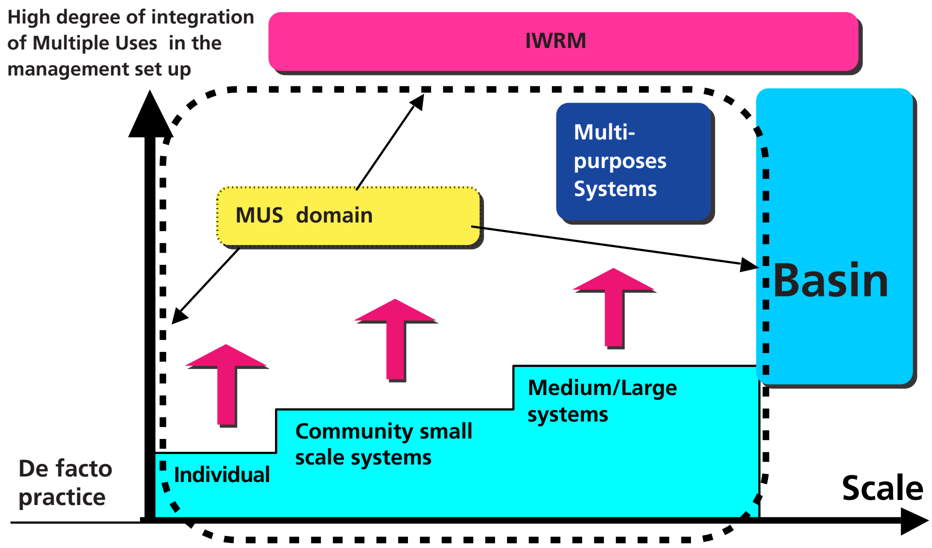
MUS and IWRM – Recognize the interrelationship between multiple uses and functions of water services and integrated water resources management.

Multiple uses practices are inherent to the IWRM approach, which should be strengthened. Management agencies of large irrigation systems are often the only water services providers, notably during dry periods. Sound governance of these systems should be ensured to encompass the principles of IWRM and to recognize the needs of all stakeholders..

Source: WWF5 Istanbul Water Guide (2009) Item No. 54

FIGURE 1.3

MUS scaled to management integration dimensions



MULTIPLE USES – PRACTICES AND SERVICES

Planned and de-facto multiple-use

Although people need and use water for different purposes, often the systems or services have not been designed or developed for multiple uses. For example, irrigation schemes may have been designed only for field crop irrigation, but are de facto used for cattle or backyard irrigation as well. We see both the de facto and planned services as MUS. The de facto MUS results of users' practices in situations where basic services are lacking (domestic and irrigation water, sewage system and garbage facilities).

De facto MUS services may suffer from a few drawbacks, for example, users may try and access water for their different needs, which goes beyond the design capacity of a system. In fact, a key rationale for the MUS approach is that of trying to recognize the reality of multiple uses, such practices can be better accommodated. It must be said that some distorted uses, which are sometimes the basis for MUS, are not desirable because the negative impacts outweigh the benefits. For instance, it is common to see irrigation canal systems used as wastewater sewage systems or garbage dumps.

Recognizing that these multiple uses exist is a first step (often as a de facto practice). Understanding why they exist is the important second step in the process, as it will help incorporate the specific use into an efficient operation and management process. Basically uses exist as external to the main process or as advantages taken by users to fulfil a need that would be financially unattainable by any other means.

The next step is to conceptualize and incorporate the uses into the management of water services, namely, the systems (physical and non-physical) that are in place to meet these needs at different levels. In this sense MUS may be considered an approach, rather than a specific type of system. Lastly, it must be recognized that some water systems fulfil roles and functions that are not strictly associated with any water delivery or any particular user, but address community needs through specific functions and beneficial roles.

Multiple uses of water – defines the practice of using water from the same natural or constructed system or infrastructure for multiple uses and functions.

Multiple-use of water services (MUS) – defines the conceptual approach of providing water services for multiple uses, also incorporates the roles and functions of water-related systems for local communities.

To conclude this section, MUS is therefore very much tied to 'systems' and services, i.e. infrastructure and their corresponding arrangements for management and governance.

DIFFERENT MUS SYSTEMS

Obviously there are various types of MUS systems in the water sector. The typology presented in Table 1.1 is not exclusive and in practice MUS systems may refer to several types: for instance Multipurpose Reservoir (MPR) that has separate networks for each water service it provides, for example irrigation water and hydropower, and MU + for irrigation within the command area (CA).

TABLE 1.1
Types of MUS systems

TYPE		Shared system	Typical situation
MPR(1)	A reservoir with separate system-networks for each use of water Usually large infrastructure	Reservoir	Multipurpose reservoir
MPN	A distribution system-network designed for serving multiple uses	Network	Multipurpose network
MU +	Single use distribution network yielding opportunities and externalities for other uses	Water resource & Network	Domestic + Irrigation +
MU Seq	Sequential system: drops cascading from one compartment to the other Successive **non-consumptive** uses of water	Water cycle/ pathway	A surface groundwater hydrosystem supporting irrigation and domestic Paddy field system
MF	Multi dimension/functions/services Several functions/roles associated with some uses of water and/or resulting from the circulation of water and/or the set of practices associated with water management	Ecosystem	Wetlands

DEFINITION AND APPROACH TO 'SERVICES' FOR WATER SYSTEMS

The term 'services' is used in numerous and extremely diverse ways, from employment and tasks, assistance, car maintenance to religious rites or the military just to give an idea of the diversity. The term 'service', which is applied to the water sector is no exception, many actors in the water business refer to 'water services' but not necessarily with the same meaning, this is why at the outset of a document presenting MUS it is critical to clarify our understanding and conceptual approach to services so any further ambiguity can be avoided.

The services as a range of intangible economical activities (third sector)

The term services is often used to define the activity in the sector, which is not the primary sector agriculture, or the industrial but the third sector, which developed based on production of non-tangible products (banks, advice, etc.). In the field of irrigation, intangible services include the advice given to the irrigation sector, choice of technical options and advice about watering schedules, which is covered by extension services.

Water service as a branch activity or a company

The term 'water service' is also used to define the activity of providing users with water deliveries and can also define the company itself that provides the service.

The organic service relationship in the business approach

In this approach service is the result of a specific task performed by a provider to produce the service requested by one user, or beneficiary. In this case, the concept of service is the organic relationship between a provider and a receiver of services (also termed customers, users, beneficiaries). This organic relationship is at the heart of MASSCOTE auditing procedures (see Figure 1.4) and deals with three intrinsically linked key elements: service = water + information + money

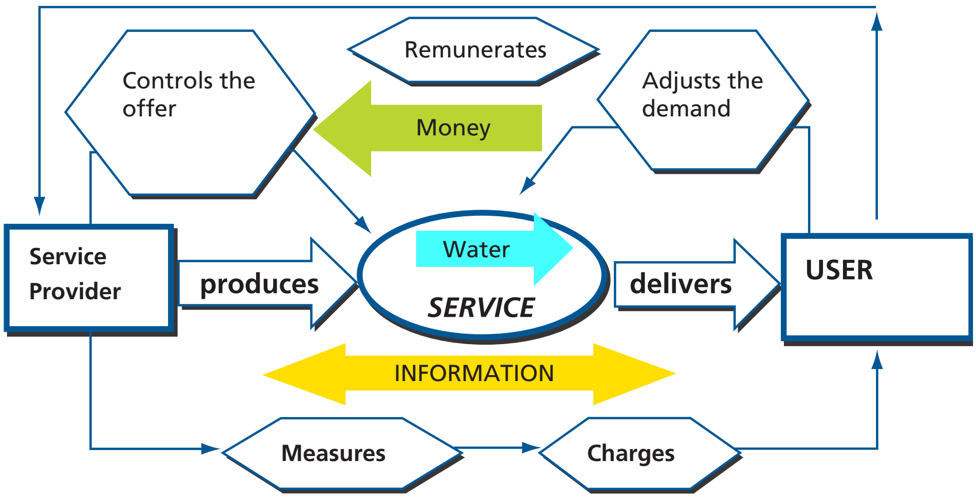
The first element is water. Water delivery is central to the service, but is not the only important component. Information is also an important element of water service. Information flows in both directions, from providers to receivers and vice versa. Users need to have information about the allocation of water, scheduling of supply, and about measurements of deliveries. Money is also a critical element in the service approach.

Sooner or later someone has to pay the bill for irrigation management services, for their own and someone else's use. Therefore, a major responsibility of management is to organize effectively the flows of money to cover the cost of producing the services.

The ecosystem services approach

The ecosystems services approach has undergone significant recent developments as a result of the Millennium Assessment of Ecosystems (MEA, 2003). People benefit from a multitude of resources and processes that are supplied by natural ecosystems, these benefits are known as ecosystem services, which are grouped into four main categories:

FIGURE 1.4
Sketch of service approach showing the three basic flows: Water (blue), Information (yellow) and Money (green)



(After Renault and Mountginoul, 2003)

Provisioning – food, fibre, freshwater, energy, wild food, spices and medicinal products;

Regulating – carbon sequestration, waste decomposition, purification of water and air, crop pollination, pest and disease control;

Supporting – nutrient dispersal and cycling, seed dispersal; and

Cultural – cultural, intellectual and spiritual inspiration, recreational experiences and scientific discovery.

The concept of ecosystem services is pertinent to the irrigated command area where water is often critical for, and strongly influences, these services. For instance, some functions are rooted in the social and cultural aspects of water management; others are related to the hydrological processes and specific agricultural practices such as terraces for paddy cultivation, others in the biological and ecological processes. Table 1.2 proposes a breakdown of uses and functions in irrigation systems using the MEA grid.

THE MASSMUS CONCEPT OF WATER SERVICES

Building upon the previous definition of services, MUS in irrigation systems can be approached as follows:

First, we approach the irrigation system as a biophysical system, which is therefore **a specific ecosystem providing ecosystem services** supported by a structured intervention for **water management.**

Second, we consider **the organic service relationship** as the core of our business with service providers and service receivers. In business language, receivers are considered customers or clients. In an irrigation system, receivers are customers and clients but also actors or stakeholders of the management through their effective participation in the governance of the scheme. For example, in a water user association (WUA), farmers are not only the customers of the service they are also involved in decision-making regarding the service. In this sense, the farmers are also actors.

TABLE 1.2
Classification of water services in a command area following the MEA grid

Provisioning services	Supporting services
Domestic water	Groundwater recharge
Food and fibre (irrigation)	Support to fishing
Water for cattle	Support to natural ecosystems and wildlife (biodiversity)
Transportation	Soil formation
Hydropower	Soil conservation
Environmental flows	
Fuel (natural vegetation)	
Biochemicals and natural medicines	
Habitat improvements (raw materials for construction)	
Regulating services	**Cultural services**
Sanitation and wastewater treatment	Social functions linked to the infrastructure and management
Drainage	Recreation and tourism
Flood protection	Cultural heritage values and landscape (ex. terrace system)
Cooling effect on habitats, shade.	
Erosion control	

Note that, as mentioned by the authors of the MEA report, this partitioning of water services is not clear-cut, many services are relevant to more than one category.

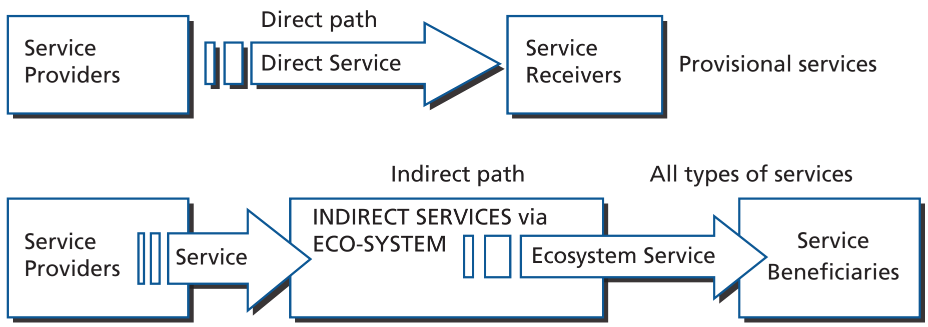
Third, we acknowledge the need to frame the system within clear-cut physical and managerial limits.

Briefly, the services oriented management (SOM) of irrigation system management, which is the foundation of MASSCOTE and MASSMUS considers that:

Water management activity within the limits of their managerial boundaries takes place and impacts a command area considered from a bio-physical viewpoint as an agro-ecosystem providing ecosystem services, and centered on a dynamic organic relationship between provider and users of services.

A business service model intervening in a large ecosystem

FIGURE 1.5
Direct and indirect service relationships in water systems



(After Renault and Mountginoul, 2003)

DIRECT AND INDIRECT SERVICES

With this organic relationship in mind we consider that water management activities provide services directly to users, which may include farmers and villages for the main provisional services, or indirectly serve beneficiaries by acting on the ecosystem processes that in turn influence the ecosystem services as described in Figure 1.5.

ECOSYSTEM SERVICES GENERATED BY FIELD IRRIGATION PRACTICES

In an irrigation command area there are two actors that play a key role influencing the provision of ecosystem services: the system manager and the farmer.

During their field practices farmers greatly influence several previously identified services. One key service that is directly attached to water is groundwater recharge; other services are listed in Table 1.3. For instance terraces for rice cultivation have several positive impacts on ecosystem service (ES).

Apart from crop production, and perhaps soil conservation and erosion control, the ecosystem services generated by farmers at field level are usually accidental.

TABLE 1.3
Ecosystem services influenced by irrigation field practices

Provisioning services	Supporting services
Food and fibre (irrigation)	Groundwater recharge Soil formation Soil conservation
Regulating services	**Cultural services**
Flood protection Erosion control Cooling effect on habitats, shade	Cultural heritage values and landscape (e.g. terrace system)

BOX 1.4
Modernization of surface irrigation to maintain groundwater recharge in Provence, France

In the early 1980s in southeastern France, large modernization programmes were carried out for surface irrigation based on a shift to sprinkler or drip irrigation. However, it soon became obvious to designers and managers that this modernization policy jeopardized the sustainability of local water supply to towns and cities based on local aquifers.

In the 1980s, two projects' (Cabannes, Tarascon) modernization programmes were redesigned based on an accurate assessment of the water balance during summer. Large areas of irrigated land were deliberately maintained under surface irrigation using modern techniques to allow groundwater recharge during summer (Renault, 1988).

SERVICE APPROACH FROM THE VIEWPOINT OF MANAGEMENT

As stated earlier, the SOM approach, which is the basis of MASSCOTE, is centred on the organic relationship between a service provider and a service requester. The task of producing a service comprises the supervision and control of water deliveries from a specific source to points of delivery for the users. The three pillars of SOM are the service itself and the two actors, i.e. the provider and the receiver (or user and beneficiary).

In previous sections the focus was on the ecosystem services focussing on the beneficiaries or receivers. In this section the specifics of the MUS services are analysed from the viewpoint of the service provider, considering the nature of service to be provided and its implications with respect to management operation and maintenance activities.

Water delivery

A water delivery service consists of providing a specific quantum of water at a particular point. The delivery service can be to a farm, a field or any point of the command area for other uses. Water can be delivered to a water body (tank) for domestic supply to villages, raw water to a domestic water treatment plant, or raw water to an industrial plant. In this case, the quality of service is mainly about timeliness and adequacy, but it is also about water quality.

Maintaining flows in local streams and water bodies: the RAW WATER service

In some low-lying areas, maintaining flows in the local drains, streams and marshes is important for preventing seawater intrusion. In other cases, maintaining water resources in wetlands is equally important for their capacity to sustain wildlife and other environmental values.

Maintaining water levels in canals and local water bodies

In some areas, surface water (canals and local water bodies) is the only source of water not only for drinking but also for other domestic uses such as bathing and washing clothes. When the canals are closed (e.g. for canal maintenance, or when there is no irrigation demand), people living near the canals or depending on water bodies fed by canals, can suffer owing to poor quality groundwater. At times, it is impossible for them to access good-quality water. This issue has put pressure on managers to periodically fill portions of the canal systems in order to maintain minimum water levels (e.g. in Pakistan and Sri Lanka).

Maintaining the capacity for storing water and flood control

In areas and seasons where heavy rains are likely to occur, one objective of water control in the system is to maximize the ability to store precipitation. This has two positive effects it: (i) improves water resource availability; and (ii) minimizes the impact of floods.

TABLE 1.4
Service types from MOM viewpoint

Type of service	Uses/Users	Deliberate/ Adjustable	Type of service and target
Water delivery	Irrigation Domestic Industry Water body Environment Fishery Aquaculture	Deliberate and adjustable	A time (and volume) bound water delivery A share of flow bulk water delivered (Discharge or volume per period); discharge and head availability. Water supply to small ponds for small industry
Support to surface raw water	People Animals Environment	Deliberate if provision of specific physical access Non deliberate if no access are built	Water supply to small ponds. Construction of ramps on canal side to facilitate access to water. A specific discharge to outlet Water presence in canals and in field (seepage and percolation) Water quality through water dilution and/or drainage control
Groundwater recharge	Irrigation Domestic Industry Cattle	No: results of seepage along the canals and field percolation	No service no specific target, just monitoring of groundwater level Preventing salt intrusion
Control of water	Drainage Flood control Transport Health control Level in water stream and water body		Water storage capacity Water level in waterways Water-level fluctuations A water presence and a given water level in water bodies

Water quality

Modern agricultural methods and the scarcity of freshwater result in some areas having to deal with water containing chemicals (pesticides and nutrients) and other pollutants. Dealing with the wider causes and effects of water quality is a major challenge for irrigated agriculture, with implications for both surface water and groundwater. Many shallow aquifers are important for domestic supply. These often receive some recharge from dry season percolation from irrigated areas, representing simultaneously a benefit (supply) and a threat (pollution). In these situations, managers will have to consider both uses and arrive at an effective compromise.

During dry periods, water supplies in natural streams maintain a minimum quality in local streams through the dilution of toxic wastewater drained from urban and peri-urban areas.

Recycling of irrigation water

Return flows from irrigated areas can be important assets in water management. Losses in one place become inputs for other areas. A good understanding of this cycle can ease the problem of upstream management substantially by allowing less precision in distribution, knowing that surpluses will not be lost. Return-flow systems present an opportunity for managers to store positive perturbations, for example to harvest rainfall as both drainage and surplus irrigation are channelled back to the irrigation network.

Water harvesting and conjunctive management

Water harvesting during rainfall periods is an important opportunity for water management. Specific operational procedures may be designed to maximize harvesting while preventing canal overflow. The conjunctive use of water (surface water, groundwater and rainfall) can provide additional flexibility to farmers. Groundwater is frequently used to compensate for rigidity or low performance in the surface water delivery system. Groundwater recharge can be a target of canal operation. Areas lacking access to additional supplies from groundwater should be prioritized for greater management attention rather than areas where pumping facilities can compensate for inadequate and/or unreliable deliveries.

Soil and water salinity and waterlogging

Rising soil and water salinity and the increase in waterlogged areas comprise significant environmental hazards in arid regions. They represent a severe threat to many irrigation schemes. The operation of irrigation systems must take into consideration the spatial distribution of these hazards in order to provide a selective and locally adapted water service. In practice, solutions are largely site-specific, and generic guidelines are difficult to derive. A general principle, however, is partitioning of the irrigated area should identify areas where freshwater must be provided, and areas where excessive percolation should be avoided to prevent the rise of saline groundwater or waterlogging.

Health impacts

Despite its positive effects on the rural economy and farmer income, irrigation may negatively impact the health of communities as a result of vector-borne diseases. The maintenance of water in canals for long periods can change the reproductive cycle of disease vectors, leading to increased numbers of species and individual vectors. The link between system operations and the incidence of vector-borne diseases can be strong.

The recommendations of health experts converge towards a requirement for increased variability in canal flow regimes to, for example, reduce the breeding of mosquitoes. However, there is a clear conflict between these requirements for vector control and the objective of irrigation management, which is stable water flow and steady deliveries. New operation techniques are required in areas where mosquito breeding is related to irrigation practices. Boelee *et al*. (2002) have recently documented the positive effect of water-level fluctuations on vector-borne diseases such as malaria.

An IWMI study (Ensink *et al*., 2002) in Pakistan showed that a significant part of the CA has unpalatable groundwater and that a large fraction of the rural population relies on irrigation surface water for their domestic supply. An estimated 40 million people are affected by water quality in the canal system, and this number is likely to double in the coming 25 years. With a basic need of 50 litres per person per day, this represents a volume of 2 million cubic metres (MCM)/day. Some people are heavily dependent on irrigation surface water to fulfil their domestic needs, and they face serious water shortages during closure of the canal system for maintenance.

In many contexts, if not all, canal water cannot be used directly for domestic purposes without proper treatment. This is particularly true for drinking water. It is recommended that there should be at least a filtration stage, which can result in having water infiltrated into the soil and pumped back from the water lenses generated around water bodies/canals.

ELEMENTS COMPOSING THE SERVICE

In a service business model, or a service oriented management approach, the fundamental aim is to supervise and control the delivery of a service from a service provider to a service requester. In irrigation management, the latter is called a service receiver. As introduced previously, the three pillars of SOM are the service itself and the two actors – the provider and the receiver (or user or beneficiary). The three major elements entering into the service are water, information and money (see Table 1.5).

Information is obviously a significant part of SOM service. Reliable and accurate information about the service of water is important for farmers when they need to make strategic decisions regarding their cropping pattern and cropping calendar. They need to know whether they will be in a position to feed the crops with sufficient volumes of water, the calendar of deliveries. It is also important for other users when they need to plan the management of their allocation of water throughout the year.

Information about the demand for water services is important for managers before and during a season. Information is needed to assess the actual services delivered and proceed with charging the users accordingly. Money needs to flow with respect to service provided in a way to fully cover the cost of management, maintenance and operation of the system.

TABLE 1.5
The three flows of water service

Provider	Service	Receiver
Operates the system to produce water deliveries.	Water flows →	Receive and manage the water flow.
Should inform receivers beforehand about the service they can anticipate for a given period of time (season, year), about the scheduling of deliveries. Information of actual service Must be collected.	Information flows ↔	Information of the demand for services from the receiver should be conveyed to the provider. Information of actual service Must be checked/collected.
Should charge for the actual service and ensure the long-term sustainability of the infrastructure.	Money ←	Should pay the service according to the volume used or benefit obtained.

SERVICE ATTRIBUTES – TARGET, TOLERANCE AND DEFAULT MANAGEMENT

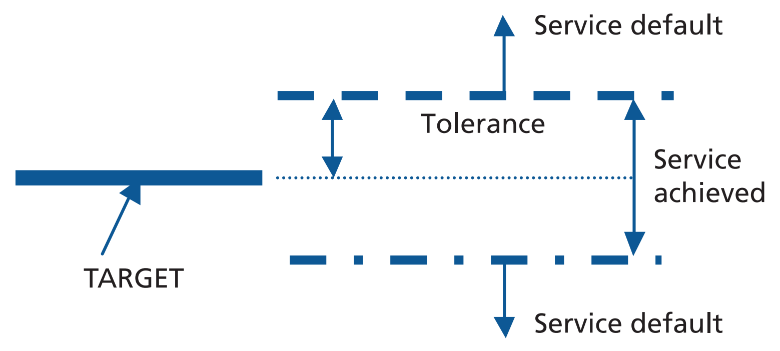
Target and tolerance

A service must be defined with a very clear and measurable target, for example the specific discharge and timing of a delivery. However this is not enough, a target must be defined with some tolerance that defines the range within which it is considered a service is met and outside of which it is not met.

In irrigation water delivery services an important indicator of service is the tolerance within which deliveries are allowed to fluctuate. Therefore, service must always be defined using two variables: target and tolerance: Service = {Target; Tolerance}. For example:

- service = 100 litres/s ± 10 percent
- service = deliveries on time ± 3 days

FIGURE 1.6
Sketch of service attributes



The tolerance sets the limits within which the delivery is allowed to fluctuate (Figure 1.6). There is a need to define a tolerance level that is: (i) possible to attain with current infrastructure constraints; (ii) acceptable to all the stakeholders involved; and (iii) consistent with the accuracy by which service is assessed.

In theory, the previous definition should allow identification of the service as being either 'achieved' or 'in default' without ambiguity. However, in practice, it may depend on the accuracy by which the service is measured.

Accounting for measurement inaccuracy

The inaccuracy of measurement adds ambiguity to the process. In short, there is no point in having a narrow tolerance to service for discharge where the measurement accuracy is low. The range of readings giving 100 percent certainty of being within the limits of the service, is equal to the target plus tolerance and minus accuracy for the maximum reading, respectively minus and plus for the minimum reading.

Default management

Using a SOM approach it is essential to consider times and places where the service provided may inevitably be in default. This is not necessarily a sign of poor performance, unless there is no mechanism to deal with the default. These mechanisms can provide immediate correction or financial compensation. With irrigation, for example, subcommand areas that have been deprived of their full right to water, in a particular distribution rotation, will receive the first priority in the next rotation and obtain additional water supply to compensate for the previous deficit.

BOX 1.5

Example of consistency between measurement accuracy, target and tolerances.

Considering a tolerance of 10 percent, for a target of 100 litres/s means that the discharge should vary within the range of 90 to 110 litres/s. Assuming that the measurement device is capable of assessing the true value with a precision of 5 percent, when the reading is 110 litres/s, its value lies between 105 and 115 litres/s. Similarly, for 90 litres/s the true value lies between 85 and 95 litres/s. As a result, the range for which there is no ambiguity for service target has been reached for readings between 95 and 105 litres/s.

This range is defined by the tolerance minus the accuracy of measurements. This is why tolerance cannot theoretically be equal or lower than the measurement accuracy. It would not be consistent to set a tolerance of 5 percent in discharge with devices that can only be 10 percent accurate.

Defining the service indicators

An important step in modern management is to decide with users about the services to be produced and supplied. The service will be defined by targets and tolerances with respect to specific indicators. In general terms, and considering MUS, these indicators are related to:

Access to water – implies physical access (turnout; ramp/stairs to access water in a canal) as well as timely access (schedule of water access during the year). In irrigation access to water is often captured through the **flexibility indicator** with a spectrum going from rigid rotation to free access).

Water quantity – defines the quantum of water which is made available to the users. In irrigation this criteria is captured through the **adequacy indicator**.

Water quality – this is especially important for domestic water.

Equity and reliability of the services provided – These two aspects consider not only one particular unit of service, but several. Equity expresses the way services are shared equitably among stakeholders. For instance, when water is scarce, how is the water deficit shared between all users? Equity is a key issue in irrigation system management.

Reliability looks at the predictability of service over time. A reliable service is basically a predictable service. Users can plan for long-term strategy when they are receiving a reliable service. For instance, in irrigated agriculture it might be better to have an inadequate service (lower than needed quantity) but highly reliable, rather than an adequate but unpredictable service in terms of schedule. With a reliable service users can plan for the season.

2. MASSMUS APPROACH to the OPEN CHANNEL SYSTEM

MASSMUS is an evolution module of the generic methodology for auditing irrigation management performance called Mapping System and Services for Canal Operation Techniques (MASSCOTE). Developed by the Land and Water Division (NRLW) of FAO it is based on experience gained while modernizing irrigation management in Asia (FAO, 2007). MASSCOTE integrates and complements tools such as RAP and Benchmarking thus enabling a complete sequence of diagnosis of external and internal performance indicators, and the design of practical solutions for improved system management and operation.

The MASSCOTE methodology aims to evaluate current processes and performance of the management of irrigation systems and to develop a project to modernize canal operation.

Irrigation managers find operation complex, as they are required to be consistently in control of all the following aspects:

- service to users;
- cost of producing the services;
- performance monitoring and evaluation;
- water resources – constraints and opportunities;
- physical systems – constraints and opportunities.

MASSCOTE aims to organize project development into a step-by-step revolving framework that includes:

- mapping of system characteristics, water context and all factors affecting management;
- delimiting manageable subunits;
- defining the strategy for service and operation of each unit;
- aggregating and consolidating the canal operation strategy at the main system level.

MASSCOTE is an iterative process based on ten successive steps, but more than one round is required to determine a consistent plan. Phase A focuses on baseline information, while Phase B aims to characterize the relative size of each water service. Phase C focuses on the vision of the scheme and the options available for improvement of water service management.

The relationship between MASSCOTE and MASSMUS

MASSMUS is simply a MASSCOTE auditing approach that has been specifically developed to address MUS for irrigation systems. MASSMUS follows the iterative step-by-step process in ten steps (Table 2.1). MASSMUS = Mapping System and Services for Multiple Uses of Water Services

A preliminary step (Step 0) has been introduced into the MASSMUS module to map multiple services provided to different users by the irrigation system. These services could be intentional or official or unintentional or unofficial. Until Step 6 the steps are conducted for the entire command area, whereas following steps deal with various scales of management units.

The objective of Step 7 is to identify homogeneous managerial units for which specific options for canal operation are further sought by repeating the various steps of MASSCOTE for each unit taken separately.

Finally, aggregation and consolidation of the outputs are carried out at the main system level with steps 10 and 11. Thus, the methodology uses a back-and-forth or up-and-down approach for the different nested levels of management.

The following chapters present the MASSMUS methodology. Although this is a standalone manual dedicated to MUS, it is assumed that the classical MASSCOTE approach for a canal irrigation network is known. If required, readers are requested to refer to the MASSCOTE manual for the details of the methodology.

What is the time frame of a MASSMUS exercise?

A MASSMUS application lasts a minimum of one week but there is no upper limit. It might take several years before a new management procedure can be set in place with numerous and diversified stakeholders.

One week is the minimum duration for a preliminary MUS appraisal of a MUS system: the outcomes will be very basic in terms of quantification of shares per use. The value of this preliminary MUS appraisal is that it reveals the various water services, sensitizes stakeholders and initializes the long-term process of modernization.

Before initiating an appraisal, a RAP should be carried out for infrastructure, which is another week of investigation. Usually an FAO intervention is a two-week exercise focusing on capacity development: while investing a system, participants receive training in various aspects of MASSCOTE and MASSMUS methodologies.

At the end of the initial two weeks the process may be considered as having started and needs to be continued by a local team. Further investigations have to be carried out depending on the needs identified during the first phase.

Several months to years are often required to discuss and consolidate the first phase with the stakeholders.

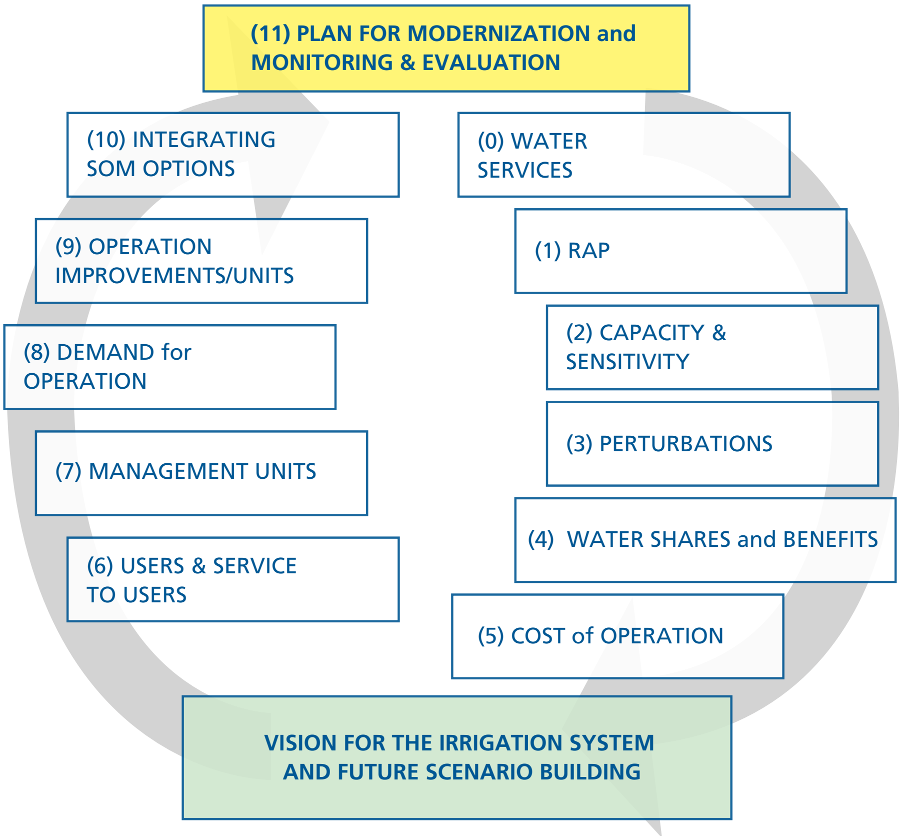
Ultimately, modernization may be considered a never-ending process: changes, adaptation improvements are continuously necessary to cope with evolving demand for services. Thus it is important to start the process and deviate from the status quo.

TABLE 2.1
The step-by-step MASSMUS process

Mapping	Phase A – baseline information
0. Water services	Initial mapping of the various services provided by the irrigation system to different users either intentionally or unintentionally.
1. Performance (RAP)	Initial rapid system diagnosis and performance assessment through the RAP. The primary objective of the RAP is to allow qualified personnel to determine systematically and quickly key indicators of the system in order to identify and prioritize modernization improvements. The second objective is to start mobilizing the energy of the actors (managers and users) for modernization. The third objective is to generate a baseline assessment, against which progress can be measured.
2. Capacity and sensitivity of the system	The assessment of the physical capacity of irrigation structures to perform their function of conveyance, control, measurement, etc.
3. Perturbations	The assessment of the sensitivity of irrigation structures (offtakes and cross-regulators), identification of singular points. Mapping the sensitivity of the system.
Mapping	**Phase B – Sizing each water services**
4. Share of water uses and benefits.	This step first assesses the share of water for different uses based on a comprehensive water accounting procedure and second determines the benefits associated to each water services (monetary, value, etc.)
5. O&M cost to produce the services	Mapping the costs associated with current operational techniques and resulting services, disaggregating the different cost elements; cost analysis of options for various levels of services with current techniques and with improved techniques.
Mapping	**Phase C – Vision of SOM and modernization of canal operation**
6. Users and service to users	Mapping the representative users that should be involved in the stakeholder process. Mapping and economic analysis of the potential range of services to be provided to all users and uses of water.
7. Management units	The irrigation system and the service area should be divided into subunits (subsystems and/or unit areas for service) that are uniform and/or separate from one another with well-defined boundaries.
8. Demand for operation	Assessing the resources, opportunities and demand for improved canal operation. A spatial analysis of the entire service area, with preliminary identification of subsystem units (management, service, O&M, etc.).
9. Options for canal operation improvements and units	Identifying improvement options (service and economic feasibility) for each management unit for: (i) water management, (ii) water control and (iii) canal operation.
10. Integration of SOM options	Integration of the preferred options at the system level, and functional cohesiveness check.
11. Vision and plan for modernization and M&E	Consolidating a vision for the Irrigation scheme. Finalizing a modernization strategy and progressive capacity development. Selecting/choosing/deciding/phasing the options for improvements. A plan for M&E of the project inputs and outcomes.

The rationale for MASSMUS is a step-by-step methodology to map performance and plan management modernization. In a nutshell, ‘Services provision’ is analysed for capacity versus demand; sensitivity or reaction to perturbations; water sharing; cost; description of services; demand for operation; and management improvements.

FIGURE 2.1
Step-by-step MASSCOTE–MASSMUS process



MASSMUS PHASE A – BASELINE INFORMATION

Step 0: Numbering water services

Objective: census taken of known uses of water services along the infrastructure and within the command area.

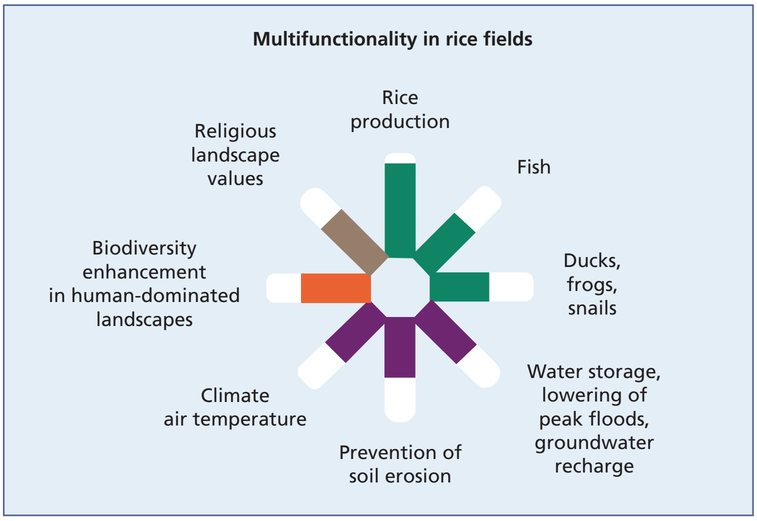
At the start MUS may be simply assessed by numbering the different water services or uses of water reported throughout the irrigation system's command area. This will not indicate the relative importance of various uses, this will be revealed by additional information of each use (see Step 4). An example of numbering the services is shown in Figure 2.2 for irrigated paddy cultivation.

This preliminary step is important for allowing rapid initiation of investigations required for each identified use before or at the start of the MASSMUS exercise.

Step 1: RAP for MUS

Objective: Initial rapid system diagnosis and performance assessment based on the RAP. The primary objective of the RAP is to allow qualified personnel to determine systematically and quickly the system's key indicators to identify and prioritize modernization improvements.

FIGURE 2.2
Ecosystem services in rice fields



Extracted from CA, 2007; Chapter 6

The second objective is to start mobilizing the energy of the actors (managers and users) for modernization. The third objective is to generate a baseline assessment, against which progress can be measured.

An accurate diagnosis of the pre-modernization performance situation is often the most important phase in the modernization process. It provides a good indication of the system's constraints and problem areas.

This step is the foundation on which to base managerial improvement and increased performance of canal operation procedures for irrigation services. The addition of MUS to the initial RAP methodology contributes to understanding how far MUS is integrated into the process and clarifies how far the infrastructure may allow improvement of the quality of multiple services to users.

Rapid Appraisal Procedure (RAP) for MUS

The RAP is a systematic set of procedures used to diagnose bottlenecks, performance and service levels within an irrigation system. It provides qualified personnel with a clear picture of where conditions must be improved and assists in prioritizing the steps for improvement. Furthermore, it provides key internal and external indicators that can be used as benchmarks to compare improvements in performance once modernization plans are implemented.

FAO developed the RAP for large-scale surface irrigation in the late 1990s together with the Irrigation Training and Research Centre (ITRC) of California Polytechnic State University (FAO, 1999). In 2008, FAO developed a similar evaluation procedure for lift irrigation systems. This section documents the relevance and main features of the RAP for MUS.

The basic aims of the RAP are to:

- assess current performance and provide key indicators;
- analyse O&M procedures;

- identify bottlenecks and constraints in the system, and
- identify options to improve performance.

Application of the RAP is based on a combination of field inspections to evaluate physical system and operations; interviews with operators and managers to evaluate management aspects; data analysis to evaluate energy balance, service indicators and physical characteristics and meetings with user groups.

The RAP is:

Systematic – conducted using clear, step-by-step procedures, is well planned and precise.

Objective – if performed by different professionals, the results do not differ.

Timely and cost-effective – does not take too much time, and is not expensive.

B**ased on minimum data –** required for a thorough evaluation.

The physical infrastructure or hardware

The physical infrastructure or hardware (pumping station, inlet and outlets pipelines, safety structures, etc.) of an irrigation system is the major physical asset of an irrigation authority or water service provider.

Keeping the infrastructure/hardware in reasonable shape and operating properly is the only way to achieve cost-effectiveness in producing water services. The main items to examine while appraising the physical characteristics of a system are:

- assets – storage upstream and downstream of the station; pumping or lifting devices; inlet and outlet lines;
- capacities - reservoir, conveyance, pumping station or plant, other structures such as safety structures;
- maintenance levels;
- ease of operation of control structures;
- accuracy of water measurement devices; and
- communication infrastructure.

The RAP exercise is supported by spreadsheets allowing data to be recorded preset indicators to be automatically calculated.

Specific Worksheet: MUS

The RAP–MUS worksheets are basically the same as for the classical RAP developed for gravity fed canal with an additional worksheet (7a.) developed for the MUS and few tables and graphs added to Sheet 1. The main elements to be filled for each use or service are shown in Table 2.2.

External indicators: ASSESSING the various VALUES of MUS

In a classical RAP, the external indicators (productivity) based on the gross value of the agriculture production are easy to estimate and are already included in Step 1. In the MASSMUS module, these indicators are discussed in more detail in Step 4: water uses and benefits.

TABLE 2.2
Elements to be filled for each specific water use or service in Worksheet 7a

Bulk water to cities
Means of delivery/provision
Characteristic of the service: definition
Service achievement
Use of water: Consumptive vs. non-consumptive – (fraction recycled)
Use vs. other uses: How would you characterize the coexistence of this use with others
In case of conflict concerning water use or system operation explain in few words in the cell below
Users and Governance
Service remuneration and associated taxes
Remuneration of the service by users/organizations directly to the Water Management Entity
Fee associated with the service paid by user/organizations to the State
Water use tax paid by user/organizations directly to a Water Basin Authority.
Value associated with or generated by the service

Internal indicators

Three internal indicators are considered in RAP-MUS. These include:

1. Number of water services – This indicator simply establishes the number of water services provided, intentionally or unintentionally, by an irrigation scheme.
2. Degree of MUS integration – This indicator establishes the level of MUS integration into the management of an irrigation scheme and the way managers see multiple uses within the command area. Table 8 provides the grid used for ranking MUS integration.
3. Importance of each water service – This indicator ranks the importance of each water service provided by an irrigation scheme (Table 2.3).

Internal Indicator 1: Number of water services

Although irrigation systems are often designed for single use, or with a limited number of additional services such as flood protection and drainage, in practice they provide water services for many more uses. The number of services reported sets the extent of MUS in one system and is the first internal indicator of MUS.

Internal MUS Indicator 2: How is MUS integrated by management?

A special MUS internal indicator in Worksheet 5 ‘Project Office question’ ranks the way managers see MUS, on a 0–4 grid. Table 8 provides the ranking of MUS integration. Parallel to the previous ‘Stated’ MUS integration, the visitor to the scheme is asked to make a similar ranking (worksheet 7a ‘MUS’ lines 8–13) after field site investigation. This MUS ranking is the ‘actual’ integration, which can be compared with the ‘stated’ as for other criteria to evaluate the indicator of chaos.

Figure 2.3 displays the number of services reported and the integration of MUS in the management based on a 30 systems surveyed by FAO. A general trend of good level of integration with high numbers of uses can be noticed.

TABLE 2.3
MUS integration ranking for management and operation

Indicator value	Management attitude	Local level operators and local practices (as seen in the field)
0	Ignoring or denying MUS and/ or its magnitude	Interventions to prevent canal water uses for other than irrigation.
1	Blind eye to MUS practice by users *Manager is aware of some MUS related practices but does not consider them part of job.*	No intervention to reduce direct pumping from canals No particular concerns about groundwater pumping No intervention to prevent use of canal as a waste disposal.
2	Positive marginal practices to support MUS. Manager is aware of some MUS and positively considers some related practices.	Local operators accommodate in their day-to-day practices the other uses of water. e.g. leaving unfixed leakages to drainage when water is used by the downstream people/villages, and letting unauthorized gate flowing into nearby small tanks or drainage.
3	Integration of other services concerns into the operation. *Manager knows and organizes management to serve other uses or to ensure that operation for irrigation does not penalize other uses.*	Bulk water deliveries to village tanks. Main canal filled with water after irrigation season to provide water to people in the GCA. Local reservoirs managed to account for other uses. Minimizing period of canal maintenance.
4	Integration of multiple uses services into the management and governance. *MUS is fully integrated into Management Operation and Maintenance. Governance is made on the basis of multiple services with multiple users/stakeholders.*	Each service is well defined. Users well identified, they pay for services; have a say in decisions regarding system management.

FIGURE 2.3
Figure 2.3 Extension of MUS and integration for management & operation

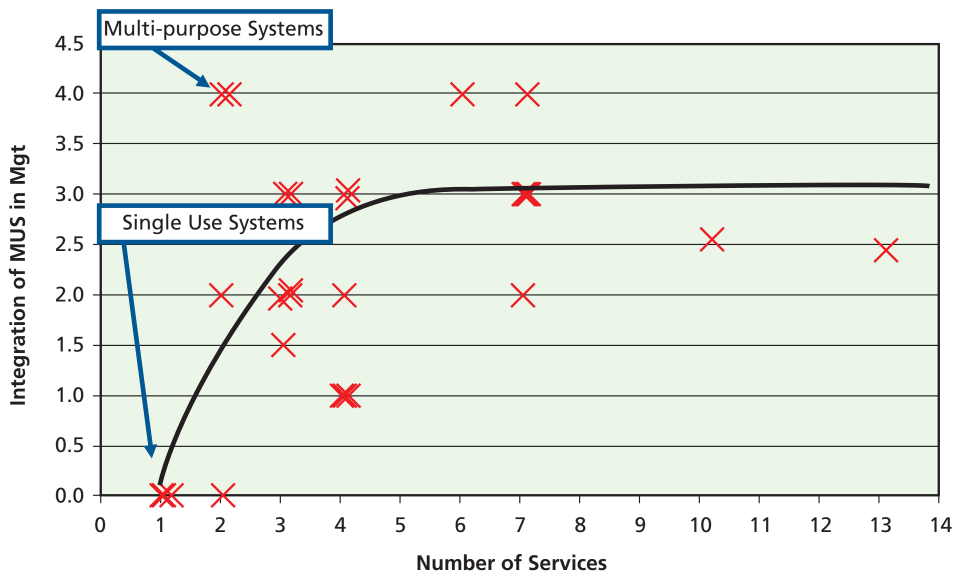


TABLE 2.4
Internal MUS Indicator 3 – Importance of water services

Water use	Importance of water use (0 = not important; 4 = extremely important)	
	Luong Tai district	Kim Dong district
Water supply to crops	4.0	4.0
Cultured fishery in ponds	3.0	3.0
Animals	1.5	3.0
Domestic water supply to small towns	3.0	4.0
Domestic water supply to villages and individuals	2.0	2.5
Small industry and businesses	2.0	3.0
Homestead gardens	2.0	2.0
Perennial vegetation	2.0	2.0
Factories and small businesses and sewage disposal	-	3.0
Environmental flows	-	3.0
Transportation	-	4.0
Flood protection	-	4.0

(Example taken from Luong Hai and Kim Dong districts in BHH Viet Nam)

Internal MUS Indicator 3: Importance of each use/service

The absolute and relative importance of each reported service is estimated during the RAP exercise using a 0–4 ranking.

Irrigation managers should assess the importance of each service based on absolute importance. They should consider alternative sources of water available for each water use, and the impact that removing canal irrigation would have on the service. Both quantity and quality of water have to be considered when rating for importance. An example is given in Table 2.4.

The details of the methodology and description of RAP worksheets are given in Annex 1. Readers are also invited to refer to the MASSCOTE document for this purpose.

Step 2: Capacity and Sensitivity for MUS

Objective: To characterize the way infrastructure capacity and management is solicited and challenged when producing the agreed upon services, and to identify the managerial and physically sensitive aspects that managers need to bear in mind when producing the services.

In general terms, Step 2 of the MASSCOTE approach refers to the physical characteristics of the canal system that are of operational importance with respect to their various functions: conveyance, water-level control (regulator), diversion (offtake) and division (proportional dividers) and storage. It also discusses the functions of some specific structures, including drops, siphons and escapes/spills.

This physical approach is tackled in terms of capacity to perform the said functions and the reaction of the structure (sensitivity) when affected by a perturbation.

With the MUS perspective in mind, these physical characteristics should be analysed not only referring to irrigation delivery services but for all other services that are important for the system operation and management. Of course, the multiple services of water are of different nature as explained in detail in the Section on Water services, thus the capacity and sensitivity might be different depending on whether the service is:

- delivery (controlled flow);
- volume over a period of time;
- presence of water;
- maintenance of a specific water level in water bodies;
- non-point groundwater recharge;
- other.

The capacity for different uses may interact and sometimes conflict. A good example of a conflict is the impact of canal seepage. On the one hand, canal seepage usually generates a diminution of flow transported at tail reaches; on the other, it augments groundwater recharge that may be useful for other uses in the CA.

Infrastructure capacity

For effective operation of any irrigation system, managers must know the capacity of the structures within their CA. System capacity needs to be assessed (or re-assessed) properly at each main structure, considering the main functions (storage, transport, diversion, etc.).

The RAP evaluates the canal capacities of structures in the system in general and provides a first indication of where capacity problems may exist. However, the system manager requires a greater and in-depth understanding and knowledge of all the structures and their capacities to enable improvements in routine operation and management.

In the MASSCOTE approach, capacity and functionality of canal system are assessed for each physical structure with respect to four main features:

Functionality – whether the infrastructure/structure is functional or not;

Capacity – if functional, what is the structure's actual flow capacity with regard to its function (possibly compare with design and/or ideal target);

Ease of operation – how easy is the structure to operate;

Interference – does the structure adversely impact the behaviour of other structures (perturbations to other hydraulic structures).

Sensitivity of the infrastructure

How a canal system behaves after the structures have been set for a particular water distribution plan and left without attendance is the central focus of a sensitivity analysis. It is important to know how structures react or behave under perturbation in order to plan adequate actions or responses. For irrigation deliveries, sensitivity is a short-term concern (hours, days).

Perturbations of discharge and of water levels along a canal are the norm, rather than the exception. Perturbations are propagated and transformed downstream. Therefore, what appear to be minor differences at the head-end may result in serious deviations from the planned operation, or even chaos resulting in overflow from canals, while others fall dry.

The analysis of the behaviour of irrigation structures should be performed based on the assessment of sensitivity of: (i) each main type of structure taken in isolation; (ii) a combination of associated structures; and (iii) at the reach and subsystems levels.

Finally, it can be shown that the performance along a subsystem is linked to sensitivity of irrigation structures at network nodes and the control of the water depth along canals.

Capacity and sensitivity for multiple services

For MUS the capacity at stake is the capacity that deals with all types of service. Capacity must be seen as a **physical capacity** as well as a **time capacity.** For instance, irrigation canal systems are regularly (annually) out of service for repair and maintenance, because the irrigation season is over or simply because of canal rotation. This results in services to other uses being reduced or cut during these periods. Thus, the capacity issue for MUS is also a calendar issue throughout the year.

The requirement for maintaining canal capacity for other uses may drastically reduce the period of time available for closure for repairs and maintenance. An example can be found in the Indus river basin irrigation systems, where health considerations for the local population mean that the canals cannot be closed for any significant period. This often conflicts with the requirement for repairs and maintenance works on the system.

As recalled previously, sensitivity analysis offers a practical method to analyse the impacts of fluctuations in irrigation systems. For the MUS system, the sensitivity would then be the result in terms of amplitude of variation of water services versus the amplitude of perturbations. In Table 2.5 indications of capacity and sensitivity issues are provided for several multi-services.

STEP 3: PERTURBATIONS

Objective: To identify and characterize any type of perturbation that is likely to occur along the infrastructure and within the CA in order to prepare appropriate responses.

This step is important for maintaining the quality of service regardless of unexpected changes of input or outputs including illicit operation.

A canal system is characterized by inherent instability of flow conditions. Perturbations of water variables (level and discharge) along an open-channel network are the norm not the exception. Perturbation is a permanent feature of irrigation canals owing to the upstream setting of structures and is compounded by intended or unpredicted changes in inflows/outflows at key nodes. So, despite management efforts to control the conditions of water flow, internal or external perturbations are generated along a canal infrastructure and, once they have occurred, they usually propagate downwards.

It is common to see amplification of perturbations along canals leading to instability that penalizes downstream users. However, systems with highly sensitive structures tend to divert the perturbations towards nearby command areas, which are served by sensitive offtakes. This is the reason why perturbation and sensitivity are interconnected (see Step 8 on the demand for operation).

TABLE 2.5
Examples of capacity and sensitivity for multiples uses

Services	Characteristics required for the service	Capacity	Sensitivity
Domestic water	Highly reliable controlled flow High quality of water	Reduced during canal closure	Highly sensitive to scarcity and pollution
Water to cattle	Access to canal water Supply to water ponds	Reduced during canal closure	Sensitive to water scarcity Sensitive to long time of travel to reach water Sensitive to pollution
Groundwater recharge	Canal seepage Field losses Specific recharge facilities	Reduced by canal lining Reduced during canal closure	Low sensitivity to irrigation interruption
Homestead garden	Groundwater pumping High water table to feed root system	Groundwater recharge and percolation from adjacent fields Vertical and horizontal distances to groundwater Pumping facilities	Low sensitivity to irrigation interruption
Environment	Environmental flows	Availability of water	Water scarcity Pollution
Fishery	Presence of water	Minimum water flows or volume in water bodies at season's end.	Sensitive to long term quality Sensitive to water scarcity

In general terms, and having MUS in mind, a perturbation is defined as:

An unplanned variation in the influencing conditions that may lead to a significant change in the intermediate or ultimate delivered services.

The nature of perturbation is a function of the service specificities. Perturbations are quite different in terms of duration: for a delivery point in irrigation, fluctuations lasting less than 1 hour can have serious impacts on the service delivered, whereas for groundwater recharge, only a shortage of long duration can yield to a noticeable change in the aquifer.

Imprecision and uncertainty of flows

Imprecision and uncertainty plague the process of canal operation. The main issues that exacerbate imprecision, and thus contribute to the complexity of canal operations, are:

- **Accuracy:**
  - inaccurate data for water demand and main sources of water (inflows);
  - imprecise anticipation of the impact of downward propagation of waves caused by operation itself; and
  - inaccurate action or gate settings.
- **Interventions:**
  - inappropriate reactions to scheduled and unscheduled perturbations;

- – incorrect operation procedures; and
- – illicit interventions.
- – Unscheduled external perturbations:
- – from the source upstream – or unexpected runoff along the canal; and
- – unexpected rainfall causing perturbations – may require closure of canals and disposal of additional water.

In this context, as far as operational decisions are concerned, fluctuations in inflows are as important as fluctuations in the demand. In general, irrigation systems may experience inflow fluctuations caused by:

Return flow – overflows from distributary channels or from fields that return to the irrigation system – these vary over time.

River diversion supply – run-of-the-river systems are subjected to greater variability in inflows than are reservoir types.

Canal branch diversion and canal serial diversion – a branch subsystem can exert a limited control on the supply rate, whereas a serial diversion has no control, i.e. the flow from upstream must be accepted at the supplied rate. Fluctuations at this point are the result of upstream operations.

Single-bank – single-bank canals, i.e. canals without a built bank on the uphill side, also called contour canals, are quite common in slightly undulating topography. Large inflow fluctuations are the results of unregulated runoff entering the canal system during rainfall events.

Some systems, however, are not as affected by inflow perturbations, these are usually those fed by a well-regulated reservoir and serving a double bank canal network where intrusion is limited if not nil.

Features that are worth considering for inflow variations management are:

Localized storage – the presence of an intermediate reservoir within the system is an opportunity to damp perturbations.

Return flow – diverting positive perturbations towards areas with return flow enables implementation of efficient reactions.

Reuse system – positive perturbations can be diverted preferentially towards areas where it is known that water can be recycled downstream.

Water quality perturbations

Additional perturbations that may need to be looked at are related to water quality, which is particularly important when domestic and water for cattle are part of the services. For example, runoff from a nearby urban area that enters the canal system may create water quality shocks that have to be considered as a perturbation to be dealt with.

Mapping and managing perturbations

Mapping perturbations is essential for incorporating perturbation into system management and operation. It means identifying and characterizing their dimensions as well as the available coping mechanisms, including: (see Table 2.7):

- origin;
- frequency and timing;
- location;
- sign and amplitude; and
- options for coping.

Managing perturbations is to ensure two basic objectives:

- passing variable flows without adversely affecting on line services;
- perturbation is integrated properly into management, by coping with service perturbation, e.g. compensating for a water deficit if the perturbation is negative, or by storing the surplus if it is positive.

To achieve these objectives, there are two options:

- Set up infrastructure in such a way that perturbations are dealt with automatically, e.g. the surplus is diverted automatically towards areas that can store or value the water.
- Detect the perturbations and have a proper set of procedures so the operators can react.

The perturbations should be assessed considering three constituents:

- causes of perturbations;
- frequency of occurrence;
- magnitude of perturbations experienced.

The causes of perturbations are largely determined by the network properties of the canal system. Static properties are: the source of supply; hydraulic layout and variability of discharges; interconnections with other networks, such as drainage; unregulated return flows, etc.; and the number and type of offtakes and regulators. A second cause of perturbation is the operation of the irrigation regulation system itself. The operation of offtakes and regulators generates transient conditions in the network, just as any obstruction of flow, withdrawal and rejection, either planned or illicit. The level of perturbations can be significantly influenced by the complexity of the distribution setup and the control mechanisms for diversion and abstraction.

The position in the network is a determining factor for the frequency and magnitude of occurrence of transients, and partially explains the well-known ‘head/tail’ issue in irrigation systems. In general, deviations from planned water deliveries are larger and occur more frequently in the tail end of a system. This is linked directly to the number and operational characteristics of upstream structures. Slight deviations in the head-end are amplified owing to minor management errors at all nodes. Furthermore, once the gates have been set, the sensitivities and flexibilities of structures determine whether perturbations are attenuated or amplified and, thus, spread throughout the system.

TABLE 2.6
Perturbations and potential solutions

Type of perturbations	Solutions (options for managing perturbations)
Positive perturbations Nature (inflow-outflow – internal) Magnitude (water-level fluctuation – relative discharge variation) Frequency	Share the surplus among users, particularly relevant where the system is proportional. Divert and store the surplus into storage capacity.
Negative perturbations Nature (inflow–outflow – internal) Magnitude (water-level fluctuation – relative discharge variation) Frequency	Use storage to compensate. Check for immediate correction. Reduce delivery to some offtakes with compensation later on (less sensitive/vulnerable areas, delivery points with storage facilities, with alternatives source of water).
Quality perturbations Pollution High silt load	Temporary closure of delivery points during first stage of runoff.

Perturbations are expected whenever there is a change in distribution. Therefore, the scheduling and distribution policy (on-demand, arranged demand, or rotation) is a key determinant of the frequency of perturbations. The greater the flexibility of the service being provided the greater will be the frequency of flow changes in the canal system. Proper consideration of the impacts of service flexibility on the perturbation domain is essential in order to identify the specific operation modes and structure characteristics required for acceptable performance.

MASSMUS PHASE B – ELEMENTS USED TO IDENTIFY WATER SERVICES

The relative importance of each water use as part of the MUS management must be assessed through appropriate indicators such as the:

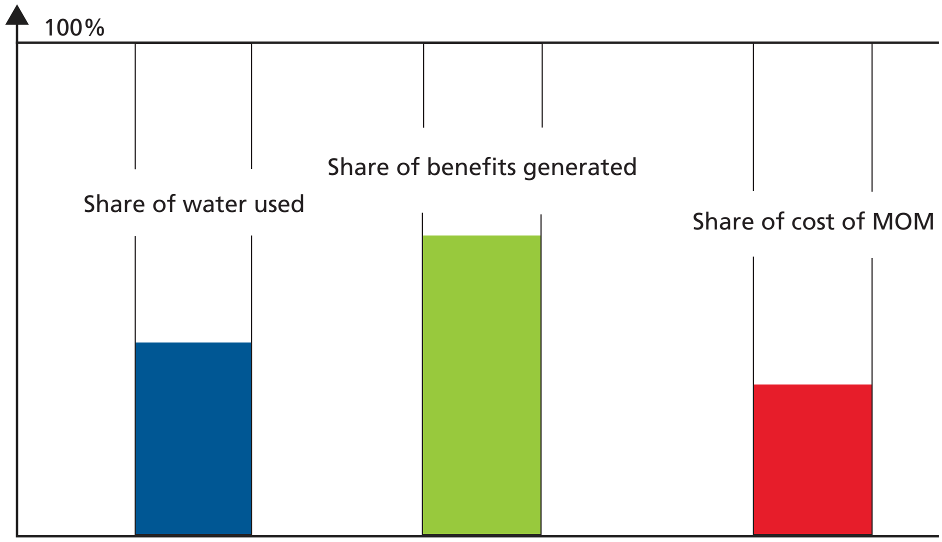
- quantum or share of water use (or magnitude of the use) considering both water quantity and water quality
- share of the total benefit generated by this use.
- share of the cost to produce the specific service.

Three elements are considered to be critical for sizing the importance of a water use: water, benefit and cost. (Figure 2.4). This is detailed in Steps 4 and 5 of MASSMUS.

The value of water use: a critical dimension for governance

Another critical issue related to the governance of a MUS system is determining how stakeholders value the various uses of water. This question goes beyond the strict approach of benefits to include the preference of users among alternatives. Approaching the values of water uses is important but requires a more in-depth survey in the form of user interviews. Interviews will allow managers to understand on what grounds comparison among uses should be undertaken, how decisions should be made and conflicts resolved. While there is no attempt in MASSMUS to address stakeholder values, a clear output of MASSMUS application can often be the recommendation that managers undertake an assessment of how stakeholders actually value water services.

FIGURE 2.4
The three main dimensions of a water use in a MUS irrigation system



The value is critical when the specific use has to be included fully into the management set up considering:

- stakeholder or actor representative of the uses;
- definition of the specific corresponding service;
- share of MOM cost coverage to sustain the water services.

Step 4: Water shares and benefits

Objective: To characterize the importance of each water use with two dimensions: the share of water use/consumption and the associated benefits to the users and population.

This step is important for promoting better understanding of the size of each use and the associated productivity (benefits per volume use).

Before detailing the process of accounting and evaluating the share of each specific use, it is important to gather critical information of the system under consideration. Most of the ‘consumptive use’ of water occurs through either evaporation of land surface (soil, stream and water body) or transpiration of the canopy (crop and natural vegetation). It is therefore critical to start the process of evaluation with **an accurate map of the gross command area (GCA) and land use within**.

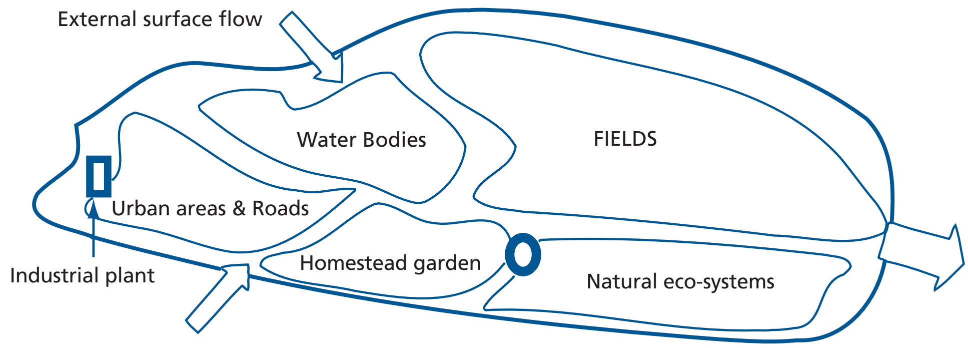
Mapping land use and water-related activities in the GCA

A good map gives a clear indication of the water uses within the CA and of the associated beneficiaries. It is important that external basins contributing to the runoff into the GCA are delineated to account for contribution from precipitation. Localized activities (not associated to a large area) also need to be identified on the GCA map (see Figure 2.5).

Mapping the groundwater system

Although it is a significantly more difficult task, the groundwater system to which the GCA is associated should also be mapped. What and where are the boundaries of the aquifers? Which lateral transfers should be considered? Physical properties and water fluxes at boundaries are often not accurately known. What is often known is the elevation of the water table over time. This gives a clear indication of the long-term changes and sustainability of water resources in the area, however this is not enough to calculate the water balance.

FIGURE 2.5
Sketch of the GCA (System upper layer) with indications of main land uses and activities



Mapping human activities in the general command area (GCA)
It is also important to have an idea of the population distribution and the extent of the various economical activities:

Farming – number of farmers, gross product

Fisheries – number of fishermen, gross product

Employment – number per type, gross product

Population – number of households (rural and urban)

Mapping water users groups, actors and stakeholders
For each use of water, one needs to identify the type of users, the users' group and actors such as the regulatory authority for the use and key stakeholders. For instance, in the Kirindi Oya project (Sri Lanka) numerous stakeholders were identified including farmers' organizations, fishers, cattle grower unions, city council, Chamber of commerce (tourism) and environmental groups. Shareholders and regulatory authorities include the many relevant departments, including health.

Step 4.1: Water shares

Determining the water share per use and service is part of an overall water accounting approach that must be carried out for the CA or subcommand areas.

Water accounting, also called water balance, refers to the accounting of the influxes and outfluxes of water in a given space and time. Water accounting is an important part of the MASSCOTE process and the foundation for a modernization project. With the MUS approach no specific demand for water balance is required but it strongly reinforces the need to measure each and every use of water in the gross command area (GCA).

FIGURE 2.6
Sketch of water balance in an irrigation system

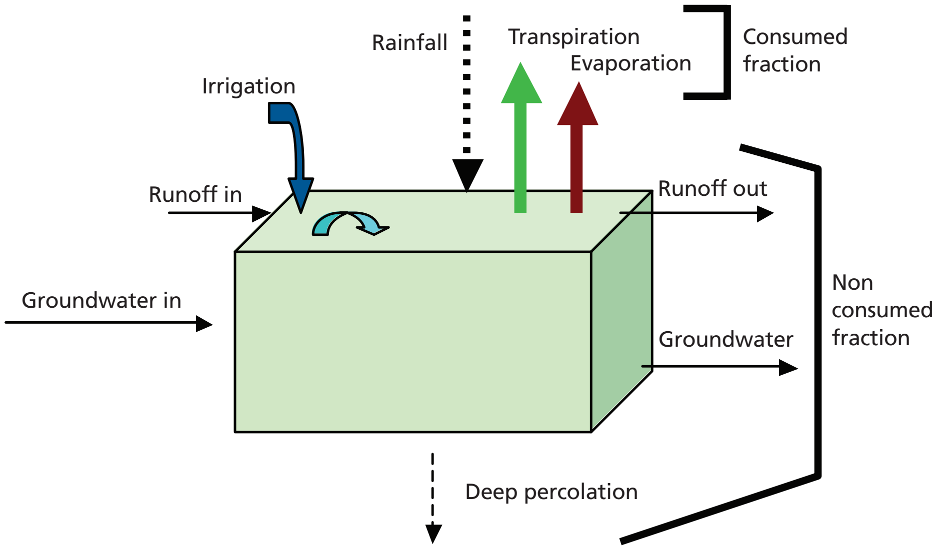
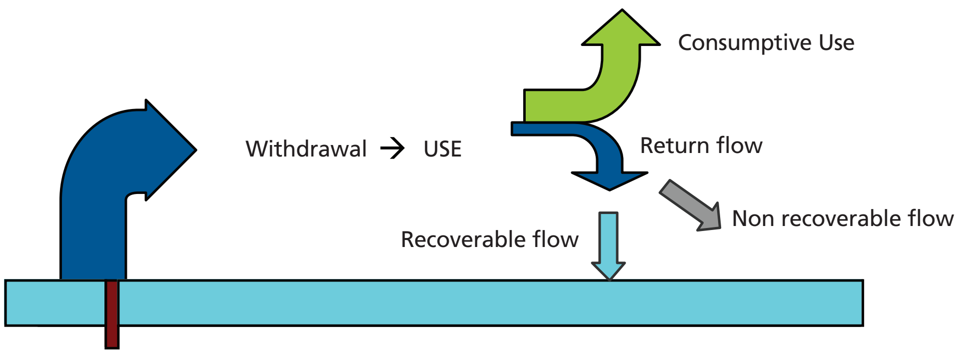


FIGURE 2.7
Sketch of water partitioning: consumptive use and return flow



(after Perry C. 2007)

Water in and water out

Water accounting must consider all water (surface water and groundwater streams, conjunctive use, storage and recharge, etc.) that enters and leaves a defined area in a particular span of time.

'Water in' includes precipitation in the CA, the GCA, runoff from adjacent basins, groundwater net contribution and of course irrigation water. 'Water out' requires accounting for evapotranspiration (ET), which is often the main component, runoff out and groundwater lateral out.

Identification of system boundaries to count water

Three important features of water balances are:

Delineation of the physical boundaries – upper limit, lower limit and horizontal limit, accounting for the groundwater boundary as appropriate.

Time frame – year, season, month, fortnight or ten-day period.

Focus – water quantity and water quality.

Water use

The term water use may have several meanings, which are essentially related to one of the following characteristics:

Quantity – water use may consume water;

Quality – water use may reduce water quality (or improve it);

Energy – use of water in hydropower consumes the elevation (energy) of water to produce electricity.

Table 2.7 presents a list of points that need to be investigated 'Water Uses' for MUS. These points are addressed in detail below.

TABLE 2.7
Check-list for estimating water shares

Water use
1. Type of use: Consumptive – Depletive
2. Accounting uses for several beneficiaries
3. Defining the system boundaries (physical and temporal)
4. Setting the terms of water balance
5. By-product of irrigation or stand-alone service?
6. Net lateral groundwater contribution
7. The risk of double-counting
8. Water quality
9. Health issues
10. Urban areas
11. Use of marginal quality water for irrigation
12. Monitoring and evaluating water quality

Checklist in detail

1. Types of use: consumption, depletion, process and beneficial

All uses of water should be characterized and evaluated in order to develop a comprehensive MUS approach. Table 2.8 illustrates the various ways in which water uses can be qualified, such as depletive or non depletive, consumptive or non consumptive, processed or non-processed, beneficial or non-beneficial.

Consumptive use means that water leaves the hydrological cycle. This is found in all uses associated with the evapotranspiration process. It is either the result of a direct process of consumption such as evapotranspiration of crops or perennial vegetation in the GCA or indirect consumption (not necessarily for the process) such as evaporation from water bodies for fisheries, environment, recreation and tourism. The rate of evapotranspiration is closely related to the nature of land use and its water status (well-fed or dry).

Non-consumptive uses are those that return a large part, if not all, of the fraction of water they have taken.

TABLE 2.8
Characteristics of water use

Characteristics of use	Definition	Examples of use
Consumptive	Water leaves the system (hydrological cycle) and returns to the atmosphere	Irrigated crops Homestead garden Perennial natural vegetation
Non-consumptive	Water is not consumed. Water maybe diverted and used but is returned after use	Hydro-power Domestic water (recycled) Animals
Depletive	Water is depleted from the natural resources	Diversion schemes Groundwater Pumping
Non depletive	Water is used on its site without any diversion	Recreational use in aquasystems Ecotourism
Process	Water is needed by the associated producing process	Crop growth Hydropower
Non process	Water consumed is not part of the process, but rather a side effect	Fisheries and evaporation from water bodies Tourism, recreational value
Beneficial	Positive externalities	Groundwater recharge
Non beneficial	No added value Negative externalities	Pollution from agriculture areas

Note:

**Qualification of water use in Table 2.8 is not always clear cut.*

** Evapotranspiration is not the only consumptive use, also found in this category is the fraction of water sunk into deep groundwater aquifers or water that becomes unusable after is has become too degraded. However this consumptive use is rare, which is why it has been restricted to evapotranspiration.*

2. Accounting water uses for several beneficiaries

Identifying beneficiaries and the benefits of water uses is important for ensuring an appreciation of the importance of each use within the GCA. Uses and beneficiaries sometimes coincide, e.g. for crop production and farmers, where the measure of water outputs is limited to one single use. However this is not always the case and water bodies provide a good example of the difficulties that can be encountered when trying to match several beneficiaries with a single water use.

While water bodies use water during evaporation, this use can be related to many beneficiaries (including fisheries, tourism and recreation, environment and wildlife, transport), in addition to storage of water for the dry season and flood protection. There are no simple rules for partitioning the water that has been evapotranspired from a reservoir. A few simple rules need to be found to reach an agreement with stakeholders as to how the consumption should be partitioned per use. The share of the water consumed by a water body can be based on the relative shares for:

- number of beneficiaries, households, jobs;
- monetary value generated per use, and
- environmental values.

3. Defining system boundaries (physical and temporal)

Many criteria need to be considered when defining the physical boundaries for accounting for water in a command area. Whatever the unit of evaluation, a field, a farm, a submanagement unit, or an entire irrigation service area upper, lower and horizontal boundaries need to be defined. Table 2.9 presents an example of defining spatial limits for water balance. It shows that groundwater use or a high water table can significantly influence the lower limits of water balance.

TABLE 2.9
Spatial boundaries of various areas

Space	Upper boundary	Lower boundary	Horizontal boundary
Farm	Crop canopy	Bottom of rootzone	Farm fields
Conveyance system	Water surface	Canal bottom	All diversions, spills and discharge points
Water district without groundwater pumping	Crop canopy	Bottom of rootzone	District
Water district with groundwater pumping	Crop canopy	Bottom of aquifer	District
Water district without groundwater pumping, but with a high water table	Crop canopy	Bottom of aquifer that is tied into the high water table	District

Source: Burt, 1999.

Spatial boundaries of water balance to assist decisions regarding system management and operation would include:

The gross service area of the project – often used as the first approach to examine a global water balance;

Canal hierarchy – main, secondary, tertiary and quaternary; and

Institutional management – federation of WUAs, WUA, farmer organizations.

The above-mentioned criteria may be included in the definition of the water balance. However, it is crucial the water balance is pragmatic. Units for the water balance should be based on realistic boundaries for which flows can be either measured or estimated with reasonable accuracy. In an ideal situation, a water balance is conducted for the entire irrigation service area and each management subunit to allow managers and operators to make decisions within their own subunits as well as at the entire project level.

However, whatever unit is chosen for the analysis, the boundaries must be clearly set and understood.

Setting the spatial as well as the temporal boundaries for water balance is very important. Failure to set these limits properly is often the main reason for errors made in computing water balances.

Setting temporal boundaries

Temporal boundaries are critical when computing a water balance. Depending on the objectives for which the water balance is conducted, temporal limits can be set as multiple years, one year, six months, an irrigation season, monthly or fortnightly. For example, making long-term recommendations on the basis of only a one-year water balance is not robust because such data are often not representative of normal conditions.

The values of most of the water balance inputs, such as rain, surface allocations, and evapotranspiration vary from year to year. For the purpose of making long-term recommendations, 4–5 year average values from water balances done on a yearly basis must be considered. If this is not possible because of data constraints, one wet year and one dry year should be the minimum required.

For the purpose of evaluating modernization strategies, a time frame of a year, six months or a single irrigation season is advisable. Monthly or fortnightly water balances are required where the objective is to use the values for real-time management decisions. However, it is often difficult to assess changes in groundwater storage on a scale of less than one year.

Nevertheless, it is necessary for managers and operators of the irrigation system to keep an account of where water is coming from, and where is it going to within the management units. This allows accurate decisions to be made regarding water conservation, allocation and distribution.

4. Setting the terms of water balance

Whatever the spatial unit being considered, a number of basic flow parameters need to be evaluated:

- irrigation diversions;
- surface runoff into and out of the spatial boundary;
- evapotranspiration (ET) from all land uses of the GCA, fields and other areas such as canals, drains and other non-irrigated areas;
- rainfall within the spatial boundaries; and
- surface drainage, lateral groundwater flows and vertical drainage within the lower boundary limit.

Irrigation diversions are often measured using measurement devices at bifurcations. For a water balance, irrigation diversions entering the spatial boundary must be known.

Rainfall should be measured with sufficient density of points to account for the spatial variability of precipitation, especially if the timeframe of events is short.

Evapotranspiration or crop water use is the largest and the most important component of water balance. It is obtained as the product of crop area and the estimation of crop evapotranspiration (ETc).

Crop evapotranspiration or crop water requirement can be assessed by multiplying the reference evapotranspiration and the crop coefficient: $ETc = Kc \times ETo$; where: ETc is crop evapotranspiration; ETo is the reference evapotranspiration; and Kc is the crop coefficient.

Drainage should be measured at key points, particularly when it leaves the spatial boundary set for water balance and, if necessary, possibly monitored for water quality. Monitoring of the quality of drainage water from irrigated areas is important, in particular where this water is to be used for irrigation downstream, in order to keep a check on the safe levels of agrochemical loads.

Groundwater fluxes, i.e. lateral flows and vertical drainage, are often the most difficult aspects to handle in water balance. While direct measurements of groundwater flows are not possible, water table levels can be measured, and groundwater or hydrological modelling can be used to reconstruct the flows using trial and error and comparison with field data. It is not always easy, however, to calibrate these models owing to a lack of empirical data. An easier way of monitoring the changes in groundwater is to install monitoring wells, which should be done locally where possible.

Groundwater is an important component of water accounting that could be considered as water supply in addition to surface water, depending on the spatial boundaries of the water balance. In order to avoid double-counting of water entering into the spatial boundary of the water balance area, it is necessary to differentiate between the groundwater that is pumped within the spatial boundary (which may be considered as the recirculation of surface water and rainwater entering the spatial boundary) and groundwater that is pumped outside the spatial boundary but is used for irrigation within the boundaries of water balance.

The setting of the lower spatial boundary will determine whether the use of shallow groundwater and/or deep groundwater is considered a supply or a mere recirculation of surface water supply and rainfall. However, a distinction between shallow groundwater and deep groundwater should be made in the water accounting procedures if they are to be conducted for assisting in management decisions, particularly in semi-arid and arid regions.

Shallow groundwater (less than 20 m) should be incorporated into the lower spatial limits of the water accounting system. If this is done, there is no need to take account of additional water supply from tubewells fed by shallow groundwater.

For deep groundwater use (more than 20 m), this source is generally beyond the limits of the system being considered. Therefore, the specific water supply from deep water should be added to the inflow.

5. By-product of irrigation or stand-alone service?

Depending on whether the service is a by-product of irrigation or a stand-alone service, the water share may vary significantly. For instance, providing raw water along the canal infrastructure for domestic purposes and/or cattle represents a marginal share of water when the irrigation season is on, as the canals are most of the time run full. However, if during the off season managers have to periodically refill the canal systems to provide these domestic services, huge quantities of water must be accounted for these services.

An example of this can be found in the Kirindi Oya Irrigation Settlement Project in Sri Lanka, where irrigation canals are the only source of water in the newly developed areas. During fallow periods, or when irrigation is reduced because of limited water resources available before the dry season, people suffered from lack of water. Without renewed supply, the water quality from sparse available sources deteriorates rapidly.

6. Net lateral groundwater contribution

The lateral net contribution of groundwater (not including recharge from the canals and surface of the CAs) can be estimated as the closure of the other terms, and as such known with considerable uncertainty.

7. The risk of double counting

The risk of double counting a water balance is real. Always ensure that only the fluxes through the boundary of the system are accounted for.

A typical example of this is groundwater pumping or recycling from drainage. While it is important to estimate their value, they should not be included in the water balance if this water has already been accounted for as inputs either from rain or from the irrigation supply. Only external water to the system should be counted, which can be deep groundwater and lateral water from aquifers. The same applies for the surface recycling facilities.

8. Water quality

The quality of water for irrigation is also an important issue for the environment, resource management and the health of the local population. A separate account of quality of water entering into and leaving a physical boundary helps identify water-related environmental hazards. This information can then lead to the identification of appropriate mitigation strategies.

The main issues of water quality in an irrigation system are related to:

Salinity – reduced crop yield, reduced soil quality (FAO 1994).

Pollution – disposal of industrial and municipal wastes into irrigation canals WHO/FAO/UNEP (2006).

Drainage water – from irrigated area with agrochemical loads (FAO 2002).

Health – water-borne diseases, arsenic and heavy-metal contamination.

The quality of water returning to the system after being used may have deteriorated (pollutant, thermal change, etc.). This has to be considered when water accounting is processed as a whole.

9. Use of marginal quality water for irrigation

There are several positive and negative points to consider in relation to the use of marginal quality irrigation water.

Positive points

Marginal quality irrigation water is an important source of water and nutrients for many farmers (small and large scale) in arid and semi-arid climates. When wastewater reuse is well managed, it provides nutrients and water helping to improve crop productivity. Wastewater is, to some extent, the only reliable source of available water for agriculture since fresh water is allocated to industries and households in countries facing physical water scarcity (Middle East, North Africa).

Recycling of nutrients from marginal quality water (nitrogen, phosphorus) leads to eventual savings in fertilizer, which on the one hand is a direct saving to the farmer and on the other provides an environmental benefit. Therefore, the use of wastewater can be a reliable source of water and nutrients for urban and peri-urban agriculture. This can raise incomes, reduce poverty and improve food and nutritional security.

When wastewater treatment services are not provided, the use of marginal quality water for agriculture acts as a low-cost treatment method, taking advantage of the soil and plants capacity to naturally remove contamination and protect the surface streams.

Negative points

Marginal quality irrigation water often contains a variety of pollutants: salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products. Any of these components can harm human health and the environment. The health of farmers can be negatively affected as a result of contact with wastewater, while consumers are at risk from eating vegetables and cereals irrigated with wastewater (typhoid, etc.). Application of marginal quality irrigation water has to be carefully managed for effective use and risk management is needed to prevent adverse health and environmental impacts.

Soil pollution/contamination – Marginal quality irrigation water can severely affect crop yields and damage soils. In particular, in semi-arid and arid countries (e.g. Egypt and Pakistan), soil salinity and sodicity are major problems that have been exacerbated by irrigation from saline groundwater because of unreliable surface water supplies. Additionally, heavy metals in the water are likely to accumulate in the topsoil and the food chain, which can have a serious negative impact on human health.

Conflict with other users – Wastewater from small industries as well as municipal waste is frequently discharged into canals and surface water streams. This creates pollution and health hazards as these canals often provide water for drinking and domestic use.

10. Urban areas

Canals running through settlements, villages and urban areas are frequently used as dumping grounds for refuse. This creates pollution and health hazards for the adjacent communities. It also causes problems of water conveyance by blocking the canals, and eventually disrupts water distribution downstream. It may generate pollution from runoff spilling over from the canal network.

11. Health issues

Although water-borne diseases are not related directly to water quality, they are caused by stagnant water that can occur in water bodies, canals and fields.

The uptake by plants of heavy metals and arsenic through direct contact with irrigation water, or through accumulation in the soil, also poses a threat to human health as these elements can enter the food chain.

12. Monitoring and evaluating water quality

Water quality requires its own monitoring and evaluation (M&E) system, which is not always possible for irrigation managers to organize and maintain because of a lack of technical and financial resources. However, a minimum dataset for water quality indicators needs to be developed and monitored in canal systems. Particularly for those providing water for multiple uses, and where water quality is a major issue, e.g. where the water is known to be contaminated with high levels of arsenic and heavy metals.

An example of water accounting for performance assessment

Figure 2.8 shows an example of water balance at the Kirindi Oya Irrigation System in Sri Lanka for one full year (1998), considering the two crop seasons as well as the fallow period. This water balance was carried out because of the presumed poor performance of irrigation management. The water balance has completely changed the methods used to improve performance in this project (Renault *et al*., 2000). The striking facts brought to light by undertaking a thorough investigation of water balance include:

- Crop evapotranspiration accounts for only 23 percent of the total water supply (irrigation plus rainfall) and irrigation water consumption, which includes the fallow period and evaporation from reservoirs is only 39 percent of total water consumed.
- The bulk of the consumption (52 percent) occurs in homestead gardens and in land covered with perennial vegetation fed mostly by lateral flows from the irrigated areas. These water uses benefit local inhabitants.
- Other users are those who fish in the tanks, and cattle growers for their use of the fallow period on paddy fields.
- A win–win situation was identified for the lagoon, where excessive freshwater from irrigated areas are generating negative impacts for a total of 3 percent of total water volume. Excessive fresh water in the lagoon dramatically reduces the shrimp population, therefore minimizing drainage losses is positive for the lagoon and for crop cultivation as more land can be irrigated.

Another example of water accounting is given in Table 2.11, based on study performed in Viet Nam.

STEP 4.2: Estimating the service benefits

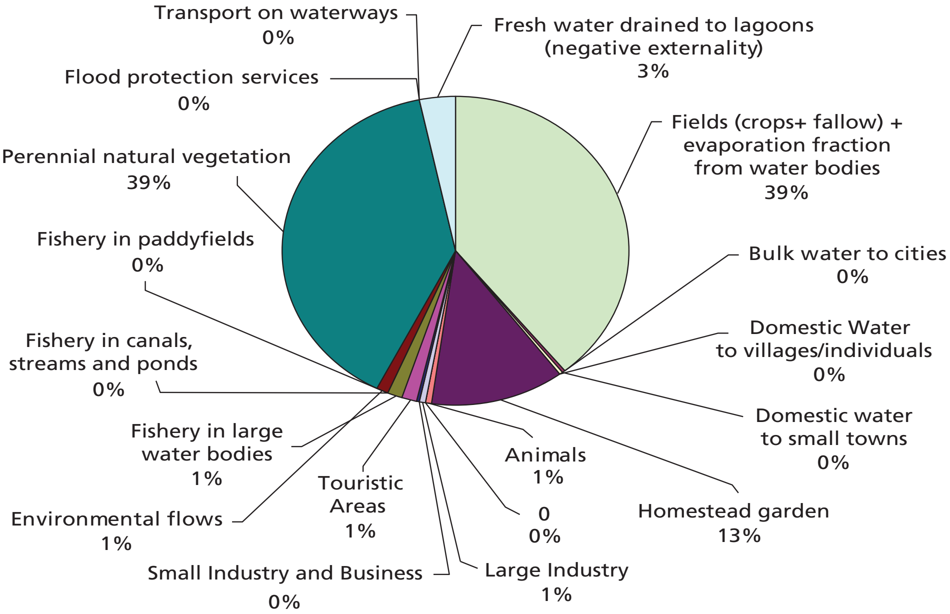
This step is added specifically to the MUS system evaluation. Accounting for the benefits associated to water uses and services is critical for management for many reasons:

1. To raise awareness among key decision makers – the first (and possibly most important) reason for mapping the benefits is to allow full recognition/awareness of the various de facto services provided by the water infrastructure.
2. To improve management and governance of the system with a true service oriented approach.
3. To improve decision-making for water allocation and cost sharing.

Elements of benefit analysis

Before undertaking a benefit analysis certain elements must be considered. First, the benefits associated with each use can be estimated using various indicators:

FIGURE 2.8
Example of the extent of water use, from water accounting



- product generated by the activity supported by this water service;
- jobs/employees;
- number of households served;
- monetary and non-monetary values (social, culture, etc.);
- health impacts;
- environmental values;
- frequentation of a particular location for cultural, social or recreational use.

Second, the actual extent of each benefit can be estimated using different evaluation methods such as:

- gross production supported by the service (crops, fish);
- additional benefit generated by the service (e.g. irrigated vs. rainfed);
- cost of a technical substitution to produce the same service and impacts;
- expressed willingness to pay.

Third, availability of data is critical for the evaluation of benefits and the accuracy with which the assessment can be made.

Finally, as part of a rapid appraisal method, time constraints, pragmatism and data availability will dictate the methodology used to evaluate the benefits.

TABLE 2.10

Water sharing for multiple-use in Kim Dong district – Bac Hung Hai, Viet Nam

	Uses of water	Annual water diverted	Percentage of water returning to the system	Water consumed = water diverted – water returned	Share of water diverted (annual water diverted in /total annual water diverted)	Evaporation fraction in the canals (fraction water diverted * total evaporation from the canal network 1.493 MCM)	Total annual water consumed	Share of total water consumed
		WATER SHARING						
		MCM	%	MCM		MCM	MCM	%
1	Domestic water to small towns	0.06	80	0.011	0.0007	0.0011	0.0121	0.02
2	Homestead garden	2.00	0	2.000	0.0266	0.0396	2.0396	2.76
3	Culture fishery in ponds	1.08	80	0.216	0.0143	0.0214	0.2374	0.32
4	Domestic water to villages/ individuals	0.02	80	0.004	0.0002	0.0004	0.0040	0.01
5	Small Industry and business	0.07	70	0.020	0.0009	0.0013	0.0217	0.03
6	Fields (crops+ fallow)	65.62	0	65.618	0.8712	1.3007	66.9190	90.65
7	Perennial natural vegetation	4.06	0	4.061	0.0539	0.0805	4.1414	5.61
8	Animals	0.79	70	0.237	0.0105	0.0157	0.2530	0.34
9	Drainage/sewage from the industry	0.00	0	0.000	0.0053	0.0079	0.0479	0.06
10	Transport on waterways	0.40	90	0.040	0.0000	0.0000	0.0000	0.00
11	Environmental flows	1.23	90	0.123	0.0163	0.0244	0.1474	0.20
12	Flood protection services	0.00	0	0.000	0.0000	0.0000	0.0000	0.00
	Total	**75.32**					**73.82**	**100**

MASSMUS rapid methodology for mapping benefits

Bearing the above in mind, it is appropriate that a thorough benefit analysis be split into two separate approaches. A comprehensive and congruent benefit analysis of the various water services is beyond the scope of a rapid assessment exercise as usually done in a MASSMUS workshop. Therefore, the first objective for the rapid assessment is to map the order of magnitude of the benefits and produce some useful recommendations for further refined investigations.

The key objective of the MASSMUS process is to identify the more prominent benefits; large inaccuracies regarding the benefits can be expected. This is why reference values can be used to characterize the benefit of each service as the first guess in the process. Further investigations will either confirm or deny the initial figures.

Calculating benefit

As stated above the benefit of the uses or functions can be expressed and determined in many different ways, each of which provides useful information. Following the MASSCOTE methodology, a RAP would serve as an adequate first step in determining

TABLE 2.11
Rapid mapping and in-depth benefit estimation

Initial MASSMUS Rapid mapping benefits	In-depth MASSMUS benefit analysis
1 Initial mapping of the order of magnitude of the benefits.	**1** Thorough analysis of the benefits per services and the values for the stakeholders.
2 Recommendation to carry out in-depth survey of benefits, beneficiaries and values associated with the main identified services as part of the modernization programme.	**2** Indications on how the MUS system should be governed.

values by identifying initial indicators that can be used as benchmarks. Basic indicators of the impacts of different uses or functions could be identified and even ranked on a qualitative scale.

The following table shows examples of value indicators that could be identified using a rapid appraisal approach.

Detailed economic valuation per use may be carried out in the command area following various methods. These methods and their comparative advantage per type of use are briefly introduced in Annex 2.

Figure 2.9 illustrates the importance of non-crop uses in terms of benefits. It is worth stressing that the extra value generated by MUS compared to crop production ranges from 42 percent for Shahapur up to 271 percent for Zanghe. Also noteworthy is the importance of animal production in four out of five systems (animals representing a constant share of 25 percent of the total value generated).

User's shares in financing MOM

Some systems are well developed for MUS, either by initial design or by a progressive adaptation to an evolving water demand. These systems usually share the cost of management operation and maintenance (MOM) among well identified users,

FIGURE 2.9
Partition of benefit shares for five MUS irrigation systems

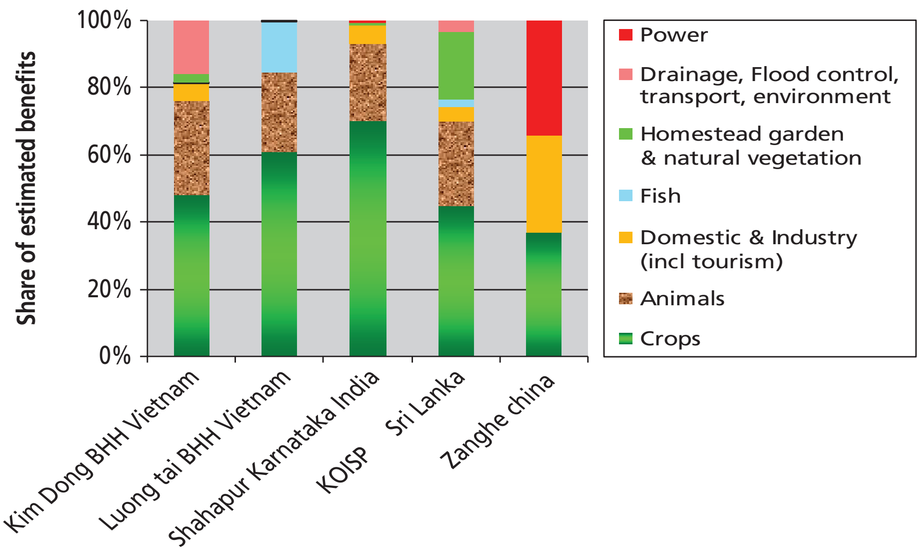


TABLE 2.12
Water use and estimators of possible benefits

Service	Estimator of benefit
Delivery to farms	Crop yields Gross production US$/ha irrigated Gross production US$/m^3
Domestic water	Cost paid by service users Quantity of water taken Estimated cost of an alternative solution Number of capita served
Drinking water for cattle	Value of annual animal products Number of households
Homestead garden	Economic value of the production Non tradable value generated (shade, cooling effect, etc.)
Support/recharge to natural surface streams (surface and groundwater) & environment RAW WATER SERVICE	Average value of water *in situ*
Industry and hydropower	Economical value generated Number of jobs
Tourism, fishing, wild animals & natural parks	Economical value generated Number of jobs
Flood control	Population and assets protected Estimated cost of an alternative solution
Control of drainage return flow	Protection of the ecosystem downstream of the CA
Transport	Quantum transported Economical value Number of jobs
Cultural	Number of rituals relating to water Number of hours/day spent at canal
Hygiene and sanitation	Number of deaths avoided
Control of vector-borne diseases in water bodies	Estimated effect on health
Biodiversity	Number of endangered species preserved
Recreation/tourism	Number of capita served

therefore an indicator of the relative value associated with each use of water is its share in MOM coverage.

This indicator, which is the relative value as a share of MOM costs, is relatively easy to calculate (tariff multiplied by volume). Care, however, needs to be taken when interpreting the results. The breakdown of cost coverage reflects how the stakeholders and authorities subjectively see the balance between the different uses of water. In other words, the way MOM's shares are defined does not necessarily reflect the cost of producing the service for each use. Instead, tariffs are often based on a combination of the importance of each use for the local economy and its capacity to contribute to the MOM coverage. The water charging policy and the range of tariffs for the different uses reflect the stakeholder driven compromise between the relative importance and the capacity to cover MOM costs.

In Figure 2.10 an example of share per use is provided for one system investigated in China. Irrigated agriculture contributes to 27 percent of the MOM costs for 47 percent of the total water consumed, whereas the large industry sector (steel and coal) covers 57 percent of the cost for only 11 percent of the total water consumed. In this case the price per m3 of water is ten times higher for industry than for irrigation.

The analysis of the share for MOM is obviously an interesting point of departure for developing an adapted vision of the MUS system based on its main features. It is very much site specific, and the same country can produce two very different situations as

FIGURE 2.10
MOM shares for the Fenhe irrigation district, Shanxi province, China

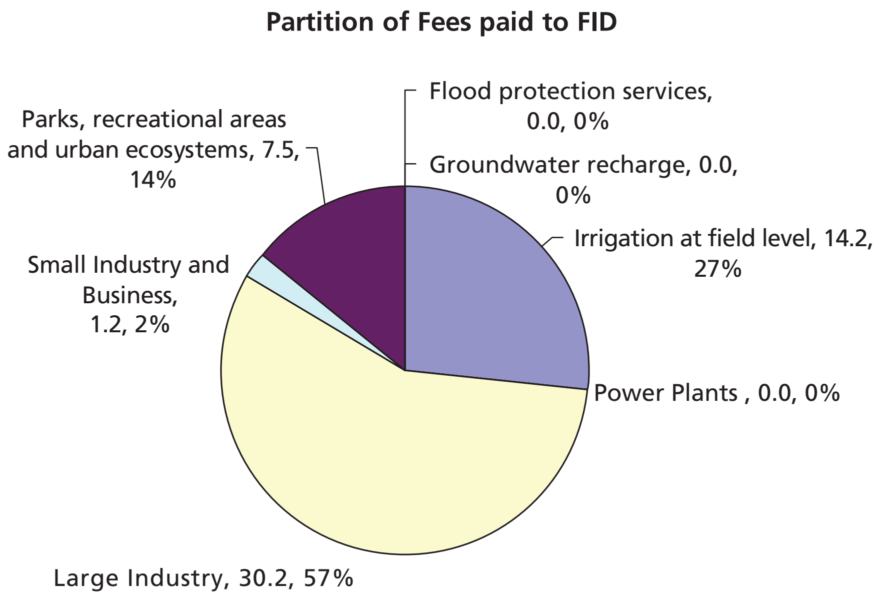


TABLE 2.13
Share of MOM coverage for two MUS systems in France

	Société du Canal de Provence SCP		Compagnie des Coteaux de Gascogne CACG	
	Volume in MCM	% of MOM share	Volume in MCM	% of MOM share
Industrial uses	50	23	7	8.5
Domestic uses	61	27	13	15.2
Irrigated agriculture	36	7.3	100	76.3
Irrigation for other purposes	22	13.6	0	0
Other uses	7	29.1	0	0

Source: Guerrin, 2009

illustrated by the French case (Guerrin, 2009). Table 2.13 summarizes key information for two large MUS systems in France. What is striking is that in 2007, some 50 years after construction, the share of fees from irrigation is still 76 percent for the Compagnie des Coteaux de Gascogne (CACG) but less than 10 percent for Société du Canal de Provence (SCP). These two systems have changed significantly over the years and today face a completely different situation *vis-à-vis* water users.

Step 5: O&M COSTS per service

Objective: To understand the operation and maintenance costs of producing each water service.

This step is important for discussion, at a later stage, the way users can share the management cost.

In a SOM strategy the issue of COST for service is central to reaching an agreement for the level of services and the cost coverage to be provided.

In order to produce the service that has been decided or agreed upon with users, managers need to mobilize a set of various resources or inputs (water, staff, energy, office, communication and transport). These resources/inputs all have a cost. This section clarifies the issue of inputs/costs for operation versus outputs/services as part of the overall management activities and as a fundamental element of the elaboration of a modernization process.

Investigating inputs and costs is important for:

- setting the service levels, particularly for exploring options related to different types of services and associated costs;
- water pricing for users, in order to propose a set of charging procedures that takes into account the real cost of service production; and
- improving performance and cost-effectiveness, by investigating technical options for maximizing the effectiveness of operation (better allocation of existing resources, automation, etc.).

Services along the irrigation infrastructure for which costing needs to be carried out are:

- irrigation services, which may include several levels of service if required;
- other services concomitant to irrigation; and
- the special operation for services during the off irrigation period of the year.

Challenges to mapping the cost of operation

Users, and sometimes managers, usually find canal system inputs and costs are seldom transparent. For many reasons, there is a dramatic lack of references regarding the real cost of irrigation services, although recently the concept of charging for water has been debated thoroughly in the water sector.

Information and knowledge of the costs of management and O&M are fragmentary. Further analysis should be made to produce reliable figures on what should be considered a reasonable cost for a given service, and what the maintenance should entail.

The challenges are manifold:

- a basic lack of information;
- difficulties interpreting information where available;
- difficulties separating operation from other activities; and
- identifying the ratio between services and inputs.

The critical question here is about the proportion of management, operation and maintenance (MOM) of the service, which can be identified by asking a set of questions, ultimately the different ratios need to be documented. Some specific questions are:

- What are the fixed costs of MOM?
- What part of maintenance is proportional to the service? What part is fixed?
- What part of management is proportional to the service?
- What is needed in terms of input changes in order to modify the service to users?
- What will be the cost (gain or additional) associated with this change?
- What are the options for reducing input while maintaining the same level of service?

The standard methods of cost–benefit analysis are commonly used to estimate costs. These methods help evaluate the financial costs and returns associated with certain projects, and they provide guidance for decisions about changes in service charges required to recover the costs associated with these projects. In these types of economic analyses, it is important to make a distinction between two different types of costs, each of which is known under different labels:

Capital or fixed costs – are the costs that have to be paid, usually at the beginning of a project, in order to buy new equipment and materials, to modify irrigation structures and to set up new information and communication systems. Usually, these capital costs are incurred only once, and the benefits are provided over a long period: 5, 10, 20 years or longer, depending on the equipment or structures.

Recurrent or variable costs – are costs that recur, for example on a daily, weekly or monthly basis. These costs are associated with providing the service, once all the equipment and infrastructure are in place. They include fuel costs for transportation, labour costs, electricity costs, and general maintenance costs for equipment (for example regular servicing for vehicles, pumping stations and diversion structures) and the cost of everyday management.

Types of service

Here the type of service presented in Chapter 2 are used for four main categories:

1. Water delivery
2. Providing access to water
3. Providing raw water and recharging natural streams (surface - groundwater)
4. Regulating water flows (quantity and quality: drainage, flood control, etc.)

Cost to produce water services

Several dimensions need to be explored:

- Cost of water (value of water resource within the basin). Sometimes this is partially or fully reflected into the water taxes paid to the water basin authority.
- Cost of investment to allow the service, for example investment cost to facilitate access (ramp, stairs, ponds, etc.)
- Cost of MOM with partition between the fixed cost and the proportional cost to the level of service (quantity and quality)
- Cost for a by-product or a stand alone service: a service can cost almost nothing when it is the by-product of a irrigation service already being provided, but this cost escalates when the service must be provided during those times when irrigation systems are switched off for repair and maintenance.

An example of the cost of providing raw water service

A good example of raw water provision is the Neste System of the Compagnie d'Aménagement des Côteaux de Gascogne, in France (figures for this system have already been presented in Step 4 Table 2.9). The Neste canal is a very peculiar trans-basin feeder it supplies on a very short reach the head of many radiating rivers (see Figure 2.7) in the nearby watershed which, as a result of geological uplift, is disconnected from the high Pyreneans mountains and is very dry in summer.

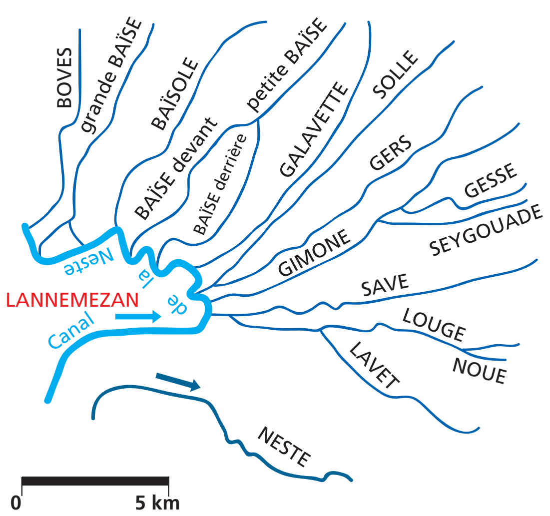
TABLE 2.14
Water pricing in Euro per m^3 charged by the CACG

Services – Uses	Price (€/m^3)
Irrigation (raw water available in the river)	0.015
Irrigation (pressurized raw water brought to the field)	0.15
Urban raw water	0.023
Industrial raw water	0.024

(after Guerrin, 2009 citing H. Tardieu, 2009)

The cost of providing raw water service and the specific services of the CACG are largely reflected in the water pricing, which is shown in Table 2.15. The cost of raw water services in the river varies from Euro 0.015/m^3 for irrigation to 0.023 and Euro 0.024/m^3 respectively for urban and industrial raw water. Farmers are charged Euro 0.15/m^{3}for the specific service of irrigation pressurized water at field level.

FIGURE 2.11
Sketch of Canal de la Neste (CACG), withdrawing water from the Neste river to supply the dry watershed nearby.



MASSMUS PHASE C – VISION AND MODERNIZATION

This phase is based on all information and knowledge gathered previously. It aims to create a strategy for modernizing management of water services that fully accounts for multiple uses. This is achieved in four steps: addressing the services; organization of management; arrangements for operation and implementation of a full SOM strategy. By carrying out all these steps it is possible to visualize how modernization of the existing management should take place and how it can be described. In fact there is an interactive process between progress at each step and the image of the result held by the stakeholders.

Step 6: MUS – users and services

Objective: To initiate a possibly long process of negotiation between users and their representatives, and the services providers about the type of service needing to be agreed upon.

This step is important for preparing sound governance of the MUS system.

Irrigation systems were originally built to supply farmers with water where crop requirements could not be met by rainfall. Thus, service to farmers has been and should still be the central focus of management. However, over time, it has become increasingly apparent that other beneficiaries besides farmers are taking advantage of irrigation water supplies for uses other than crop production that can conflict with irrigated agriculture. Today, services to users are much broader than at the initial stages of irrigation development, although water demanded by farmers is still the central focus of management and often agriculture is still the main consumer of water.

In the extended category of multiple services within an irrigation project, the following services and functions can be found:

- domestic supply to villages;
- recharge to groundwater;
- environmental flows;
- health;
- industrial uses;
- fishing;
- recreational areas;
- tourism.

The manager's task in dealing with all these water uses is basically to move from informal practices into formal services provision activity with well-identified users. The push here is thus in two complimentary directions:

1. Identify the users of water services and their possible representatives.
2. Identify, with the users, the services to be provided and the means of payment.

Services in a MUS system must be discussed and defined in strong consultation with users. This is a basic condition that will lead to an agreed upon service and ensure that the associated cost of service will be paid to the service provider.

Thus, Step 6 of the process deals with USERS and SERVICES.

Defining the service, and determining the requirements for operation, primarily comprises answering the following questions that address both the definition of the service and the consequent requirements for operation:

- What services do the different user groups require?
- How do these relate spatially, in time and in terms of operational requirements?
- What services can be offered to the users?
- What is the possible range of services and fees to be considered?
- What mode of operation can be followed and with what precision?
- What is the frequency of checking and intervening?
- Which setup is required to monitor the service?
- What are the mechanisms to ensure services are provided and paid for?

Several possible irrigation service arrangements can usually be conceived. Even where the physical infrastructure is pre-set, there can be a number of variations in planning, flexibility and accuracy of operation that can improve the delivery of a service. It is logical to expect that an increase in inputs (labour and money) will generally result in a higher level of service. However, it is not that simple. A key factor for successful canal operation is targeted improvements that meet the real demand of the users.

In order to meet contemporary irrigation demands for canal operations, it is useful to follow a service-oriented approach. This implies that users and service providers are jointly responsible for designing and defining the best compromise between the level and cost of service, bearing in mind that users will ultimately reap the benefits and bear the costs of operation.

Mapping a vision for the scheme

During mapping all services, actors, users and beneficiaries of the water scheme, a vision of the irrigation infrastructure in rural society emerges. At the end of this step it is therefore critical to spell out clearly what that vision is, as this will be one of the main drivers for the MASSMUS steps.

Certainly, the various stakeholders engaged in modernization should be in agreement about the vision of the future of the system. Therefore, this initial stage is referred to as a ‘preliminary vision’. This vision should cover both agriculture and the water management domains. An example of a vision crafted during a MASSCOTE workshop is shown in Box 2.1.

Moriarty *et al*. (2007) developed methodologies and tools to address water governance and empower the stakeholders. The early phases of the management cycle were highlighted as *‘a clear and shared future vision and a preferred strategy to achieve that vision’.* This also applies to a MUS system. The approach and associated tools may be easily adopted to work out a vision having similar objectives:

- Establish the active participation of stakeholders and/or their representatives in the activities of a stakeholder platform.
- Facilitate semi-structured discussions on the nature and severity of water-related problems.
- Reach agreement on a preliminary vision of future water services and water resources.
- Agree on the process to be followed and the broad scope and timetable of follow-up activities.

BOX 2.1
Example of vision crafted during a MASSMUS workshop

The vision for Almatti dam (Karnataka India): '*A strong service oriented management with integrated multiple use water resources management practices, balancing surface and groundwater potential, supporting a productive agriculture system and sustaining the eco-system*'.

Step 7: MUS management units

Objective: To identify efficient manageable domains and responsibilities through the design of coherent and effective spatial management units where proper sharing and grouping of the various services is to be provided.

This step is important for reforming the managerial set up: splitting large-scale agency managed systems into a set of viable units each having a critical size, or grouped into larger units for small-scale contiguous systems.

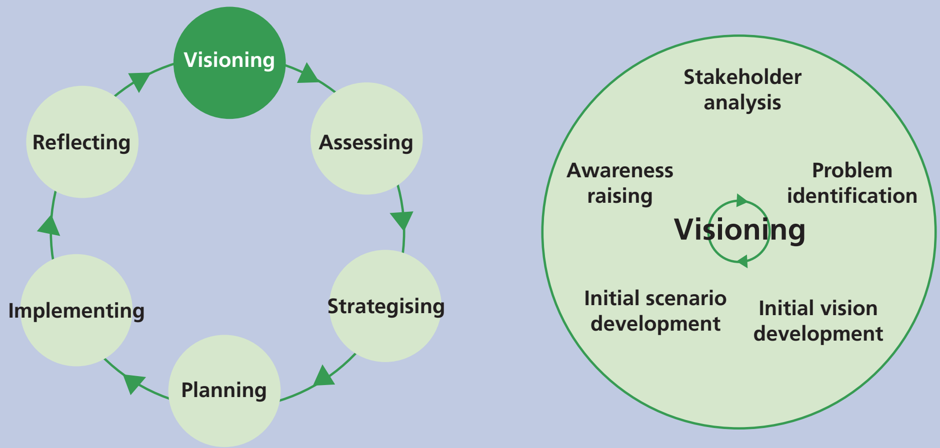
TABLE 2.15
Mapping uses and user's representatives

Service	User's representatives
Delivery to farms	Farmers' organization – WUA –FWUAs
Domestic Hygiene Sanitation	City Council – Town Council – Water companies Villages Council – local authorities
Drinking water for cattle	Livestock organization – Farmers' organization
Homestead gardens	Local authorities Environmental association
Support/recharge to natural surface streams (surface and groundwater) and the environment	Local authorities Environmental association
Industry, hydropower transport	Private companies
Tourism, wild animals and natural parks recreation/cultural	Council of trade and business Hotel corporations, travel agency union Environmental association Religious authorities
Flood control	Local authorities
Fishing	Fishing associations
Control of vector-borne diseases in water bodies	Health department
Biodiversity and other ecosystem services	Environmental department

Identifying effective management units is central to both MASSCOTE and MASSMUS. This will often results in the partitioning of the CA for large systems, or grouping several systems for small-scale infrastructure. Medium to large irrigation systems usually serve thousands of users. Therefore, efficient organization of responsibility is required between the central project management unit and the numerous users.

BOX 2.2

Visioning process developed for the governance of stakeholders' water systems



The aim

A provisioning process is used to develop a precise and shared description of how an individual or a group of stakeholders would like the water resources and water services to be in their area of interest at some future time. The overall aim of the visioning phase is to come to a shared understanding between the main stakeholders at intermediate and local levels about the main water-related problems which affect them, and to develop an initial vision for local level water management and service delivery.

The challenge

Visioning helps stakeholders to think beyond the day-to-day reality of problem solving, And to imagine an achievable medium to long-term future for which they can plan - typically 5 - 15 years ahead at local level, And 10 - 25 years ahead for the intermediate level. It may prove useful to differentiate between short, medium and long-term visions each with their own target date for achievement.

Source: Moriarty et al. (2007)

The partitioning of management and operation must be done on two (sometimes conflicting) grounds:

- homogeneity in the grouping of users and flexibility in providing service to users;
- managerial efficiency, responsibility and professionalism in the definition of the different management levels.
- When these two rationales do conflict, a compromise needs to be found.

Spatial differentiation of service and management

As explained in the previous sections, the MASSCOTE mapping exercise first calls for mapping the entire canal system:

- physical features and capacities;

- water balance flows and destinations; and
- the service requirements and requirements for canal operations.

It is assumed that during this mapping exercise that heterogeneity within the project is the rule rather than the exception. The result is an information database that allows consideration of the entire system comprised of the numerous units having homogeneous features.

A central question for managers attempting to ensure operational cost-effectiveness is: how far should the differentiation go?

Too much differentiation of the service requirements can lead to excessively high operating costs (or even impractical and incompatible operational demands), while too little differentiation does not respond to the needs for more adapted service. A compromise must be found between manageability and differentiated service.

In some types of systems, this principle of differentiation can be applied all the way down to the end users. This is the case with pressurized pipeline systems, where individual farmers can select the service (pressure, discharge and timing) they think is best for their production conditions.

In canal systems, however, this principle of differentiation is often limited for practical reasons and cannot be extended down to the level of users, but more often to a group of users, or to a low level of the canal system.

Discussed in this Section is how the whole service area is partitioned into various levels of spatial and management units to devise efficient management and operation procedures and better service to users.

The partitioning should identify management units down to the lowest management unit that will be operated with ‘professional staff’, who are paid and technically-trained employees. The size of these units depends on the agricultural and economic context, but the order of magnitude ranges from one to several thousand hectares.

The number of canal system levels in the partitioning depends on the size of the service area. Very large systems, such as those found in the Indus river basin in Pakistan or in India (more than 400 000 ha below one single intake), require several different levels in order to reach down to the lowest management unit with professional staff.

Rationale for partitioning: grouping and splitting

The partitioning of a canal system into manageable spatial units is required for effective decision-making and management, which in turn contributes to improved water service delivery. The main parameters for partitioning into subunits are:

- consistency and responsibility for the main system management;
- cost-effectiveness – too many units are too costly and chaotic; too few units are not responsive enough;
- critical size of the management unit – to allow for the provision of professional staff for its operation;
- compactness and sense of ownership for users; and
- integration of the concepts of IWRM – may need to incorporate multiple uses and multiple sources.

The process of management partitioning is a two-way process, having two rationales:

- splitting the CA into small units; and
- grouping and ensuring a clear responsibility for the main system.

Hence, it is normal that when considering a new partitioning of management it is necessary to consider two actions:

- grouping at the level of the main system to increase responsiveness; and
- splitting the CA into professional local units.

STEP 8: Demand for operation for MUS

Objective: To map the intensity of the demand for services and the requirements for canal operation to produce the services.

This step is important for optimizing allocation of resources for managing the system so as to avoid waste or lack of inputs.

The general idea of this element is that good and cost-effective management means being able to adjust the efforts or inputs to the demand. The spatial assessment of the demand for operation should influence allocation of EFFORTS along a given canal and the setting of priorities for the water distribution.

The three drivers of the demand for operation

From the viewpoint of the operator or manager, canal operations may be perceived as an industrial process. Inputs are transformed into outputs (water delivery to users) by organizing a complex interaction of production elements including canals, structures, storage and energy. To manage the inputs effectively, managers have to consider:

- The precise service demands and the tolerances allowed by the respective water uses and users – output.
- The impact of decision-making on the output – vulnerability of output.
- The characteristics of the structures involved in the process. How sensitive are the irrigation structures? Which modes of operation can be achieved? What are the constraints and opportunities? – the system's behaviour.
- The variability of inputs (water availability and storage) and the frequency and impact of perturbations on the system – input and behaviour.
- The organizational and financial resources available or required in order to achieve the required level of performance and keep the process going – management setup.
- Requirements of the process setup – rules, transparency, etc.

Assessment of the requirements for canal operation needs to be done parallel to and in combination with the definition of the service by users and stakeholders. However, canal operation requirements cannot be solely derived from service demands. The system presents opportunities and constraints that set the boundaries for possible modes of operation. In short, the requirements are to be found in three domains: (i) service demand; (ii) perturbation and (iii) sensitivity. As mentioned in Chapter 2 the rationale is straightforward: the higher the sensitivity, perturbations and service demand, the higher the demand for canal operation.

The three drivers of the demand for operation are:

Service – the higher the service the higher the efforts (targets – opportunity or vulnerability).

Perturbation – the higher the perturbation the greater the need for checking (maintain service; manage perturbation).

Sensitivity – (highly sensitive structures require more effort).

The three domains outlined above are interelated and must be combined to map the demand for canal operations. The rationale can be captured in the relationship:

Demand for operation = Service × Perturbation × Sensitivity

There are some exceptions to this generic equation, for example where high criteria do not lead to high demand. This is the case when highly sensitive structures (reaches or offtakes) are used to divert high perturbation towards areas that will not be penalized by either a surplus of water or a temporary shortage.

The service demand domain refers to the articulated and other demands for canal operation to produce multiple services. Many demands are interrelated; they can add to or be in conflict with one another. Some demands can be seemingly autonomous, as some refer to deliveries, others to canal flows and others to modes of operating the infrastructure. The integration of these demands enables the definition of spatial and temporal operational scenarios that provide the required services.

Once the scenarios have been articulated in the service demand domain, the perturbation domain gives the boundary conditions from the supply side. The perturbation domain refers to the frequency and magnitude of perturbation events that are likely to occur in a subsystem, and enables evaluations of the stability of service with respect to the demands.

As irrigation systems are subject to continuous modification of flow conditions, from both scheduled and unscheduled events, managing perturbations is important to ensure the required service is achieved and for water management efficiency. This domain of the demand determines the needs for the mode of observation, measurement and regulation along the system to ensure the water service is achieved.

The sensitivity domain is characterized by the physical properties of the distribution system. The behaviour of irrigation systems under operation and affected by perturbation determines the reaction of the system under non-steady flow with respect to the service demands. This domain sets the precision of control required.

The assessment of the requirements for canal operation should include all these overlapping domains. The technical, organizational and financial boundary conditions can be set in this overlay and compromises will have to be made.

Types of operation required for multiple services

In theory, the basic physical operation of gates in the system is the same for providing any type of service. However, the process of decision-making and planning for these activities may differ from that of farmers and canal managers.

An important aspect of operation for these 'other uses' is planning and allocation. Canal managers need to know the water demands and requirements, as well as available resources, for these different users in order to be able to allocate water properly for these activities.

The multiple uses can sometimes conflict with one another and there is a need to compromise when the operation requirements are antagonists.

Step 9: Improvements for Managing MUS Systems

Objective: To Identify improvement options (service and economic feasibility) for each management unit for: (i) water management, (ii) water control, and (iii) canal operation.

This step is important for initiating modernization of management. It must be clear that there are no blue prints covering options for improvements. Options must be generated and largely discussed locally before being consolidated. Options must be technically sound and agreed upon by all stakeholders.

As mentioned earlier, it is not the objective of the rapid MASSMUS exercise to yield enough accurate information about the various uses their values, cost, or to provide a clear definition of the related services. The proposal for improvements for managing a MUS system, therefore, will be initially vague. Often, the most important recommendation of a preliminary MASSMUS exercise will be to invest in studies to better characterize the various water services in the system, the benefits, the cost, the values for the stakeholders, etc.

Managing a MUS system requires deviation from business as usual with the usual stakeholders (farming community) to embark on a dialogue with other user representatives. This is a long and progressive process.

Improvements for managing a MUS system mostly concern governance of the system. Of course, some physical characteristic of the infrastructure may have to be adjusted to allow improvement of the services to all users and this may include installation of control structures or measurements devices, but this will result from mainly governance arrangements among users. Therefore it is fair to say that **improvement management of MUS system will essentially focus on governance.**

Many steps need to be taken when moving towards effective and fair governance, thus the recommendations of a MASSMUS exercise may be generic. A key recommendation could be as simple as carrying out another MASSMUS investigation, but delving further into the details.

A detailed MASSMUS investigation is carried out as follows:

- consolidate the mapping of water uses;
- quantify the uses of water;
- identify the stakeholders representing each use;
- carry out economic studies to size the benefits associated to each use;
- carry out a cost-benefit analysis; and
- estimate the value of each use of water (using appropriate valuation methods).

A MASSMUS detailed investigation is clearly a task that irrigation engineers or managers are neither prepared nor skilled enough to carry out themselves. There is a need to approach key partners from universities, research centres or consultancy firms where there is the technical expertise required to carry out the investigation. However, irrigation managers should lead the process and, in particular, they should organize the dialogue among the stakeholders.

Step 10: Integrating the service oriented management strategy

Objective: To integrate the various options discussed at management unit level, at ensuring a functional cohesiveness when all options and all units are aggregated.

This step is important to avoid inconsistency of improvement options within the CA.

Ultimately, each service will need to be integrated, either partially or fully, in the overall SOM strategy. Step 10 of MASSMUS aims to recall and reiterate the important elements needing to be investigated, discussed and agreed upon with the users and the stakeholders.

The last major step in the methodology is to progressively integrate the service into the overall SOM strategy by debating and agreeing upon the following elements with users and stakeholders:

1. Service definition and objectives.
2. Indicators of the service.
3. Specific targets and tolerances for each indicator.
4. Means of verification (measurements).
5. Compensation measures when service is in default.
6. Representatives of the specific users in governance.
7. Charging procedures.
8. Means for cost recovery.

PART TWO - Detailed approach to each water service

In this second part, each of the different services one may find in a command area of an irrigation system are described, with the objective of gathering the information needed for the MASSMUS step-by-step process presented in Table 2.1.

For each service, the following chapters will cover:

1. Description of the service and users/beneficiaries of the service.
2. Capacity, sensitivity and perturbations associated to the service
3. Water share
4. Estimation of the benefits
5. Cost analysis
6. Management units
7. Specific demand for operation

These services are addressed in a sequence based on the **nature of service**, and not for example, the nature of outputs. In the proposed groupings, fishing activities are split into two groups, one for aquaculture and another for fishing in water bodies and streams. A similar split occurs for domestic water, with domestic water to individuals and small communities differing from raw water to large cities.

The partition between direct and indirect services is based on the elements presented in Section 2.3 and sketched in Figure 2.7.

Direct distributed services in the CA:

- Irrigated agriculture
- Water for animals
- Aquaculture
- Domestic water to individuals and small communities
- Small industries

Indirect distributed services

- Homestead garden
- Natural perennial vegetation

Raw water delivery services

- Hydropower
- Raw water to large cities
- Raw water to industry

Services related to water bodies

- Fisheries
- Environmental services
- Recreation and tourism
- Transport

Other regulating services

- Flood protection
- Drainage

Externalities

- Externalities

3. Direct distributed services to agriculture users – Irrigation

DESCRIPTION OF THE SERVICE AND ITS USERS OR BENEFICIARIES

Agricultural demand is highly heterogeneous

Services for agriculture activities may encompass different elements. The first and usually most important element is providing water to crop growers. However, agricultural activities are not limited to crops. Livestock and fish production often form a significant percentage of the productive output from an agricultural area. Therefore, when we talk of agriculture it is important to bear in mind these three activities: crop, livestock and fish.

This chapter tackles the services for irrigation, which have been, and remain most of the time, the central activity of the management of irrigation infrastructure, and as such the analysis of the services for irrigation is a key aspect in MASSMUS for itself. The fact that many indirect services are generated from the services of irrigation itself also means that a good understanding of irrigation services is crucial.

Irrigation is the central focus but that does not imply that the service is homogeneous throughout the CA, in fact this is the contrary that happen in practice. The concept of a uniform service defined once and forever and for everyone at the design stage is no longer valid. Given the diversification of crop production and marketing strategies, as well as the development of alternative sources of water (e.g. shallow groundwater pumping), the demand for service is increasingly variable within the area served by the canal system and throughout the cropping season or from one season to another. The question is the extent to which the variety of demands can be accommodated, in the knowledge that more flexibility makes operation more complex and often more costly.

Water users are growing increasingly capable of articulating their demands in debates on service provision. Any debate on irrigation service demand will have to face a mosaic of demands that might be difficult to accommodate, or that may even be mutually incompatible. The final service agreements will need to reflect different crop water requirements, spatially different irrigation methods, established rights, local power relations, economic interests, etc. These service agreements must also be in line with the water resources available and O&M budgets. They may be different in time and location, with some designated critical periods per year.

In summary, it is important to start examining irrigation services bearing in mind that the **agricultural demand is highly heterogeneous in time and space**. As such, the concept of multiple services is already embedded in a modern management practice of irrigation systems.

Direct and indirect irrigation services

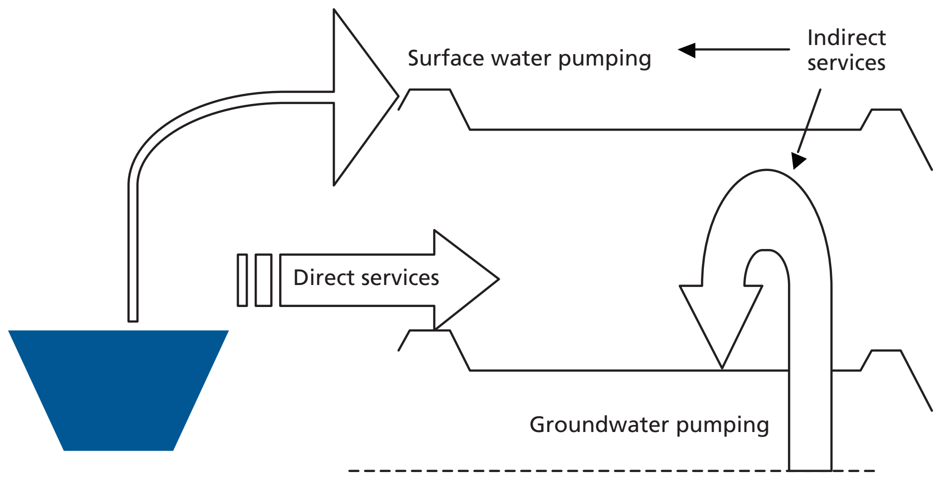
In many irrigated command areas, recent developments in pumping technology have diversified the nature of services for irrigation. These include:

'Direct service' for irrigation (see figure 15) from the irrigation management to farmers or farmer's organization within the command area;

pumping from the shallow groundwater, if the aquifer is recharged by irrigation practices (seepage and percolation losses), then it is an 'indirect service'.

the surface water pumping (being legal or illicit) by people leaving close to water streams and bodies (canals, drainages, tanks) whose land is not supplied either due to elevation or exclusion of the command area for other reason (soil conditions). This should also be considered as an 'indirect service'.

FIGURE 3.1
Direct and indirect and services



Comprehensive vision of irrigation services

It is important to start with a comprehensive view of the service to farmers. This should be defined with reference to three time-related aspects that are of significant importance for the farmers in taking strategic decisions (such as choice of crops) before the season starts, and tactical adjustment thereafter.

The three time-related elements are:

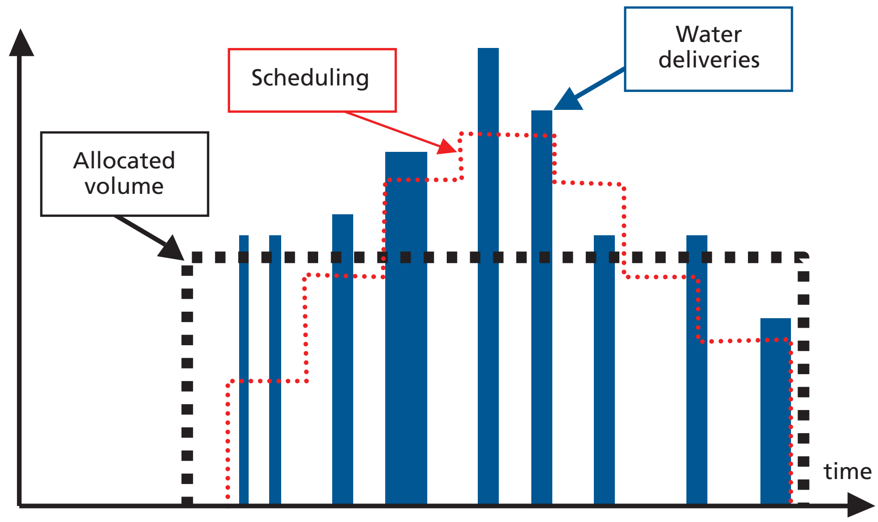
- allocation of water for the season or year;
- irrigation scheduling;
- water delivery.

It is important to note that the predictability and reliability of the service is of fundamental importance to users as it allows them to make informed decisions about their business.

Although the emphasis in this section tends to be on the service in terms of water delivery, it is necessary to bear in mind the three dimensions of the service to farmers (Figure 3.2).

In terms of allocation of water for the season or the year, the service includes not only the quantum (volume) of water but also the flexibility in negotiating variations around that value. This aspect is important in relation to the structural decision in matching water demand and water supply, for example, in adjusting the cropping pattern to whatever water is allocated, or in securing additional water supply to cover crop needs.

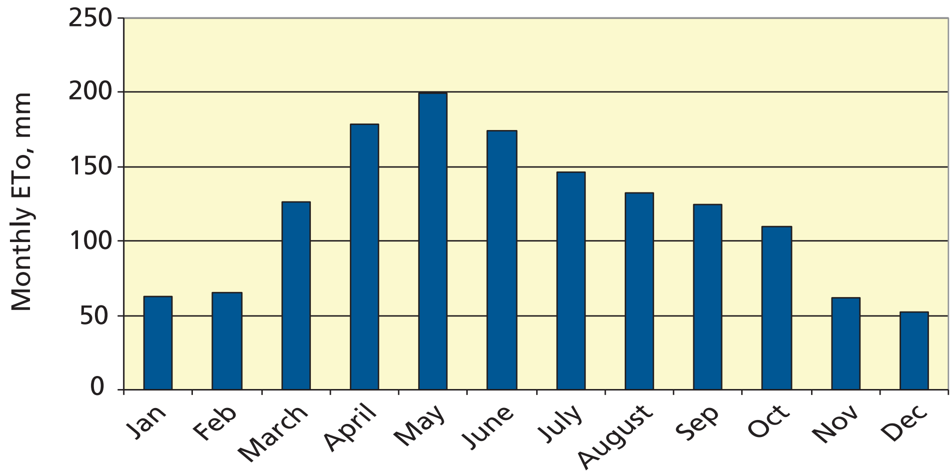
FIGURE 3.2
Dimensions of service: allocation, scheduling and deliveries



Irrigation scheduling is the way that successive irrigation turns or water applications will take place throughout the season. The quality of service is specified by the frequency with which water will be made available, e.g. every week, fortnight or month, and again the flexibility in modifying the schedule to match unexpected changes. This aspect is important for ensuring that the water supply will prevent moisture deficit at field level, and also for the organization of the human resources and equipment at farm level. Flexibility here means that for a given allocated volume, the scheduling of supply can be adjusted. For example, some farmers may want to reduce the initial scheduled deliveries and reserve their allocated volume for the peak or the end of the season.

A key way in which irrigation services depart from most other uses of water is that the needs for irrigation are not constant throughout the year. Many other uses of water also vary, but within a reasonable range around the average. Contrastingly, irrigation needs at the peak of the season can be as much as ten times larger than those at the start of the season. Additionally, irrigation can be completely off for several months of the year. This is due to both the variation of crop coverage and of the climatic demand as illustrated in the Figure 3.3. Often, the peak of the demand corresponds to the peak of the canopy coverage, therefore the crop coefficient is about 1, whereas at start of the season after sowing it can be as low as 0.1-0.25.

FIGURE 3.3
Monthly ETo (climatic demand) in Meerut Uttar Pradesh, India



Irrigation services

The water delivery service provided to farmers is defined by the characteristics with which water deliveries are made to the end users' outlet. Specifically, the service deals primarily with discharge (instantaneous flow) and volume (quantity over a period of time) of water delivered, and in terms of the timeliness of supply with respect to demand.

TABLE 3.1
Irrigation services

	Description	Conditions	Example of quantity
Special services	Provision of water for salt leaching	Extra water quantity to leach down salt below the root zone	Extra quantity of water (+25%) compare to crop water needs to ensure leaching of salted water.
	Provision of water for land preparation and sowing	Soil profile moistening to allow ploughing. Flooding the upper layer of soil for puddling in paddy fields	A set of one or more waterings of a large amount at beginning of the season.
Routine irrigation service	Provision of water to match crop needs.	Maximum water supply defined by the soil storage capacity of the effective root zone. Irrigation water should be provided before soil moisture gets below silting point. This is dependent on climatic conditions and the stage of crop development.	Sandy soil = low storage capacity = small quantum of water more frequently. 20-40 mm per irrigation Clay soil = high storage capacity = high quantum of water less frequently. 40–70 mm per irrigation

Water quality is also an important aspect of the service that must be considered by the managers and users. It is often not easily controlled, and may be more the result of given conditions, but the definition of irrigation service must address this dimension. Elements of water quality for irrigation are: silt content, salt content, chemicals, pollutants and temperature.

TABLE 3.2
Irrigation depth of application for different soil types and irrigation methods

Soil type	Rooting depth of the crop	Net irrigation depth per application (mm)	Irrigation method
Sand	Shallow	20-30	Short furrows
	Medium	30-40	Medium furrows, short borders
	Deep	40-50	Long furrows, medium borders, small basins
Loam	Shallow	30-40	Medium furrows, short borders
	Medium	40-50	Long furrows, medium borders, small basins
	Deep	50-60	Long borders, medium basins
Clay	Shallow	40-50	Long furrows, medium borders, small basins
	Medium	50-60	Long borders, medium basins
	Deep	60-70	Large basins

Types and characteristics of irrigation services

Service targets and indicators for water delivery to farmers (rate, duration and frequency) are to a large extent dependent on the infrastructure/technologies and water-control method. The main options for service delivery are:

- pre-set;
- arranged (on-demand);
- free access (full flexibility).

A comprehensive description of all irrigation service parameters can be found in MASSCOTE (FAO, 2007).

Service indicators

The quality of service to an agricultural user can be specified through indicators similar to those used for performance assessment, including: adequacy, flexibility, reliability and timeliness. Equity is another important indicator at the CA scale.

Adequacy – defines the matching between the provision and the demand (request, needs, etc.).

Flexibility – can be defined as the level of freedom to change the variables of water delivery (rate, duration and frequency), for example the possibility to request a certain volume of water at a certain discharge at a certain place and time. It defines the conditions of access to the water services, and particularly whether the user decides when to will access water services and with what intensity. Low flexibility is when rotation dictates the access together with constraint of discharge. High flexibility is when user can access the network to get water anytime and with a sufficient intensity. Flexibility is important when crops are diversified and sensitive to drought (cash crops, vegetables fruits, etc.).

Reliability – defines the predictability of the service. Highly predictable service allows decision makers to optimize their seasonal trajectory, and take reasonable risks, while unreliable supply leads to adverse risk strategies.

Timeliness – defines the way the service arrives at the agreed upon time at the point of delivery. It relates to the farm organization and the resources users have to carry out water application (human resources and equipment).

Equity – defines the way the share of services is distributed among users within the CA. Inequity is often found on irrigation infrastructure with head-enders taking too much water while tail-enders suffer from deficit. Inequity has strong implications for social order along the system and on the capacity to share the MOM costs.

CAPACITY ASSOCIATED WITH THE IRRIGATION SERVICE

The Capacity of the irrigation network to produce cost-effective irrigation services is analysed in MASSCOTE (FAO, 2007) by looking at each specific functions of the infrastructure:

- **STORAGE**
- **CONVEYANCE**
- **DIVERSION**
- **DISTRIBUTION**
- **CONTROL**
- **MEASUREMENT**
- **SAFETY**
- **TRANSMISSION**

Two points should be stressed at this stage:

1. High level performance for these functions means high overall capacity to deliver services to users;
2. Capacity is zeroed or reduced to almost nil during canal closure, which is either part of the rotation distribution pattern, or when irrigation is off for long period of maintenance. This aspect is critical for other uses of water, which are strictly dependent on irrigation water.

SENSITIVITY ASSOCIATED WITH THE SERVICE

By definition sensitivity is a ratio of input and output variation as follows:

Sensitivity = Variation of OUTPUT/ Variation of INPUT

Sensitivity in MASSCOTE is mainly addressed as a characteristic of irrigation structures that capture the way they react to perturbations of flow conditions. The concept in MASSMUS is applied to analysing the services. Thus, sensitivity would characterize the consequences (Variation of OUPUT) of an expected variation of service (Variation of INPUT or default). Sensitivity is therefore a characterization of the **vulnerability of users to service perturbations.**

losses as a result of a default in water services, such as a system with highly valuable crops. For example, cash crops in arid areas with no other sources of water are certainly sensitive (or vulnerable), whereas rice cultivation is more resilient and thus less sensitive. Also, farmers who have access to alternative sources of water are less vulnerable than those who rely on only one source.

PERTURBATIONS ASSOCIATED WITH THE SERVICE

Looking at services, perturbation has two aspects:

1. The classic MASSCOTE approach, which looks at each and every source of disturbance along the infrastructure.
2. The perturbation of the demand for service.

An example of a perturbation of demand is when it rains unexpectedly and the demand for service drops dramatically in some areas. Another example is at night when farmers are reluctant to go out to irrigate.

It is important to determine whether a service is subject to perturbation. If so, information about the characteristics of the perturbation should be gathered including type, magnitude, frequency, location and timing. All these characteristics must be known in order to tackle the perturbation properly. For instance when the perturbation is runoff entering the canal system, it is clear that special operation procedures have to be set when rainfall is announced somewhere along the canal. These procedures will have basically two objectives to protect the canal and its surroundings from floods and spills and to store the water wherever it is possible. If the perturbation is the surplus of water at night, when farmers are unwilling to irrigate, specific operational procedures may be implemented so as not to loose water that is already inside the system.

WATER SHARE

While water for crops are both the reason for, and the central focus of, the irrigation infrastructure; after some years, crops may not necessarily be the main user. In many canal irrigation systems, water that is evapotranspired at field level accounts for less than 50 percent of that diverted at the headworks. The remaining water either serves other uses or is returned to the natural surface or groundwater streams. To compare and identify what is consumed and what is diverted, a water balance for irrigated crops should be performed at the scale of the command area with the objective of estimating the actual evapotranspiration at field level.

The quantity of water used by field crops during evapotranspiration is usually high. For instance, a rather common seasonal irrigation requirement of 500 mm corresponds to a volume of 5 000 m^3 of water/ha (1 mm of water corresponding to 10 m^3/ha). To this amount required by crops the amount of water that percolates and runs off at field level needs to be added, as well as the volumes needed for other special services (land preparation, salt leaching) and the water losses occurring along the canal network. Adding all this, it is not unusual to find a volume of irrigation water amounting to 10 000 to 20 000 m^3/ha/crop or season.

BENEFITS

Estimating the benefits of irrigation services can be carried out in several ways. Three estimation methods are presented below, from the most simple to the more precise.

Gross production

In the Rapid Appraisal Procedure of MASSCOTE, the benefit for irrigation service is estimated as a gross production in terms of monetary value calculated from the yields on irrigated fields and farm gate prices. This is the simplest way to evaluate the value for which data is usually available: average yields and areas per crop.

The gross production is interesting in the sense that it can indicate the broad economy linked to irrigation activity such as inputs, energy and equipment. It is one way to roughly assess the leverage factor of irrigation investment: for one job created at farm level another one or more is generated upstream and downstream of the activity.

Net benefit

The net benefit attributable to the introduction of the irrigation services is the gross value of agricultural output minus the production cost (Molle and Renwick, 2005).

With and without service

To estimate the impact of the introduction of irrigation services the net benefit should be calculated with and without the irrigation project. Considering agriculture would have evolved with a lower productive trajectory without it. Ultimately the real benefit of the irrigation service is the difference between the two net benefits. This is the more precise method which can used for detailed studies of values of MUS.

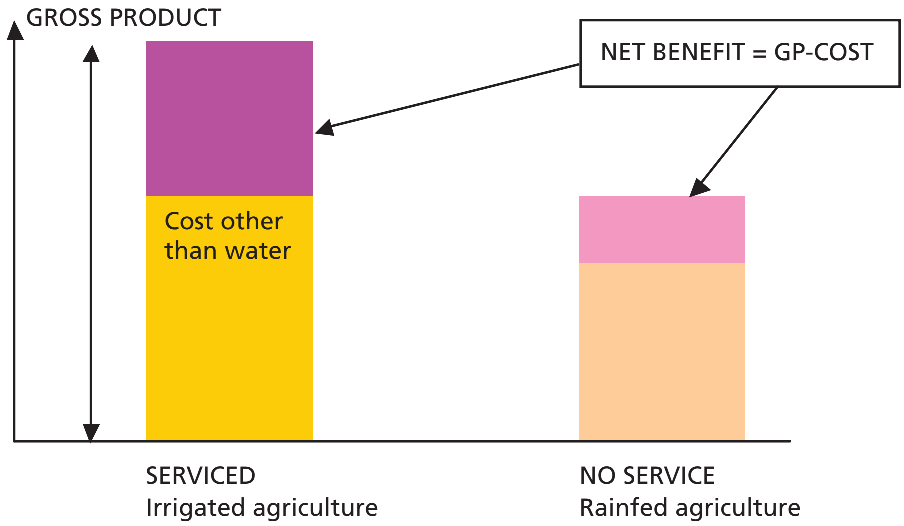
COST

The cost of providing the irrigation service is estimated from the analysis of the budget of the managing agency, by relating each component: maintenance, operation and administration to the level of service provided. There are elements of costs that are strongly related to the services produced, for example the cost of energy if water is pumped. Other costs are relatively independent of the quantity of services produced including aging of the canal, bank erosion and administrative tasks. The main objective is to partition MOM costs into those that are proportional-to-services and those that are fixed.

MANAGEMENT UNIT

Medium to large irrigation systems usually serve thousands of users, sometimes even several hundreds of thousands. An efficient organization of responsibility, between the central office and the end users, is critical. Attempts have been made in recent decades to devise a more effective management regime rather than that of public agencies based on either the administrative partition or inherited from the construction phase.

FIGURE 3.4
Estimating the net benefit of the irrigation service



Irrigation management transfer (IMT) and participatory irrigation management (PIM) are two of the major worldwide initiatives that have tried to split the overall irrigation organization into more effective units. This has proved to be a very difficult task and success has been elusive. Nevertheless, regardless of the success and failures of the past, modern management needs to be based on a consistent institutional set up, and in particular large irrigation command areas need to be split into more manageable units. For more information, see Part 1, Step 7 of MASSMUS: Management Units for MUS.

The partitioning of a canal system into manageable spatial units is required for effective decision-making and management, which contributes to improved water service delivery. The main parameters for partitioning into subunits are:

- consistency and responsibility for the main system management;
- cost-effectiveness – too many units = too costly and chaotic; too few units = not responsive enough;
- critical size of the management unit – to allow for the provision of professional staff for operation;
- compactness and users' sense of ownership;
- integration of the concepts of IWRM – may need to incorporate multiple uses and multiple sources.

The process of management of partitioning is a two-way process, with two rationales:

- splitting the CA into small units;
- grouping and ensuring a clear responsibility for the main system.

Hence, it is normal that when considering a new partitioning of management it is necessary to consider two actions:

- grouping at the main system to increase responsiveness;
- splitting the CA into professional local units.

TABLE 3.3
Implicit MASSCOTE managerial model for a large irrigation system

Level and domain	Management unit	Features	Typical size
Water resources management	State responsibility	Regulate water management and ensure that state policy is applied.	Basin
Main system management	Main system agency Autonomous multi-stakeholder body	A high-level professional agency providing services to local agencies/users.	20 000 ha and above
Subcommand areas – secondary canals	Local management agency	Professional agency governed by local stakeholders (mostly farmers)	500–10 000 ha
Local distribution	Farmers and user group	The size of this group is designed to ensure social cohesion within the group.	Fewer than 500 ha

DEMAND FOR OPERATION

The basic assumption of the MASSCOTE approach is that the demand for operation varies with the level of service. For example, highly reliable and flexible services are usually much more demanding than proportional rotational services.

The generic relationship, which is used in STEP 9, applies as follows:

Demand for Operation = Service x Perturbation x Sensitivity

The mapping of the demand is essential for allocating resources to the operation of the system.

BOX 3.1
Demand mapping exercise for Kirindi Oya Project in Sri Lanka

The result of the mapping exercise for KOISP, which was undertaken in the late 1990s is described below and shown in Figure 3.5. The entire command area was divided into four classes of demand with the two following extremes:

Very low demand (green): Low perturbation (head-end) – medium to high sensitivity of irrigation structure – low sensitivity for cultivation (rice) – drainage recycled in downstream tanks.

Very high demand (red): High perturbation (tail-end) – high to very high sensitivity of irrigation structure – low sensitivity for cultivation (rice) – drainage water is real loss (not recycled).

Between these two categories (yellow and orange), respectively, are classified as medium and high demand.

After the demand was mapped, an analysis of the then human allocation and the interventions along the right bank canal showed that the density of staff and interventions did not match the difficulties and the demand of operating the system. One of the main recommendations of the modernization project was to reallocate management resources.

FIGURE 3.5
Mapping operation demand; example from KOISP, Sri Lanka

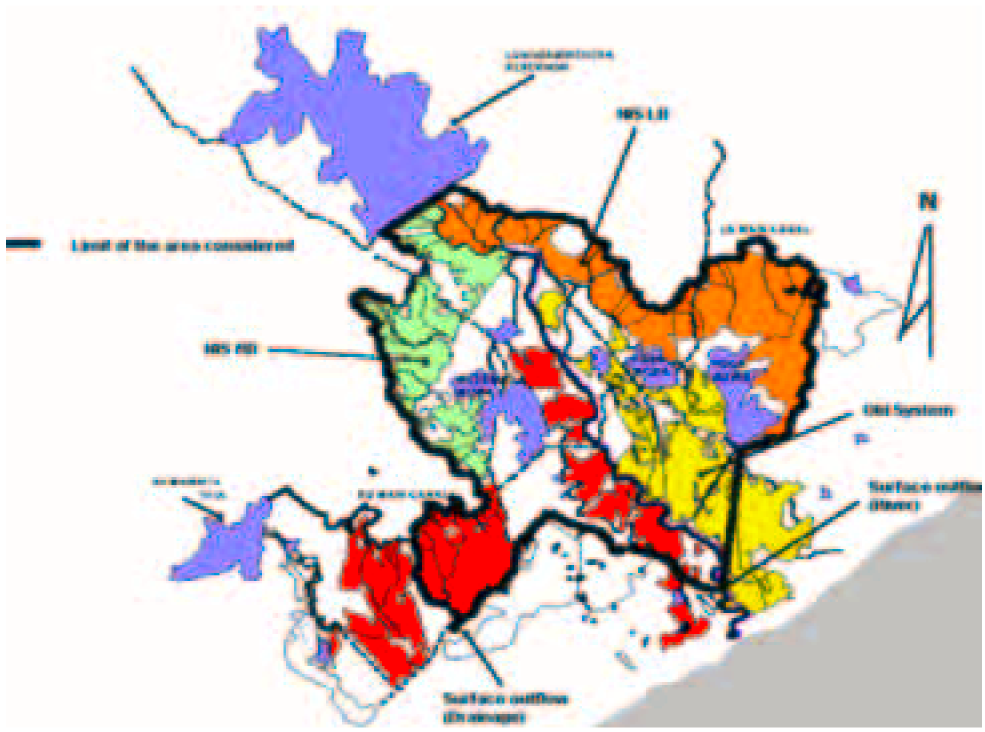


TABLE 3.4
Summary for irrigation services

Provisioning services	Main features
DIRECT SERVICES	Farm outlet/field deliveries (performance indicators are adequacy, efficiency, reliability, flexibility, equity)
INDIRECT SERVICES	Groundwater recharge (pumping) Surface water (authorized or non-authorized pumping from surface water).
CAPACITY	Physical and managerial bottlenecks As primary function of the infrastructure time is usually not a constraint within the pre-set seasonal irrigation schedule
SENSITIVITY	Sensitivity of irrigation structures
PERTURBATION	Internal and external
WATER SHARE	Consumed fraction by crops through evapotranspiration, which is often the main share of water consumptive use.
BENEFITS	Estimators often taken as gross products (Yield in US$) per ha and per cubic metre; assessing more than the benefits to direct users.
COSTS	The production of irrigation services represents the main part of the MOM cost.
MANAGEMENT	Large irrigation systems often need to be split into smaller management units that are still big enough to allow the recruitment of professionals and for them to engage in genuine stakeholder management.
DEMAND for OPERATION	Essentially centered on water quantity – variable spatially and timely depending on local availability of alternative sources of water, the level of irrigation services and perturbations.

4. Direct Distributed Services to Agriculture Users: Livestock

Preliminary MASSMUS applications have shown that livestock or animal production make up an important share of the value generated within the command areas of irrigation systems (as seen in Figure 2.9 in Chapter 2). Animals need water, not necessarily in large amounts and not necessarily of high quality, but they need reliable and accessible water sources. Distance between pastureland or farms and the water sources should be limited to avoid wasting time and energy.

At the global level, animal production is an important part of agricultural production. An estimated 1 billion of the world's poor are engaged in livestock activities (full-time or part-time) (FAO, 2006a). Livestock contributes to 17 percent of average human energy intake and to 33 percent of protein intake.

The importance of livestock in irrigated command areas can also be seen by looking at figures of head and production as a function of a production system in developing countries (Table 4.1). It can be seen that 'irrigated mixed' contributes to at least one-third of all animal products.

Furthermore, it is important to recall that in terms of water productivity, livestock is by far the most productive of the agricultural uses.

TABLE 4.1
Livestock population and production in different production system in developing countries

Parameter	Livestock production system			
	Grazing	Rainfed mixed	Irrigated mixed	Landless/ industrial
	Population (million head)			
Cattle and buffaloes	342	444	416	1
Sheep and goat	405	500	474	9
	Production (million tonnes)			
Beef	9.8	11.5	9.4	0.2
Mutton	2.3	2.7	3.4	0.1
Pork	0.6	3.2	26.6	26.6
Poultry meat	0.8	3.6	9.7	25.2
Milk	43.8	69.2	130.8	0
Eggs	0.4	2.4	15.6	21.6

Animal production can be carried out in **separate production units** in this case units are usually large. The livestock unit can be **integrated into the farming system**, and in this case animal products are one part of the entire farming activity (crops, meat, milk, etc.) and units are usually small. Of course the implications of these two modes of production are different when it comes to pasturing practices, feed supply. In return it influences water management and system governance. When animal production is fully integrated into the farming system, there is less chance of conflict between crop and animal production.

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

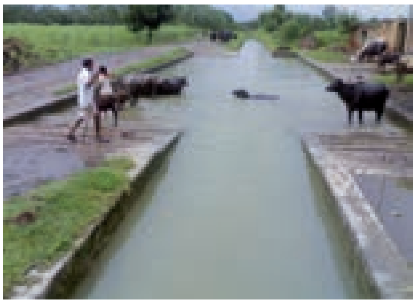
Water is important for animals for:

- drinking;
- cooling;
- cleaning and processing; and
- feeding (with fodder, fallow land and natural greenery from irrigation).

Producing feed for livestock is no doubt the main water user with respect to livestock production. The other uses (drinking, cooling and cleaning and processing) are relatively low in terms of quantity, as they are usually only minimally consumptive.

Animals may significantly affect the quality of water flows. This is of particular concern when animals and people use the same source of water such as from a canal.

PHOTO 4.1
Cattle ramps on a distribution canal (Main Ganga canal – Uttar Pradesh)



As the quantity of water consumed by animals is often not an issue, the critical issue is safe access. When this is not provided along the canal infrastructure, the cattle are placed at risk and bank erosion can occur.

An example of good access to canal water on both sides of a secondary canal is shown in Photo 4.1. This special equipment is very useful for cattle growers. However, in a multiple use system where people may be using the water downstream, it is better to have a small pond to the side of the canal, where cattle water cannot return to the canal.

Drinking water needs

Livestock needs for water obviously varies with climate. Needs may increase by up to 50 percent between low temperatures (0–10 °C) and high temperatures (more than 27 °C).

TABLE 4.2
Livestock water consumption in tropical countries

Livestock water consumption		litres/head/day	m^3/head/annual
Large	Cattle, buffalo	20–25	7.3–9
Medium	Goats-sheep-pigs	5–7	1.8– 2.5
Small	Poultry	0.15–0.3	0.055– 1.1

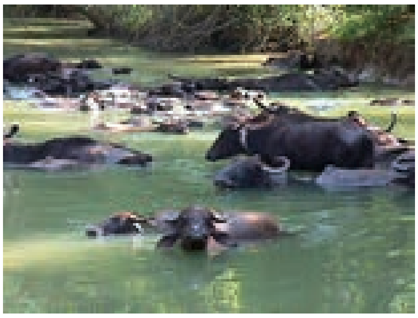
Source: Pallas 1986 and Renwik et al., 2007

Animals can usually tolerate poor quality water, except when heavily polluted such as when there are heavy metal loads. Animals can accommodate salt water with upper limits of 3 g/litres for poultry 7.1 for cattle (dairy) and up to 13 g/litres for sheep. Beyond the tolerance to salt content, however, animals are sensitivite to magnesium concentration: 0.25 g/litres for lactating cows and horses to 0.5 g/litres for adult sheep (Pallas, 1986).

CAPACITY ASSOCIATED WITH THE SERVICE

Access is the main capacity characteristic associated with water service to livestock. This is important in terms of physical access and schedule. As described in the next Chapter on domestic services, within an irrigation command area, the density of canals and streams offers a potentially high density of water sources. However, the rotation of water distribution can create local problems if there are long periods without water along a secondary or tertiary canal. The distribution method for domestic water must be checked to see if this will generate problems of water services to animals, and to identify the intervention that may be proposed to compensate for the lack of water during off periods (for example by creating ponds).

PHOTO 4.2
Canal water use and misuse for cooling in a very hot tropical climate (Sri Lanka).

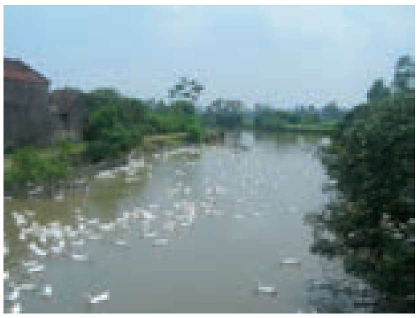


SENSITIVITY ASSOCIATED WITH THE SERVICE

Livestock are sensitive to off irrigation periods. During canal closure animals may suffer in the command area while they are pasturing on fallow lands.

The canal banks are sensitive to livestock, particularly if physical access routes are not provided, which can result in degradation of the canal banks.

PHOTO 4.3
Ducks in irrigation canal (Bac Hung Hai, Viet Nam)



PERTURBATION ASSOCIATED WITH THE SERVICE

The main source of perturbation of service to livestock is when the canal closes during rotation periods and maintenance.

WATER SHARE (ACCOUNTING)

As seen previously the quantity of water directly consumed by animals is marginal compare to irrigation water (Table 4.7).

ESTIMATING THE BENEFITS

Livestock provides numerous products: meat, milk, eggs, blood, hide, cash incomes, farm power and manure for fuel and soil fertility. The poor keep livestock to accumulate wealth (CA, 2007).

TABLE 4.3
Estimated annual income generated by livestock

	Mixed cattle sheep and goats US$	Goats US$	Chicken US$
Median	18	1.3	7.6
Mean	25	2	7.6
Stdev	21	1.2	2

Source: Renwick et al., 2007

The value generated by livestock is fairly significant. As shown earlier in Figure 2.9, four out of five MUS systems investigated exhibit a value for livestock that accounts for 25 percent of the total value estimated for water services. In another study, Renwick *et al.* (2007) estimated the average benefit from livestock at US$52 per capita. See more details of the same study, as income per type of animal in Table 4.3 and Annex 3 Livestock references.

Given the high values generated and the small quantities of water consumed, the productivity of water is generally extremely high compared to crop production. For instance, in Bac Hung Hai, Viet Nam, productivity for livestock was estimated at US$50/m^3 of water, which is similar to the values reported for small industry (US$50–90/m^3) and more than 100 times that for crop cultivation (US$0.35/m^3).

PHOTO 4.4
Cow-dung cakes to be sold as fuel (Upper Ganga Canal Uttar Pradesh, India)

PHOTO 4.5
Fieldwork using animal power (Malaprabha Karnataka India)

Energy

The benefit of manure production (not included in the above-mentioned figures) should be accounted for as a contribution, either for replenishment of soil fertility or for cooking energy.

In rural India the second source of cooking energy is cow-dung cake together with liquified petroleum gas (LPG). Firewood and chips are used by 75 percent of households, 9 percent use either cow-dung cake or LPG. In states where livestock represents a significant part of agriculture this use can rise to more than 20 percent (Uttar Pradesh, Haryana, Bihar, Punjab).

Cow-dung cakes are sold for fuel on the Indian market at about two rupees per kg, which is US$0.05/kg. Given that an animal of 250 kg live weight produces around 1 000 kg of dung every year the total dung production generated by the animal is worth US$50 dollars annually on the market, making this benefit double that mentioned in Table 4.3 for mixed animals.

Energy for farm power

Although tractors are increasingly common, in many agricultural settings animals are still one of the main sources of power in the field and on the farm. The benefits of animal power must be accounted for.

Given the importance of the share of value for livestock as stated in many projects, it is critical to have a reliable assessment of the value by having the right number of units produced per year and the right value/benefit per unit. Here, as in Table 4.3, we provide global averaged references. More contextualized additional references are also given in Annex 4. It is important to have the **best local references** that match the studied context. Where possible, it is recommended to approach the agriculture department and use their local data to estimate the amount of benefit from livestock.

COST ANALYSIS

Investment costs for livestock include special equipment to access among others surface water, watering troughs, drinking space, storage tanks, pumping from groundwater. To shift from basic irrigation to basic MUS with *in situ* add-ons for livestock such as drinking troughs and cattle crossings the capital investment is an estimated US$11 dollars per capita with a recurrent cost of US$1 per year (Renwick *et al*.,2007).

The above-mentioned cost estimations are made on the assumption that the canals are functioning. To deal specifically with canal closure periods (off-season, maintenance, rotation, etc.) specific interventions for storage must be added including additional deliveries.

MANAGEMENT

No management considerations.

DEMAND FOR OPERATION

There is no specific demand for operation for animals when irrigation is on. Special operations are required during the off period.

TABLE 4.4
Summary for services for animal production

	Main features
SERVICE	Direct services to animals for drinking, washing cooling. Indirect services to support natural feed, fallow land or water supply from groundwater pumping.
CAPACITY	Off period of the irrigation canal is usually a constraint for accessing water (long distance to be covered)
SENSITIVITY	Sensitivity of livestock to water shortage
PERTURBATION	Dry canal periods if alternative source or storage are missing.
WATER SHARE	Very limited, water quantities consumed are minimum.
BENEFITS	References production unit per type of animal and type of production Nutritional value (Protein) – Energy for cooking – Energy for farm power. Livelihoods
COSTS	Investment for making specific structure to access canal water (ramps) Running for special canal operation when irrigation is off.
MANAGEMENT	No management considerations.
DEMAND for OPERATION	Special operation during off period.

5. Direct Distributed Service to Agriculture – Aquaculture

Water is a supporting environment for aquatic life. In the MEA grid, water for fish is classified as a 'supporting service'. As soon as there is a regular presence of water, local residents will often use this environment for fishing and aquatic production. This occurs for various reasons, from producing basic intake or providing basic income for the family in poor areas to more leisure activity such as recreational fishing in more developed countries.

In 1997, world aquaculture production amounted to 36 million tonnes, which was valued at US$50 billion. China, India, the Philippines and Indonesia are the dominant producers. Asia accounts for 89 percent of the world's aquaculture production (FAO, 2000).

One of the most important aspects of fisheries and other aquatic resources in rural areas is the positive impact this has on nutrition and livelihoods of local people, especially for the most vulnerable (Meusch *et al*., 2003). Fishery activities may be significant in terms of economic value, however it is important to first estimate the impact on nutrition, jobs and livelihood support that fisheries and aquaculture provide.

Fishery activities and aquatic resources management in an irrigated command area are:

- fishing in water bodies (extensive to intensive);
- fishing in natural streams (drainage and rivers) and artificial streams (canal irrigation);
- coastal aquaculture in mixed lagoons;
- inland aquaculture in ponds and small reservoirs;
- aquaculture as part of integrated farming systems.

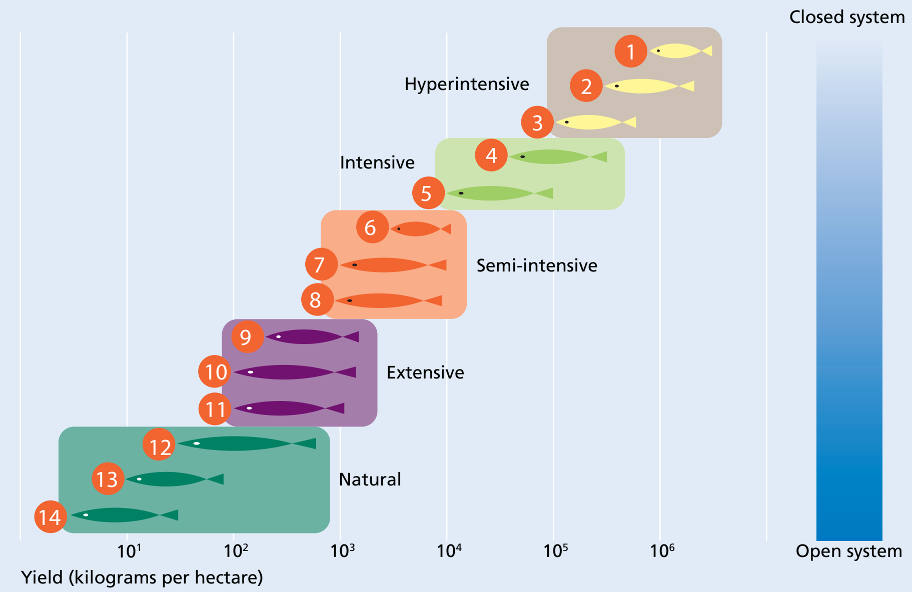
The last two elements are dealt with in this Chapter. The first three are addressed in Chapter 13.

Aquaculture can be further split into land-based systems (ponds, rice fields and other facilities built on dry land) and water-based systems (enclosures, pens, cages and rafts) that are usually found in sheltered coastal and inland waters (FAO, 2000).

Fishing and aquatic resources management encompasses a wide-range of practice from extensive exploitation of natural streams and bodies to hyper-intensive aquaculture in re-circulated systems (e.g. shrimps) as shown in Figure 5.1. Fisheries can be a completely separate activity, or integrated as part of the main farming activity as shown in Figure 5.2.

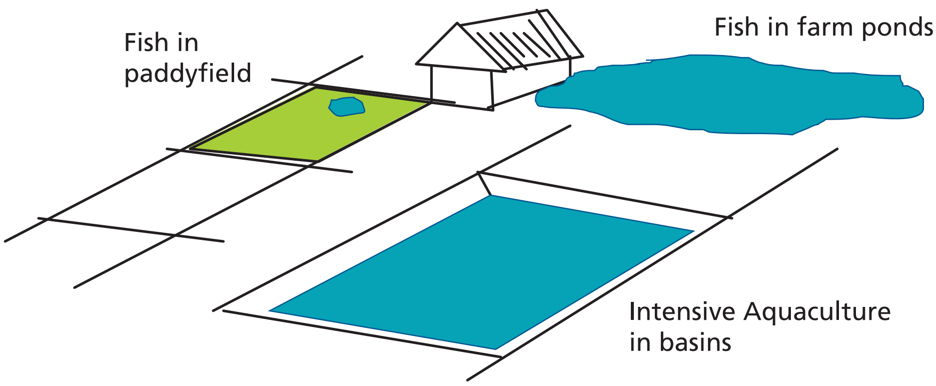
FIGURE 5.1
Production types and yields from different capture and aquaculture systems

1	Recirculation systems	8	Heavily stocked, fertilized ponds
2	Raceways	9	Extensive stocked unfertilized ponds
3	Cages	10	Drain-in ponds
4	Completely fed and aerated ponds	11	Extensively stocked natural systems
5	Fertilized and fed ponds	12	Tropical lakes and rivers
6	Brush parks and pens	13	Temperate lakes and rivers
7	Fertilized ponds	14	Cold temperate lakes and rivers



Source: Adapted from Welcomme and Bartley 1998.

FIGURE 5.2
Sketch of various types of inland aquaculture



BOX 5.1
Definitions of integrated farming

Integrated farming is commonly and narrowly equated with the direct use of fresh livestock manure in fish culture.... Our focus is on the integration of livestock and fish, often within a larger farming or livelihood system. Although housing of livestock over or adjacent to fish ponds facilitates loading of wastes, in practice livestock and fish may be produced at separate locations and by different people yet be integrated.

Manure may be produced next to the fishpond and elsewhere on the same farm. A wider definition includes manure obtained from off-farm and transported in bags, e.g. poultry manure, or as slurry in tanks such as for pigs and large ruminants.

Integrated farming, involving aquaculture defined broadly, is the concurrent or sequential linkage between two or more activities, of which at least one is aquaculture.

Source: FAO, 2003

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

1. Service to aquaculture farms

Aquaculture is the cultivation of fish and other aquatic organisms in farm ponds. As shown in Figure 5.1 the intensity of aquaculture practice is highly variable. The low intensity small ponds (less than 500 m^2) produce between 1 000 and 2 000 kg of fish/ ha annually, while high intensity aquaculture (with mechanical aeration and intensive feeds) can achieve more than 10 000 kg per year (CA).

2. Service for rice-fish farming

Fish in paddy fields differ significantly from other aquaculture techniques in the sense that the fish are fully integrated into irrigated rice cultivation and are in the same field. The water service to fish activities in the paddy field highly differ from the service to water bodies and streams, which is why there is a separate section on fish and paddy fields.

This section relies heavily on two source of information: one reference document produced for the Year of Rice in 2004 (Halwart and Gupta, 2004) and one produced in 1987 as part of a training course on fish culture in rice fields (Kutty, 1987).

The rice-fish culture is an ancient practice, traces are found in China from over 1 700 years ago. Initially the rice-fish culture was linked to separate aquaculture activities. Fish progressively colonizing paddy fields near by before being integrated into rice growing.

PHOTO 5.1
Fish and rice in China

Source: GIAHS–FAO project

This rice-fish practice is the result of a compromise between antagonist requirements. In particular, the use of chemicals for rice is often in conflict with the biological requirements of fish. In several places, the rice-fish practice declined, during the second half of the twentieth century, with the intensification of rice cultivation. However, recent signs indicate a reversing trend. For instance, recently China has significantly increased the rice-fish farming area from 0.85 million ha in 1994 to 1.5 million ha in 1999.

In Asia there are two types of rice-fish farming systems, concurrent mixed or rotational: capture fish with wild fish 'seed' and low to intense and cultured fish 'seed' (Koohafkan and Furtado, 2004).

The practice of rice-fish farming is improved following modification of rice fields for fish culture:

- increasing dyke (bund) height;
- provision of weirs or screens;
- provision of drains;
- fish refuges.

PHOTO 5.2
Livestock and fish integrated farming (Viet Nam)

3. The integrated livestock-fish farming system

The integrated livestock-fish farming system is primarily defined as the direct use of fresh livestock manure in fish culture. Housing of livestock over or adjacent to fishponds facilitates the loading of wastes. In a broader definition, integrated farming systems involving aquaculture are the concurrent or sequential link between two or more activities, of which one is aquaculture (FAO, 2003). The key link between livestock and fish culture is the nutrients.

Integrated livestock-fish farming systems are found in Asian countries, they are well developed in Viet Nam and China.

Users and beneficiaries of the service

Users involved in fishing and aquaculture activities can be:

- farmers, when fishing is integrated;
- aquaculture producers, when fish are separated from farming.

CAPACITY, SENSITIVITY AND PERTURBATION ASSOCIATED WITH THE SERVICE

These three characteristics: capacity, sensitivity and perturbation, are related because perturbation affects the capacity of sensitive systems.

- The sensitivity of fishing activities can be related to:
- water shortages and low water levels;
- water quality (salt and other chemical contents, temperature, turbidity).

Perturbations can thus be the result of different phenomena:

- polluted drainage water from agriculture, cities or industrial sites;
- canal closure during off periods or maintenance, which dramatically reduces the availability of fresh water; or
- any drastic and lasting change in water characteristics including physical, chemical, biological, temperature.

When production is intense, the aquaculture production sites can generate perturbations that affect the environment and users downstream.

Some elements raise the capacity to withstand water shortage by reducing sensitivity to perturbations:

1. The presence of fish refuges within the field or nearby to accommodate fish when the field is dried for rice harvesting. The refuge also acts in the capacity of a buffer during exceptional water shortage.
2. Storage capacity within the aquaculture ponds, as much time can pass between two rotations of water deliveries or there may be extended and exceptional water shortages.

WATER SHARE (ACCOUNTING)

Water is not consumed directly for fish and aquatic production, but evaporates from the surface of the water body and stream. Evaporation in aquaculture can be calculated by multiplying the climatic demand (ET_o) by the area covered by the fishponds, assuming a conversion coefficient of 1.

ESTIMATION OF THE BENEFITS

To estimate the benefit of the fishery and aquatic production one needs to specify the units used and the estimated amounts.

PHOTO 5.3

Aquaculture in Viet Nam (Fish nursery in Kim Dong district)

Yield

Rice-fish farming

Halwart and Gupta (2004) have analysed numerous studies about rice and fish farming in Asia. The yield/ha for fish production is extremely variable from a few kilograms to

TABLE 5.1
Indicator and estimator of fishing and aquaculture benefits

Indicator	Estimator of the benefit
Jobs	Number of fishers
Households	Number of households concerned Fraction of the livelihood generated by the fishing activity
Production in kilograms	Total catch and production
Local consumption	Production exported from and imported into the CA
Nutritional contribution in protein	Percentage of CA population needs produced locally
Economic value of production	Monetary value (US dollars – local value) Share of the total economic value generated in the CA

a few tonnes/ha. This depends on many factors of intensification shown in Table 5.2. More details are provided in Annex 4.

Research was also conducted on rice-fish farming, Nguyen-Khoa *et al*. (2005) reported a yield of 60 kg/ha/year of fish in Laos.

Halwart and Gupta (2004) concluded that for rice production in most cases (80 percent), growing fish in rice fields results in higher yields than for rice grown without fish. This result is important considering that when rice is grown with fish chemicals (pesticides) cannot be used as they are if rice is grown alone. This demonstrates that the productivity of land used for fish and rice is higher than for rice alone. Similar results are reported in China (Xiuzhen, F., 2003) with an increase of 250 kg yielding up to 7 500 kg of rice and 750 kg of fish/ha without artificial feeding.

Aquaculture

As illustrated in Figure 3.5, aquaculture yields are extremely variable depending on the intensity. An example from Indonesia is given in Table 5.3.

TABLE 5.2
Production reported for fish in rice-fish farming

	Fish yield (kg/ha)						
	Bangladesh	China	India	Indonesia	The Philippines	Thailand	Viet Nam
Mono-culture	125–239	2 000–3 100		143	44–263		48–79
Poly-culture	116–605	150–1 500	500–2 000	2 000–3 500	78–636	88–1472	677

Source: Halwart and Gupta, 2004

TABLE 5.3
Aquaculture in Indonesia (kg/ha/year)

Extensive	Semi-intensive	Intensive
100–300	1 000–5 000	1 000–250 000

Source: Halwart and Gupta, 2004

Monetary value

The data for worldwide aquaculture production leads to an average of US$12/kg (Tacon, 2003). References for cost and returns for fish-rice production are provided for Indonesia, the Philippines, Thailand, Viet Nam in Annex 4 – Information on fish and rice.

COST OF OPERATION

The cost of operation for specifically delivering a water service for fish production in water bodies is usually low. When irrigation is closed in the off-season, or for rotation, specific operation to deliver water to local water bodies will be required and the cost will increase. The cost of delivery to fish and rice fields is the same as that for irrigation deliveries.

MANAGEMENT

No management considerations.

DEMAND FOR OPERATION

The demand for operation is only important when irrigation is off and water scarcity becomes an issue.

TABLE 5.4

Summary for aquaculture water services

	Main features
SERVICE	Field delivery to fish and rice field Indirect services from pumping groundwater
CAPACITY	Water storage, water refuges Capacity of letting the water level varying in fishponds
SENSITIVITY	Water shortages, low levels, water quality
PERTURBATION	Flood, drought, water shortages, pollution
WATER SHARE	A fraction of water evaporated from water bodies (fraction equal to 1 if fish is the only use)
BENEFITS	Reference of US$12/kg of fish and aquatic products Extremely variable with intensity.
COSTS	Usually low except when canal is off
MANAGEMENT	No management considerations
DEMAND for OPERATION	Special operation during off period

6. Direct Distributed Services for Domestic Water

Domestic water within the CA concerns various users as shown in Table 6.1. Domestic water services are defined here as the provision by the irrigation infrastructure of water services to people living in the CA for their domestic use.

Delivery of water to towns and large cities is treated separately and in a different manner than that of a delivery service for raw water and, similarly, that of raw water delivery to large industry (see Chapter 10). Domestic water in this chapter deals with indirect and sometimes direct services spread throughout the CA to individuals, local communities and small towns.

TABLE 6.1
Classification grid for domestic water

USERS	Services	How service is provided
CITIES, TOWNS	Raw water delivery before treatment Indirect service (recharge groundwater benefiting towns and cities drawing water from groundwater)	Delivery to a specific point Sustaining water source [Groundwater]
VILLAGES	Raw water delivery Indirect service (recharge groundwater benefiting villages drawing water from groundwater)	Delivery to a specific point, e.g. tank inlet. Sustaining water source [Groundwater]
INDIVIDUALS	Water presence on surface streams Indirect service (recharge groundwater benefiting individuals drawing water from groundwater)	Easing access to water (Canal flow – specific flow into drainage) Sustaining water source (Groundwater)

The two main concerns related to domestic use are **water quality** and **access to water**. These can be split into: i) **conditions of access** (physical and social); ii) **distance** between source and uses or source and users.

Quantity is less of a problem than quality and access because the amount of water used is very small relative to irrigation requirements. This can be easily illustrated by looking at the average values considered for water needs per capita per day. Drinking water 4 litres – domestic water between 40 and 400 litres and food production between 2 000 and 5 000 litres. There are one or two orders of magnitude between the amount of water for food and that of water for domestic.

DESCRIPTION OF THE SERVICES AND USERS/BENEFICIARIES

Domestic water encompasses different basic uses:

- drinking
- cooking

- washing utensils
- laundering
- bathing
- house cleaning
- sanitation

It is important to note that the quality requirements for each of these uses are very different. Of course, many domestic water distribution networks deliver the same high quality of water (for drinking) but it is costly. In some other contexts, water from the tap is unsuitable for drinking and water needs to be treated at home by boiling and ceramic filtering. Guidelines for water quality for all these uses can be found at national levels. Internationally, the WHO guidelines for drinking water, and for bathing are the most commonly used (WHO, 2003 and 2006).

In practice people mix different sources of water of different quality and quantity to address various domestic needs. For example in KOISP, Sri Lanka water for drinking and cooking is almost 100 percent provided from a standpipe or a well, whereas laundering and bathing are mostly provided by surface water (canal, river, tank). Annex 5 provides two examples of partition of water sources for all domestic purposes.

Beyond basic uses, water distribution along a domestic system often includes productive activities, which fall into the category called Domestic MUS (also called 'Domestic +' in the typology proposed by Renwick *et al.*, 2007). This Domestic MUS can provide water for gardening and for any other small-scale activity such as arts and craft.

Services

Domestic services provided along an irrigation system can be:

- water services to cities;
- water services to towns;
- water services to villages and individuals.

Basically, these water services within an irrigation infrastructure can be physically characterized by:

1. A specific delivery of raw water at a given point.
2. A sustaining supply to artificial and natural water streams and to water bodies to ease access to the local population (surface and groundwater).

As mentioned in the introduction to this Chapter, the delivery of raw water to large-scale domestic and industrial users is tackled in Chapter 12. The domestic service from irrigation infrastructure usually does not go beyond raw water

PHOTO 6.1
Handpump (near canal) Sunsari Morang Nepal-Terai

delivery. It is generally the duty of another company to capture the raw water, store, treat and distribute it to domestic and other users.

Defining domestic water services

How can 'domestic water service' within an irrigation command area be defined?

An answer can be derived from an assessment by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) (Howard and Bartram, 2003), which estimated that '*one-sixth of humanity (1.1 billion people) lacked access to any form of improved water supply within 1 km of their home*'.

Furthermore, the WHO–UNICEF Joint Monitoring Programme (JMP, 2005) specifies the meaning of 'improved water supply', which is summarized in Table 6.2.

TABLE 6.2
Type of improved and unimproved water supply based on WHO–UNICEF JMP (2005)

Improved water supply	Unimproved water supply
Piped into dwelling, plot or yard	Unprotected dug well
Public tap/standpipe	Unprotected spring
Tube well/borehole	Cart with small tank/drum
Protected dug well	Tanker truck
Protected spring	Surface water (river, dam, lake, pond, stream, canal, irrigation canal)
Rainwater collection	Bottled water

The previous grid must not be taken as a guarantee for safe water. JMP cautions that the grid does not allow the establishment of a relationship between safe water and access to improved water supply. For instance, bottled water is, in most cases, safe and water from house connections may be contaminated because of weakness in the treatment or recontamination along the network.

A classification grid for domestic water services is given in Table 6.3, based on the ranking of the access characteristic.

It is considered that:

1. Surface water in an irrigation command area should be considered raw water (untreated) therefore a *priori* unimproved and probably unsafe.
2. Groundwater inversely may be considered 'improved' water.
3. Within an irrigation command area the '1-km-Access definition' can serve as the threshold between populations served for raw domestic water and those remaining un-served.
4. The question of whether the inclusion of water in the drainage network, as part of 'raw water services', deserves special consideration. The quality of drainage water does not allow this, particularly where ditches drain intensely cultivated areas. In this case drainage water is loaded with undesirable chemicals and should not be considered. There are at least two cases, however, where the drainage network may be considered. This is where channels act alternatively as irrigation and drainage, depending on the time of year (some systems in Viet Nam), and where the drainage

TABLE 6.3
Classification of domestic water services and related health concerns

Service level	Access measure	*Needs met*	Level of health concern
No access (quantity collected often below 5 litres/c/d)	More than 1 000 m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 litres/c/d)	Between 100 and 1 000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – hand washing and basic food hygiene possible; laundry/ bathing difficult to ensure unless at source	High
Intermediate access (average quantity about 50 litres/c/d)	Water delivered from one tap on plot (or within 100 m or 5 minutes total collection time)	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 litres/c/d and above)	Water supplied from multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

Note: litres/c/day: litres collected a day
Source: Howard and Bartram, 2003

network is purposely fed with raw water from irrigation canals to allow good access for the riparian population (many cases in South Asia). In both cases one has to ensure that no hazardous residues are present.

Extension coverage of surface services

With the concept of '1 km distance' in mind, the question of where and when domestic water services are provided in a CA is reduced to an analysis of the density of various types of canals and streams and the periodicity of flows.

For instance using the 1-km-access criteria analysis of the density of secondary canals and drainage streams shows that the entire command area of Shahapur canal (Karnataka India) is served by either an irrigation or drainage canal (Figure 6.1). Potentially, therefore, all people living in the command area can benefit from improved water supply from the irrigation canal. However, the rotation practised at secondary canals is 10 days ON and 10 days OFF, therefore access conditions are intermittent. No doubt access to water and quality rapidly deteriorate after closure of the second canal headwork. A specific study on conditions of water access during the off-period must be carried out to map actual domestic water coverage.

Those directly benefitting from water supplied by the irrigation infrastructure are obviously not those who are connected to a domestic network. Even those who are connected to the domestic network often augment their supply by accessing the irrigation infrastructure.

Indirect water services for domestic use result from groundwater recharge from seepage and percolation.

FIGURE 6.1
Example of 1 km zoning around the canal infrastructure of Shahapur canal. Right blue main and secondary canals – Left red with tertiary canals considered – drainage network.

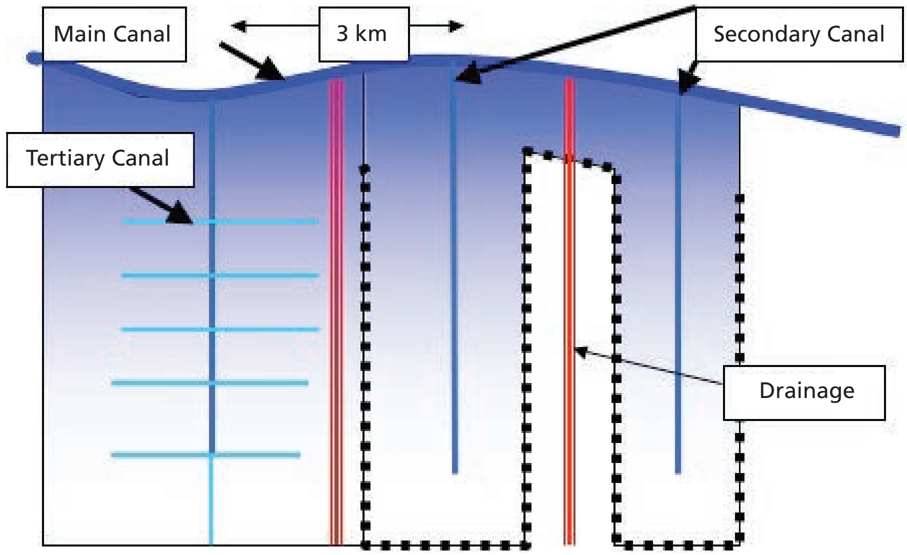


TABLE 6.4
Direct domestic water services along an open channel infrastructure

Type of canal	Presence/Access	Service	Quality	Problem
Main Canal	Permanent during irrigation season	Reliable Adequate	High if the source is good	Safe access often not provided (see Photo 6.9)
Secondary Canal	Permanent Rotation is also met	*Upstream*: Reliable Adequate *Downstream*: unreliable and lack of water	Medium	Safe access often provided
Tertiary Canal (Lateral)	Rotation often	*Upstream*: Reliable Adequate *Downstream*: unreliable and lack of water	More risk of contamination by upstream users	Easy access
Drainage canal	Permanent (Often leakages in the infrastructure are not repaired on purpose)	*Service tolerated to feed areas away from canals and/or landless people leaving on the banks*	Quality is a significant issue if quantity is low	

Quantity of water for domestic

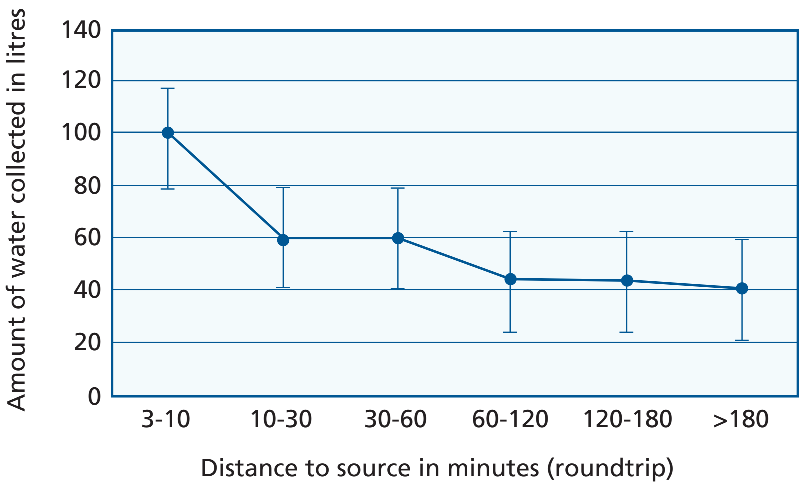
Most of the time when irrigation is running in the CA, the issue of quantity for domestic use is not so much a question of availability but a question of transport. The quantity of water used for domestic purposes is inversely proportional to the distance between the household and the source of water as illustrated in Figure 6.3.

Quality of water for domestic

The quality of water provided by a canal system usually falls into the category of unimproved. Further, the quality of the domestic water service degrades as we go downwards along the infrastructure, by design because rotation is more important on lower canals. In practice quality declines as the result of upstream uses and pollution and, often, decreasing irrigation performance: adequacy and reliability decline downwards.

FIGURE 6.2

Volume of water collected by an average household as a function of distance to the source (after Scheelbeek, 2005 cited in Van Koppen et al., 2009). The cutoff value of 40 litres corresponds to two jerry cans transported by a donkey; poor households without a donkey collect less water.



After analysis of many multiple use projects, researchers proposed a water ladder, which is a generic link between access characteristics and water needs that can be met (Van Koppen and Hussain, 2007. This proposal was adapted by Renwick *et al.*, 2007), who categorized the 'multiple-use' service levels (Table 6.5). Because contexts vary, there are broad ranges and boundaries between categories are unclear. Planners can use this table to think through the access characteristics that need to be in place to meet a certain level of water needs.

A quantity of water between 40–100 litres/c/d, within less than 10 m from the point of use, is the estimated access level required to support multiple-uses of water at a significant scale. In addition, water availability needs to be reliable. Domestic uses require daily availability, either from daily supply from the system, or from storage at the household level. Water quality issues are not mentioned in the table above, but should not be forgotten. The quality of

PHOTO 6.2

Example of purposely unrepaired leak on an escape gate to served population along the drainage canal (Y Junction Naryanpur canal, Karnataka)

drinking water obviously needs to meet international quality norms on all levels of the ladder. For other uses, quality needs are less stringent.

TABLE 6.5
Multiple-use ladder

Service level	Distance or roundtrip	Quantity (lpcd)*	Potential needs met
Maximal multiple-use service	Water at the homestead	>100	All domestic needs Not all but in some combination: Livestock Extensive gardening small-scale enterprises
Intermediate level multiple-use service	Water at the homestead, or within 5 min roundtrip	*40–100*	Basic domestic needs. Not all but in some combination: couple of large livestock, gardening up to 50 m^2, some micro-scale enterprises
Basic multiple-use service	Round-trip less than 15 min distance between 150–50 0m	*25–40*	Basic domestic needs, not all, but in some combination. Some livestock; gardening, especially with re-use; micro-scale enterprises.
Basic domestic service	Round-trip up to 30 min, or at a distance o less than 1 km	*10–25*	Sufficient for drinking and cooking. Hardly sufficient for basic hygiene Insufficient for other domestic uses. Possibility for re-use for occasional trees and very limited livestock (e.g. few chickens or a goat).
No domestic	Round-trip more than 30 min, or more than 1 km	< *10*	Sufficient for drinking and cooking, insufficient for basic hygiene.

Source: Van Koppen and Hussain, 2007 and Renwick et al., 2007

PHOTO 6.3
Bathing and washing clothing (KOISP–Sri Lanka)

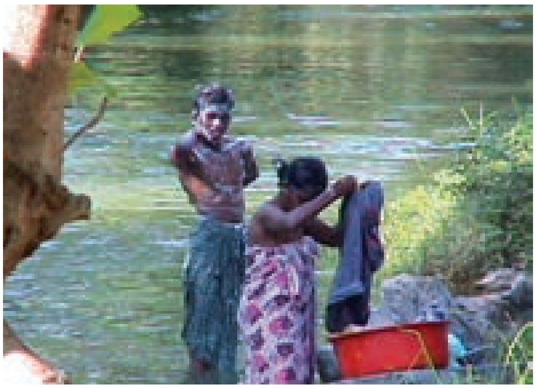


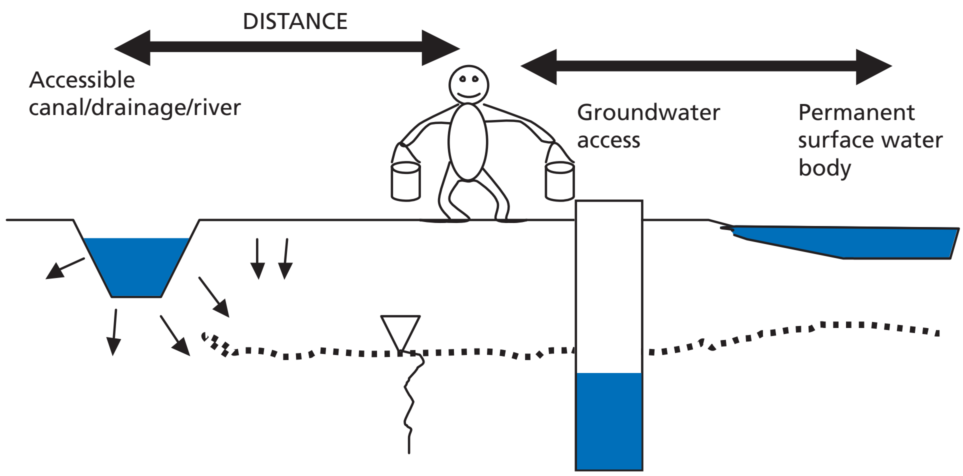
PHOTO 6.4
Washing items on a secondary canal (Doukkala -Morocco)

Mapping the access to services

As a first step towards domestic water services it is important to map the network of canals, drainages ditches, water bodies and groundwater aquifers.

Basically, in many large irrigation systems the service provided is defined as 'basic domestic service' (see Table 6.5).

FIGURE 6.3
Distance to access for water sources in a command area



CAPACITY ASSOCIATED WITH THE SERVICE

The capacity of irrigation canals to supply domestic water is not related to the size of the infrastructure, but more to the quantity required for domestic use, which is less than for irrigation. An issue does arise, however, when a canal is shut off. If, within the usual irrigation command areas, the density of canals and streams provides a potentially high density of water sources for local inhabitants, the problem may arise from the rotation of water distribution. This may result in long periods without water along a secondary or tertiary canal. As for domestic water, the distribution method must be checked to see if it is compatible with adequate domestic water services. Special arrangements for deliveries to small water bodies can partially compensate the absence of water when the canal is off.

Thus the first aspect concerning capacity is whether or not water is present in the canal. During canal closure the capacity is zero or reduced to almost nil. This may require the installation of a reservoir that permits the closure of the canal.

The second important point regarding capacity is water quality.

The third point is access, whether access to water is eased and safety ensured with the use of a specific structure or if no provision is made, meaning that access to the water source is dangerous, as shown in Photo 6.5.

SENSITIVITY ASSOCIATED TO SERVICE FOR DOMESTIC USE

The sensitivity of the domestic service on a MUS system is obviously related to its main characteristics. Quality and access are the two most important criteria. Thus the main aspects that need to be addressed are quality degradation, for example pollution when runoff enters the canal system when it rains, and lack of access.

PERTURBATIONS ASSOCIATED WITH THE SERVICE

During the analysis, there is a need to be aware of perturbation. Perturbations are variations in flow conditions that can generate problems with services in relation to the sensitivity criteria identified in the previous section these include problems of access to the services and water quality.

The perturbation must be characterized by the following points: what type, magnitude, how often, where, when. All these characteristics must be known so that the perturbation can be dealt with correctly.

WATER SHARE

It has already been identified that domestic water consumption is miniscule relative to the requirements for irrigation (except in large cities). Often domestic use is only a low percentage of the total water allocated. Further, 80 percent of the amount of water used for domestic purposes is returned to natural streams inside or outside the CA.

There is, however, a quality issue concerning the return flow from cities/industries, which can be heavily loaded with pollutants. If this is not properly treated it can be a major issue for a MUS approach in the CA. So, from the viewpoint of water management within the CA, the problem that needs to be addressed is not so much the water input to cities but the water outputs from cities.

PHOTO 6.5
Washing items on canals of Shahpure Branch canal system, Upper Krishna project, India (left: with no safety structure; right: steps provided for safety)

TABLE 6.6
Analysis of sensitivity and perturbation for domestic uses

Type of service	Sensitivity criteria	Perturbation
Direct surface	Water quality degradation	Pollution from urban areas, industrials areas Runoff during rainfall events Non point source pollution from agriculture areas.
Direct surface	Access to water	Rotation of canals Closure of canal during off season or for maintenance
Indirect groundwater services	Non-point source pollution from field percolation Lack of recharge	Field practices for chemicals and water Canal and irrigation closure

ESTIMATING THE BENEFITS OF DOMESTIC WATER SERVICES

It is rather difficult to estimate the benefits of unproductive domestic use. In fact, there are useful references represented by the cost of providing the service (investment and annual costs), but very few for estimating the benefit of basic water service for domestic use. This is paradoxical considering that the overall health benefits of providing safe and reliable water services are so high.

In the study carried out by Hutton *et al*. (2007) health and non-health benefits were calculated for different regions around the world, along with the different investment scenarios for domestic water supply and sanitation. In the study, costs included recurrent costs of operating and maintaining the system built.

The first important result is that the main contributor to economic benefits was time saving, which is associated with better access to water and sanitation services, contributing at least 80 percent to overall economic benefits. The second important result is that all improvements to water and sanitation are cost-beneficial in all developing world subregions. In developing regions, the return on a US$1 investment for non-piped solutions ranged from range US$5 to US$46, depending on the intervention. Table 6.7 presents the relevant values in South Asia.

To translate the benefit of basic domestic service into economic value, it is suggested that the size of the services (number of people served, volume of water used) should be evaluated first, and second that a few references be established for each unit of service.

- time saved when water does not have to be collected with/without analysis;
- value of *in situ* raw water;
- cost of an alternative source of water.

Depending on the methods used the results will vary significantly. Studies on time saved in water collection in Gujurat show the extreme variety of benefits, depending on the type of income generation that may substitute time spent collecting water. This is anywhere between US$15 and US$ 1100 per woman (household), with 45 to 152

TABLE 6.7

Benefit-cost ratios for different interventions in South Asia (After Hutton et al., 2007) including: Bangladesh, Bhutan, Democratic People's Republic of Korea, India, the Maldives, Myanmar, Nepal

Nature of intervention	Description	Benefit cost ratio US$ economic return on US$1 expenditure
Water supply MDG	Water supply MDG: Halving the proportion of people who do not have access to improved water sources by 2015, with priority given to those already with improved sanitation.	4.8
Water supply + sanitation MDG	Water supply and sanitation MDG: Halving the proportion of people who do not have access to improved water sources and improved sanitation facilities, by 2015 (millennium development goal 7, target 10).	6.7
Universal basic + disinfected	Universal basic access plus point of use treatment: Providing household water treatment using chlorine and safe storage vessels, on top of improved water and sanitation services, to all by 2015.	6.5
Regulated piped water supply + sewer connection	Regulated piped water supply and sewer connection: Increasing access to regulated piped water supply and sewage connection in house, to reach universal coverage by 2015.	2.2

working days being saved annually (Upadhayay, B., 2004). Another study in Nepal mentioned a savings of up to 50 days per year as a result of a MUS domestic supply, worth some US$46 per year and per household (Pant *et al*., 2006).

In the *Water and Sanitation Challenge Paper* (Whittington *et al*., 2008) the authors consider all costs associated with water services and sanitation and estimate the opportunity cost of raw water at a typical value of US$0.05/m^3. This value combines with a consumption of 100 litres/day per capita for a value of US$1.1/year per capita, which in turn can be converted into the value per household of US$4 to 7/year. The estimation based on the opportunity cost of raw water effectively lowers the value of the benefit.

In agreement with reported data from Gujurat and Nepal a reference value of US$10/year per capita was chosen (US$50 per a household of five).

COST ANALYSIS

The cost of operation is usually reduced; direct water services are often limited to very few delivery points.

The cost of providing the service is estimated from the budget of the managing agency, trying to disaggregate maintenance and operation and affect both to services but not necessarily in the same way. There are cost elements that are strongly related to the services produced, such as the cost of energy if water is pumped, and others that are independent of the quantity of services produced (including aging of the canal, banks erosion), some administration tasks. The objective is to try to partition in proportion to services and the fixed costs of MOM.

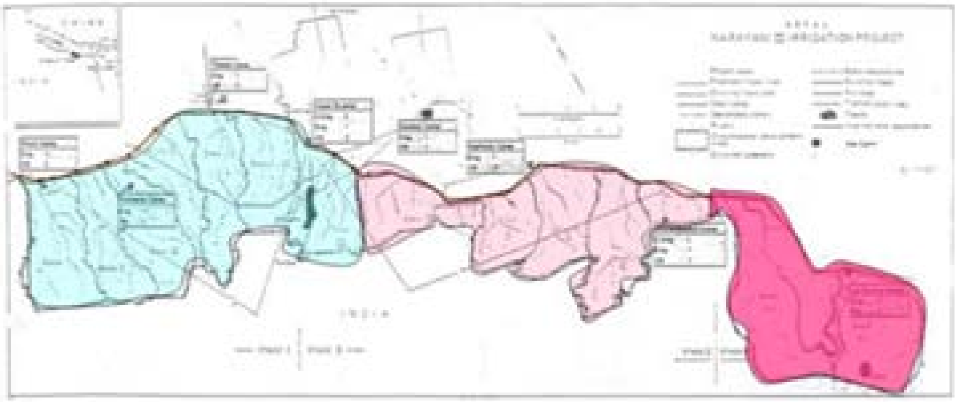
MANAGEMENT

If there is a significant difference between access to water for domestic use and quality, this should be fully incorporated into the partitioning of the command area. If it is homogeneous, then partitioning of the irrigation system should be based on other criteria.

The Narayani system in Nepal is one example of partitioning management based on domestic water conditions and health issues (Figure 6.4). The downstream part of this system (red) has never been fed properly by canal water and, therefore, extensive pumping from groundwater was developed. This practice, however, resulted in contamination of irrigation and domestic supplies with arsenic. An alternative to groundwater must be found with improvement of canal operations. On the other hand, the upstream part of the system seemed less vulnerable to arsenic and, therefore, pumping should be encouraged.

Specific operations in this example include high-level irrigation services from the canal infrastructure, and specific arrangements for domestic raw water supply to the population to prevent use of groundwater by farmers and other users.

FIGURE 6.4
Map showing three zones related to the classes of demand for surface water services in the Narayani irrigation system, Nepal [red = high arsenic contamination]



DEMAND FOR OPERATION

The MASSCOTE approach considers that the demand for operation varies with the level of service. Highly flexible services are usually much more demanding in terms of operation than proportional rotational services.

The general equation discussed in STEP 9 applies:

Demand = Service x Perturbation x Sensitivity

In some areas, such as Pakistan (Ensink *et al.*, 2002), a significant part of the CA has unpalatable groundwater and therefore a large portion of the rural population rely on irrigation surface water for their domestic supply. In Punjab, Pakistan an estimated 40 million people are affected by the canal system's water quality, which is likely to double in the next 25 years. With a basic need for 50 litres per person per day, this represents a volume of 2 MCM/day. Some people are heavily dependent on irrigation surface water to fulfil their domestic needs, and they suffer during closure of the canal system for maintenance.

In many countries, water is treated for domestic use, but there is no guarantee that this is the case for water in canal systems. One option for canal water is to have water infiltrated into the soil and to pump it back from the water lenses on brackish water, in which case quantity is as important as quality.

Demand for Operation

With direct services limited to few delivery points the demand for operation is low when irrigation is on. However, for areas and for periods of the year when water quality from other sources is low, such as groundwater and surface water bodies, then a specific operation needs to be implemented to increase the demand for operation.

TABLE 6.8
Summary for domestic water services

	Main features
SERVICE	Delivery Support to natural streams and bodies.
CAPACITY	Quantity is usually not a problem but time is a constraint
SENSITIVITY	Water quality Access during canal closure
PERTURBATION	Pollution No water running
WATER SHARE	Withdrawn amount is limited Consumed fraction is low Return flow from domestic use can be polluted
BENEFITS	Reference per year: US$10 per capita and/or US$50 per household
COSTS	Minimum = cost of providing raw water + cost of specific operations if needed
MANAGEMENT	Specific constraints concerning domestic water may influence the management of partitioning Special operations for domestic water services during non-irrigation periods and/or canal closures
DEMAND for OPERATION	Protection of water quality Special operation or arrangements when irrigation is off

7. Direct Distributed Services to Small Industry and Business

When water is running in irrigation canals people tend to use it to for any activity where water is needed. Thus, along irrigation canals various small-scale activities may be found such as clothes washing or milk cooling, as shown in Photos 7.1 and 7.2. It has been reported that activities such as brick and curd-pot making also take place. Usually these additional uses of water are not well documented, as no one keeps records for these informal activities.

Less distributed than other uses

Inversely to other uses of water, small industry and business are often very **punctual and seldom**: and they rarely occur at significant densities. This characteristic differentiates this use from others such livestock.

These small-scale activities need water for:

- washing – water is needed to wash the product (Photo 7.1 and 7.3); or
- as part of the process (pottery, industrial, cooling, etc.)

Exotic uses can be found along canals, as shown in Photo 7.2. Milk containers are being cooled in the canal. Managers should not support this specific use because of the related health issues.

PHOTO 7.1

Small business, a laundry on the irrigation canal, Badra Karnataka

PHOTO 7.2

Cooling milk in the canal (Uttar Pradesh India)

DESCRIPTION OF THE SERVICE AND USERS/BENEFICIARIES OF THE SERVICE

Water service to small industry and business in the CA is a direct spread service. In fact the service to small businesses may be double. The first service is provision of access to water and the second, is the more important, drainage.

For example, when MASSMUS was first applied in Viet Nam the study showed there were about 20 small to medium factories in Kim Dong district that manufacture a

PHOTO 7.3
Patchwork-making: washing and drying in the Shahapur canal, Naryanpur Karnataka, India

range of products including car accessories, locks, garments, textiles and food processing. Some of these factories, such as for food processing, receive their water supply from water supply companies. Others use water from the irrigation company for the staff members' personal use. All these factories discharge their wastewater into the irrigation network. Water quality is a significant issue because this water is not treated.

CAPACITY, SENSITIVITY AND PERTURBATION ASSOCIATED WITH THE SERVICE

As for other spread services, capacity during canal closure, for any reason, is reduced (if not zeroed) and this may create problems for users with no alternative resources.

WATER SHARE

Usually this use represents a very low share of water compared to other uses.

VALUES AND COST

Values associated with small industry and business may be assessed based on households or jobs. In the example of Bac Hung Hai in Viet Nam, the benefits of small business have been calculated as the product of the jobs provided by the small businesses and the annual salaries. The annual salaries, estimated from US$600/person/year in Luong Tai district for small-scale activities (handicrafts) up to US$1 200/person/year in Kim Dong district for demanding industrial activities.

Water productivity for small industry is usually extremely high, as a result of reasonably high value products that consume only a small amount of water. Table 7.1 reports some values for productivity in KOISP: the order of magnitude of the net value per m^3 of water consumed ranges from about US$0.05 for rice, US$0.3 for other field crops (OFC), US$0.1 for livestock and US$13 for curd-pot making.

Renwick *et al.* (2007) reported that small-scale enterprises are often seasonal and generate low returns but can be crucial for income security (see Table 7.2).

MANAGEMENT

No management considerations.

DEMAND FOR OPERATION

No specific demand for operation.

TABLE 7.1
Water productivity for KOISP 1996/1997

	Gross value	Net value
	Rupees/m^3 depleted	Rupees/m^3 depleted (value of US$ in 1996)
RICE	7.1	3.6 (0.05)
Other field crops (chili, onion, green gram, okra, soybean, etc.)	28.7	22.8 (0.3)
LIVESTOCK	19	7.6 (0.10)
CURD POT MAKING	1333	982 (13.3)

Source: Bakker, 1998

TABLE 7.2
Examples of income for small-scale enterprises

Type of enterprise	Estimated income in USD
Beer brewing	90–120/year
Ice block making	22–56/year
Tea making	34–113/year
Toddy tapping	150/year
Rice wine/cakes	4–7/day
Brick making	90–122/year

After Renwick et al., 2007

TABLE 7.3
Summary for small industry and business

	Main features
SERVICE	Direct and Indirect services along canals Delivery – support to natural streams and bodies
CAPACITY	Time is usually a constraint
SENSITIVITY	Sensitive to canal closure
PERTURBATION	Canal closure
WATER SHARE	Small share of water Water quality may deteriorate as a result of the activity
BENEFITS	Reference to small business jobs (Viet Nam US$600–1 200/year/job]
COSTS	No cost considerations
MANAGEMENT	No management considerations
DEMAND for OPERATION	No specific demand

8. Indirect Distributed Services to Homestead Gardens

A homestead garden is the area surrounding the house where people grow agricultural products, sometimes with several layers of canopy. This may include vegetables, fruit trees, medicinal plants and large trees. Benefits to the household are numerous and may include food, income and raw material for construction, also shade and a cooling effect.

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

Mostly indirect services

The service is provided to the homestead garden either directly by a specific infrastructure network and outlet or, more often, indirectly as a side-effect of nearby irrigation, canal seepage and percolation from fields that recharge the shallow groundwater.

Homestead garden is a significant user of water in many tropical monsoon agriculture irrigation systems. In Sri Lanka, for example, perennial vegetation may be extremely important in the command area as shown in Photo 8.1 for the Kirindi Oya project. Molle and Renwick (2005) report similar figures for a system nearby.

PHOTO 8.1
Typical homestead setting (1 ha of paddy field – 0.25 ha of homestead garden)

The importance of area covered, is confirmed by the aerial photograph (Photo 8.2), which illustrates the mechanism of gravity water supply to perennial vegetation. The higher the elevation the lower the density of trees because of reduced supply.

PHOTO 8.2
Relationship between density of trees and elevation (above sea level) KOISP Sri Lanka

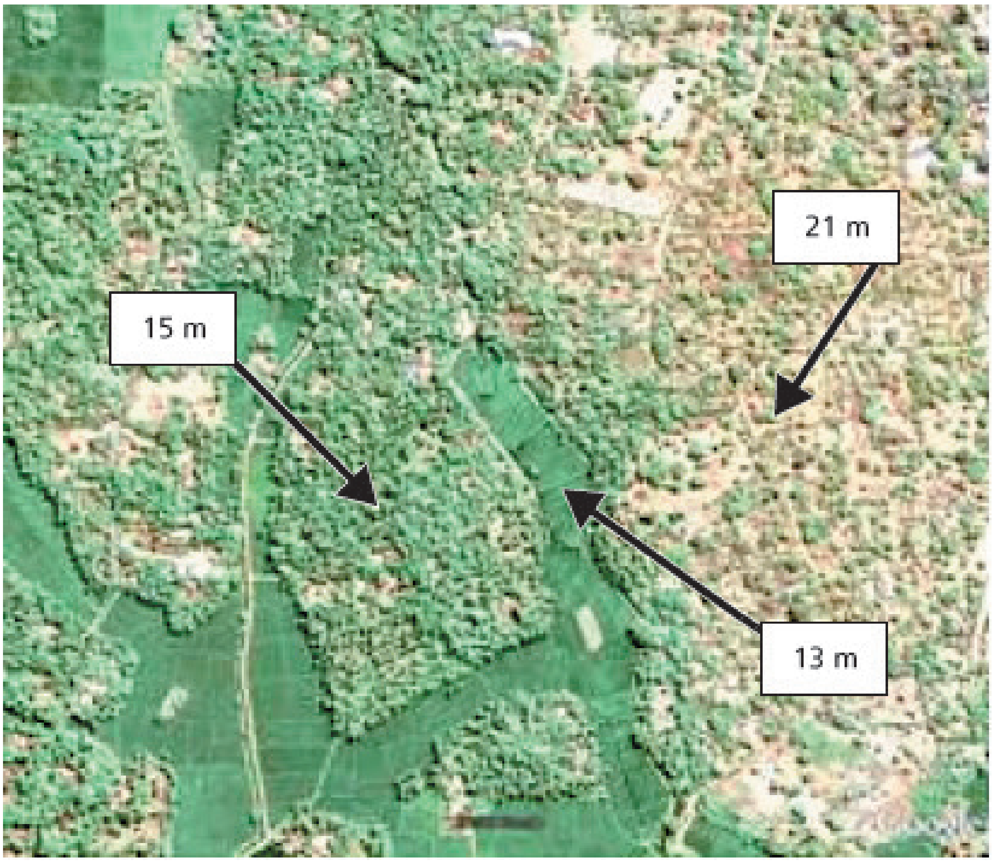


TABLE 8.1
Homestead services supported by irrigation supply

Provisioning services	Supporting services
Food and fibre, vegetables, sugar and alcohol;	Support to natural ecosystems and wildlife (biodiversity)
Fruits, nuts, spices	Soil conservation
Fuel (natural vegetation)	Habitat improvement (cooling and shade)
Biochemicals and natural medicines	
Raw materials for construction (timber – ropes – leaves)	
Manufactured materials (ropes, baskets)	
Regulating Services	**Cultural services**
Cooling effect on habitats	Cultural heritage values and landscape
Erosion control	
Biodiversity	

Typical outputs of perennial vegetation trees and homestead garden

It is not by chance that the coconut tree is called 'the tree of life' in tropical humid regions of South India and Sri Lanka. Together with other layers of production, these trees can produce numerous valuable goods and services for the local population as shown in Table 8.1.

PHOTO 8.3
Showing the imbrications of trees and paddy field in a command area east Sri Lanka

CAPACITY ASSOCIATED WITH THE SERVICE TO HOMESTEAD GARDEN

In areas where the cropping intensity is high (200 percent or above), capacity is usually not limited. During the off-period vegetation may suffer, however the damage is usually minimal.

The capacity of the root system of perennial vegetation to tap shallow groundwater is obviously linked to the proximity of irrigated fields and the elevation of the location as shown in Photo 8.3. Trees can easily tap groundwater at a few meters, but more than 4–5 m is difficult and therefore the density of the trees decreases, the type of tree changes with vertical distance from the water table.

SENSITIVITY ASSOCIATED WITH THE SERVICE TO HOMESTEAD GARDEN

The service is sensitive only to long periods without irrigation water. With a two-crop intensity per year there is no risk of groundwater being depleted or being out of reach of the root system. In this case, water can be provided by small pumps.

PERTURBATIONS

No specific perturbation is identified for this service.

WATER SHARE (ACCOUNTING)

The consumption of water during evapotranspiration by vegetation can be very high given the multi-layer canopy involved and the density of vegetation. In terms of calculating the evapotranspiration from climatic demand ETo, it is normal to take Kc values that are greater than 1.

To make a first assessment of the water share of a homestead garden, together with natural perennial vegetation, estimate the area covered by perennial vegetation. Assuming, as a first guess, that perennial vegetation evapotranspires at full ETo this gives a rapid estimation of the water use for this service.

The water consumed by perennial vegetation (Homestead + natural) can be estimated by closure of the balance after having estimated all other terms.

Remote sensing images can be used to map perennial vegetation within the CA. In this case, it would mean that the homestead and natural perennial vegetation are grouped together.

For instance for the Kirindi Oya Settlement Project, Sri Lanka, the estimated area covered by perennial vegetation is 15 000 ha, significantly higher than the cropped area (8 500 ha). Thus it is expected that consumption by perennial vegetation is almost double that of the paddy field.

BENEFITS AND VALUES: ACCOUNTING FOR THE PROVISIONING SERVICES

The few cases that have been investigated show that the homestead garden is highly beneficial to local households. Figure 8.1 shows worldwide references as reported by Renwick *et al*. (2007). This shows that productivity decreases with the size of the homestead garden. The statistical adjustment can be derived by a rough estimate of the production value of a homestead, which can be calculated using the following formula:

$$\textbf{VALUE (\$)} = 22.5\ A^{0.36} \quad [A = \text{size of the garden in } m^2]$$

The Molle and Renwick (2005) study of the Uda Walawe scheme, Sri Lanka, estimated the total value as US$248/year for an homestead garden of 0.405 ha (1 acre) to which should be added around US$200 for timber per year per homestead garden. This amounts to about US$450/acre, which is US$ 0.11/m^2.

One of the main conclusions is that the productivity of land in the homestead garden is usually quite high and comparable to that of paddy fields, between SU$1 500 and 2 000/ha. For homestead garden of 0.25 ha each, as for KOISP in Sri Lanka, generates a productivity of US$1 500/ha whereas the paddy fields nearby generate US$1 900/ha.

The issue of accounting for the other types of services provided by homestead gardens: supporting, regulating and cultural still needs to be addressed.

COST ANALYSIS AND DEMAND FOR OPERATION

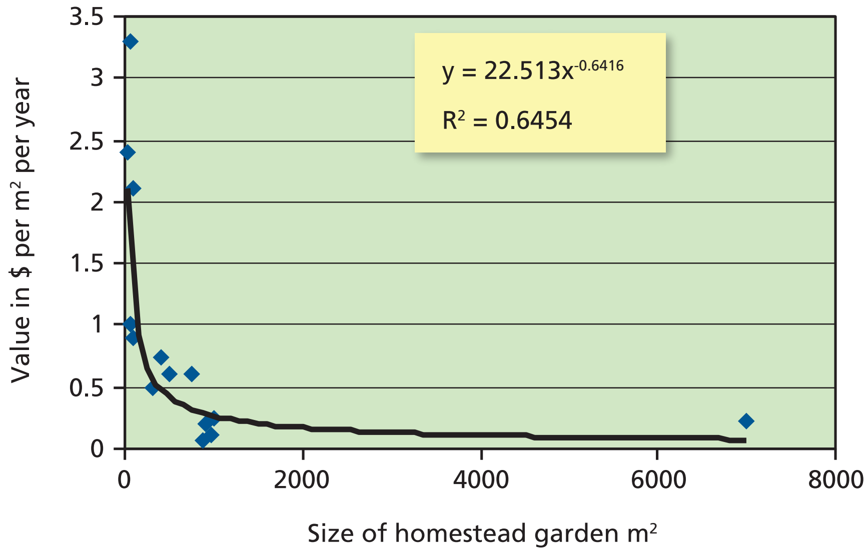
The water supply to homestead and perennial vegetation is often an indirect service from irrigation through seepage from irrigation canals and percolation from irrigated fields. Thus there is no special cost for operating the canal system to serve the homestead garden.

As long as irrigation is practiced over long periods and the fallow period does not last too long there is no special request for operation to produce the service to homestead gardens. The only problem may be if the cropping intensity declines drastically, or if the techniques at field level dramatically change. In some contexts for example moving from paddy cultivation by basin to precise irrigation such as drip irrigation of cash crops may jeopardize the water supply to the garden and trees.

MANAGEMENT

No management considerations.

FIGURE 8.1
Productivity of homestead garden for provisioning services as a function of size



After Renwick et al., 2007 [trend line added by the author]

TABLE 8.2
Summary for homestead garden

	Main features
SERVICE	Indirect services as by products of shallow groundwater recharge from canals and irrigated fields. Direct services if water comes through specific delivery points
CAPACITY	Link to irrigation intensity – terrain elevation might be constraint for lateral water transfer
SENSITIVITY	High deficit in groundwater recharge
PERTURBATION	Lasting closure of irrigation
WATER SHARE	High consumption of water per unit area (ETo and more)
BENEFITS	VALUE (US$) = 22.5 $A^{0.36}$ (A = size of garden in m^2)
COSTS	No specific cost for indirect services
MANAGEMENT	No management considerations
DEMAND for OPERATION	No specific demand for operation for indirect services

9. Indirect Distributed Services to Perennial Natural Vegetation

Non-crop vegetation in the CA may be an important term for water balance, as many trees thrive on water made available from surface irrigation. This phenomenon can be assessed visually by looking at areas within and outside the CA. In dry zones of the tropics, there is often a clear difference in terms of type of vegetation and foliar development, and, as a consequence, water consumption. However, it is not easy to estimate the areas covered or the unit consumption.

Contrary to homestead garden, perennial natural vegetation thrives on public or common land (not private), along natural streams and around water bodies. Although less numerous than for the homestead garden, perennial vegetation may still include various services as shown in Table 9.46.

TABLE 9.1
Ecosystems services linked to perennial vegetation

Provisioning services	Supporting services
Fuel (natural vegetation)	Support to natural ecosystems and wildlife (biodiversity)
Biochemicals and natural medicines	Soil conservation
Raw materials for construction (timber – leaves)	
Regulating Services	**Cultural services**
Erosion control	Cultural heritage values and landscape
Biodiversity	

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

The service for natural perennial vegetation is in the category ‘Indirect services’, because of lateral flows from adjacent irrigated fields and groundwater recharge.

CAPACITY, SENSITIVITY AND PERTURBATION ASSOCIATED WITH THE SERVICE

The capacity for perennial vegetation is linked to the practice of irrigation and only very long periods of canal closure are likely affect the vegetation.

WATER SHARE (ACCOUNTING)

There are two ways to estimate the share of water used by perennial vegetation:

- as closure of the balance after having estimated all other terms;
- by calculating the climatic demand ET_o and using a K_c coefficient of about 1.

Remote sensing images can be used to map the perennial vegetation within the CA. This means the homestead and natural perennial vegetation are grouped together.

ESTIMATING THE BENEFITS

The provisional values generated by the perennial vegetation are somewhat lower than that estimated for the homestead garden.

Bann (2002a and 2002b) provides information on tropical forestland use and mangrove management strategies. She estimated the values of a tropical forest and mangrove in Cambodia. The annual total forest benefits US$750/ha (at 6 percent discount rate) and US$452/ha at 10 percent discount rate. A figure of US$500 would then correspond to a rate close to 9 percent. These figures are gross estimates and harvesting costs should be subtracted to yield the actual value.

For the mangrove study (Bann, 2002b), average net benefits per household per year were an estimated: fuelwood US$50 and construction materials between US$85 and 159/year/household. Charcoal production is treated separately as a small-scale industrial activity.

Therefore in the absence of local references it is suggested that the following values be considered for perennial vegetation:

Natural perennial vegetation (Forest) annual benefit = US$500/ha forest = US$0.05/m^2

COST AND DEMAND FOR OPERATION

No specific cost, no specific demand associated with perennial vegetation.

MANAGEMENT ORGANIZATION AND IMPROVEMENTS

No specific management organization and improvement is associated with perennial vegetation.

TABLE 9.2
Summary for natural vegetation

	Main features
SERVICE	Indirect services as by products of shallow groundwater recharge from canals and irrigated fields
CAPACITY	Link to irrigation intensity – terrain elevation may be constraint to lateral water transfer
SENSITIVITY	High deficit in groundwater recharge
PERTURBATION	Lasting closure of irrigation
WATER SHARE	High consumption of water per unit area (ETo and more)
BENEFITS	Annual US$500/ ha
COSTS	No specific cost for indirect services
MANAGEMENT	No management considerations
DEMAND for OPERATION	No specific demand for operation for indirect services

10. Direct Service to Hydropower Plants

Electricity from hydropower plants is obviously an important option to consider when discussing natural resources management or climate change and the reduction of greenhouse gas emissions.

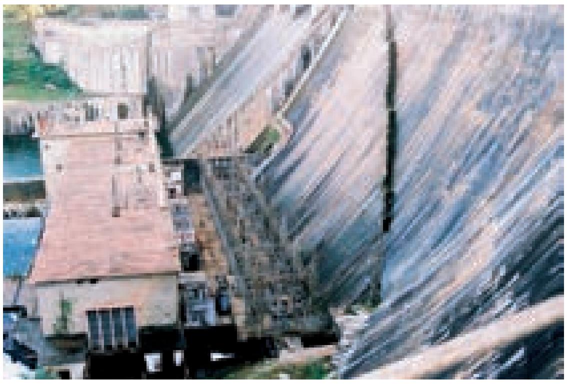
With regard to irrigation infrastructure, electricity production is usually carried out with high head power plants at the upstream reservoir of the CA or low head power plants within the CA itself.

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

The process of producing electricity at turbine level transforms the elevation energy of the water into power and returns the same amount of water at a lower elevation. Therefore production of electricity is a non-consumptive use of water at the turbine level.

If the plant is on line along a canal network, then the use is non-consumptive, but if water is stored in an upstream reservoir for hydropower, then there water is consumed during direct evaporation from the water surface. Therefore a certain share of water consumption in the reservoir should be linked to hydropower together with other uses if needed.

PHOTO 10.1
Power plant at a reservoir Karnataka, India



Even as a 'non-consumptive water use', competition with other uses of water may occur with regard to the:

- timing of use, which may not coincide seasonally as well as hourly;
- resource itself if the return flow is below the command area;
- the local environment because the special pipeline before the plant deprives the natural stream of its flow.

CAPACITY ASSOCIATED WITH THE SERVICE

The capacity for producing electricity may be restricted by the irrigation calendar and the need to store water during the wet season. Locally unregulated discharge may generate an hourly deficit that may affect the capacity as there is no buffering capacity.

SENSITIVITY AND PERTURBATIONS

No specific sensitivity or perturbation issues.

WATER SHARE

Only energy is extracted, water is returned fully to the water system.

BENEFITS - ELECTRICITY PRODUCTION: ONLY A SMALL SHARE OF THE BENEFIT

Electricity production can be an additional asset for the local economy. However, in most cases benefits, when compared to water use for irrigation, are marginal. High benefits from hydropower can be obtained when high drop is combined with high discharge. In the irrigated command areas, drops are often limited to a few metres; therefore the production of electricity is limited.

The amount of electricity produced can be calculated using the following formula:

Power in Kilowatts = Q. H. [Eff]. 9.81

With:

Q discharge in m^3/sec

H drop in elevation metres

Eff efficiency of the process

The annual energy produced by the plant is:

AE (KWh) = Volume. H. Eff./367

and the gross product is then the previous multiplied by the local value of a KWh.

Considering a volume of 25 000 m^3, which is the quantity required for one crop season on a mixed system (paddy + bananas) and a head of 20 m the value of electricity yielded is about US$100.

To compare with crop production, the value produced with these 25 000 m^3 on 1 ha is about US$2 500 (see detailed calculation in Table 10.1)

It is only with very high elevation difference that electricity can match the agriculture value. With a head of 200 m, the gross value of the same quantity would be US$1 020 achieving the same order of magnitude as irrigation.

With a low head drop, as is found often at the reservoir and along canals, the electricity contribution to the overall benefit of the system would remain small. In the multiple-use Shahapur system, electricity production represents a share of 0.6 percent of the estimated value of provisioning services. In Uda Walawe, which is similar to KOISP in Sri Lanka, the electricity contributes to US$1.1 M, which is 2 percent of the total benefit generated by water (Molle and Renwick, 2005). Out of the five MUS systems presented in Chapter 2, Figure 2.9, only one represents a significant economic value that is associated to power generation. This is the Zanghe system in China, which amounts to 34 percent of the provisioning services total value (Dong Bin, 2008).

TABLE 10.1
Comparison between power and crop production

	Power	Irrigation
Volume m3	25 000	25 000
Head	20	Area 1 ha
Efficiency	0.75	Crop = 0.75 % rice and 0.25 % bananas
Quantity produced	1 020 KWh	
Gross value in US$	102 (US$0.01/KWh)	2 500

COSTS

No specific costs are associated with serving power plants.

MANAGEMENT

No specific management considerations.

DEMAND FOR OPERATION

No specific demand for operation is associated with the power plant.

TABLE 10.2
Summary for natural vegetation

	Main features
SERVICE	Various nature Delivery – support to natural streams and bodies
CAPACITY	Time/calendar is often a constraint
SENSITIVITY	NO
PERTURBATION	NO
WATER SHARE	Non-consuming, however water diversion may have a local impact on natural streams
BENEFITS	Limited compared to irrigation use, except for high drops systems
COSTS	No cost considerations
MANAGEMENT	No management considerations
DEMAND for OPERATION	No demand considerations

11. Indirect Distributed Services to Perennial Natural Vegetation

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

Large cities and industrial sites use the most amount of raw water in the CA. Water to cities differs from domestic water discussed in Chapter 6 in that the service is strictly limited to raw water delivery with no responsibility for matching domestic water standards. It is the duty of another company to treat and distribute the raw water to users.

PHOTO 11.1
Example Shahapur Upper Krishna system, Karnataka, India

Although direct service of raw water is considered here, cities and large industries can also benefit from indirect services, especially groundwater recharge, which may be insufficient to match dry season needs without irrigation.

Often the most important point linked to capacity for domestic service is during canal closure for maintenance or when there is no irrigation; capacity is then zeroed or reduced to almost nil. This may require the installation of a reservoir that will permit closure of the canal (Photo 11.1).

PHOTO 11.2
Canal supplying raw water to the city SAFI downstream of Office des Doukkala, Morocco

PHOTO 11.3
Head regulator, Bhagirithi WTP, Delhi Jal Board-1, withdrawing from the Upper Ganga canal

TABLE 11.1
Summary for service to large cities and industry

	Main features
SERVICE	Mainly direct raw water services Indirect service through support to natural streams and bodies
CAPACITY	Time is usually a constraint
SENSITIVITY	Industry might be very sensitive to any failure of supply during some critical periods of their production process
PERTURBATION	Failures of distribution Closure of canals
WATER SHARE	Variable
BENEFITS	Domestic water users served Value = cost of alternative – Production values – Jobs supported
COSTS	Set to the cost of supplying raw water to a delivery point Coverage of MOM costs can benefit from enlarged numbers of users.
MANAGEMENT	The presence of cities and industries with high demand for services might influence the managerial partition of the whole command areas.
DEMAND for OPERATION	Might create high demand for services

12. Services to Capture Fisheries, Water Bodies and Streams

The last set of MUS services is composed of those mostly related to water bodies and streams in the command area. The various potential services (some of which have already been discussed) are listed in Table 12.1.

TABLE 12.1
Ecosystem services directly generated by surface water bodies

Provisioning services	Supporting services
Transportation	Groundwater recharge
Environmental flows (streams)	Support to fishing
Domestic water	Support to natural ecosystems and wildlife (biodiversity)
Water for animals	
Regulating Services	**Cultural services**
Flood protection	Social functions linked to the infrastructure and management
	Recreation and tourism
	Cultural heritage values and landscape

The following chapters will address the following services:

- support to fisheries:
- cultural services – social, tourism, cultural and recreational activities;
- environmental flows;
- transport;
- other regulating services – flood control, drainage and externalities.

As outlined in the chapter on aquaculture, water is a 'supporting service' for aquatic life (MEA grid). This chapter deals with capture fisheries in water bodies and streams that are supported by water management.

Recall that fishery activities may be significant in terms of their economic value, and that it is important to first estimate the impact on nutrition, jobs provided and support to livelihoods.

There are different types of capture fishery activities in an irrigated command area:

- capture fishing in water bodies (natural to extensive);
- capture fishing in natural streams (drainage and rivers) and artificial streams (canal irrigation);
- capture aquatic products in coastal mixed lagoons.

Points to consider:

1. Capture fisheries can be a completely separate activity, or additional to the main farming activity.
2. In large command areas fishing activities often take place in water bodies upstream of the system (main reservoir) and within the system (intermediate reservoirs, natural streams).
3. Recreational fishery represent a high value for those practicing it as well as those engaged in tourism activities.

PHOTO 12.1
View of Tissamarama shallow tank KOISP, Sri Lanka

As preliminary studies of the implementation of IWRM, economic studies of the various water values have been performed in river basins in France. In Table 12.2 the results for the Adour Garonne basin (Southwest) are given. It is not surprising that domestic water is 47 percent of the estimated total value. The value of recreational fisheries (6 percent) is also noteworthy, which surpasses irrigation (5 percent). The value generated by the ecosystem functions, adding purification to recreational fishery is 36 percent of the total value. Productive activities hydropower and irrigation is only 16 percent.

TABLE 12.2
Value of water in the Basin Adour-Garonne France

Function	Unit value US$	Quantum	Total value million US$	Percentage share
Recreational fishery per fisher	290	765 000 fishers	221	6
Hydropower	0.20	Reduced during canal closure	Sensitive to water scarcity Sensitive to long time of travel to reach water Sensitive to pollution	
	1 900 MCM	383	11	
Domestic water	2.46	670 MCM	1 650	47
Irrigation	0.224	811 MCM	181	5
Purification	0.024	43 Billion m^3	1 059	30

Source: Tardieu, 1999

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

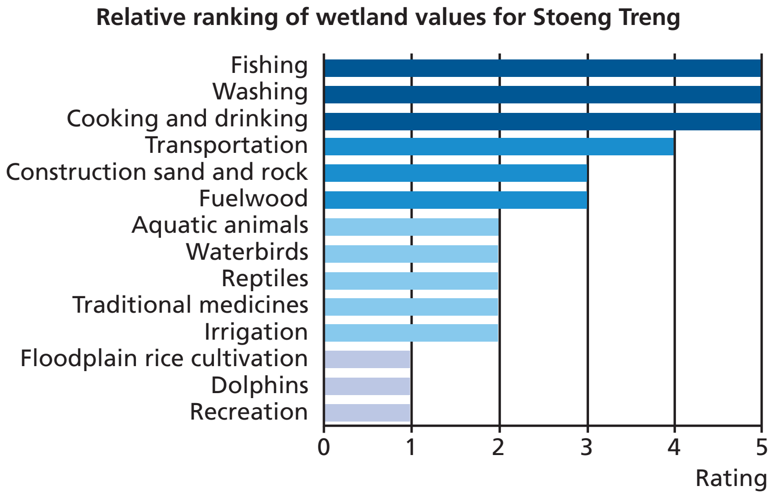
Most of the time the service to water bodies and fishing activities is a direct service. Main and localized water bodies and streams are filled and unfilled following the processes linked to the main uses of water, which is often irrigation in the case of rural infrastructure. Usually the fishing activity is not the principal user of water and therefore cannot drive the process, but it is often important enough to ensure that the interests of fishing activities are preserved in times of water shortages at the end of the season.

PHOTO 12.2
Fishing in a shallow tank KOISP, Sri Lanka

The direct service for water bodies can be defined as maintaining a minimum level in water bodies, and minimum flows in streams together with some specifications concerning water quality (pollution prevention).

Figure 12.1 is the result of a rating exercise performed to assess the value placed by people on the service in Stoeng Treng Ramsar site, Cambodia. The rating is based on 36 households that ranked uses from 0 to 5 (FAO, 2006b), showing the high importance of fishing for the local community.

FIGURE 12.1
Users relative ranking of various water uses at Ramsar site (Cambodia)



Users involved in fishing activities may be:

- fishers when fishing is their sole source of livelihood;
- farmers when fishing is a part time activity;
- local inhabitants when fishing is a recreational activity rather than a livelihood.

CAPACITY, SENSITIVITY AND PERTURBATION

These three characteristics are related as perturbation affects the capacity of sensitive systems.

The sensitivity of fishing activities can be related to:

- water shortages and low levels of water;
- water quality (salt and other chemical contents, temperature, turbidity).

Perturbations can then be generated by different phenomenon:

- polluted drainage water from agriculture, cities or industrial sites;
- canal closure during off-periods or for maintenance, dramatically reducing the availability of fresh water;
- excessive fresh water drained to the lagoons (see Box 12.1).

BOX 12.1

Too much freshwater in coastal lagoons KOISP, Sri Lanka

In KOISP the coastal lagoons system are highly dependent on the way irrigation water is managed. Impacts can be positive or negative and water management must be carefully monitored to optimize services. Too little water from irrigation areas can create a problem for water quality, but the reverse is also true. Studies in the late 1990s showed that too much fresh water from drained paddy fields was reaching the lagoons, which drastically modified the salt balance in the aquatic ecosystems and impacted shrimp development.

This impact is of concern to two types of user. The first is the seasonal fisher who harvests shrimps and fish, the second is the environment because the lagoons are an important source of food for migratory birds. It has been reported that prawn fishing, which once sustained several hundred families prior to the KOISP project, has almost disappeared

Source: Matsuno, 1999

When the aquaculture production sites are intense they may also generate perturbations for the downstream environment and users.

WATER SHARE (ACCOUNTING)

Water is not consumed directly during the process of fish and aquatic production, but is evaporated from the surface of the water body and stream. Only a fraction of the evaporation from water bodies can be attributed to each use/user. In the MASSMUS methodology it is proposed that evaporation from water bodies and streams first be calculated and second that the estimated value be shared among the various users concerned with this water body (irrigation, domestic, livestock, fisheries, environment, recreational). There is no universal rule as to how to partition evaporation. It is suggested that benefits we used as an indicator to simply weigh the process of sharing among the shareholders.

BENEFITS

To estimate the benefit of the fishery and aquatic activity one needs to specify the units used and the estimated amounts.

An example of a more in depth analysis of the impact of a water project on fisheries is presented in Table 12.5, which compares the situation before and after the Kirindi Oya

TABLE 12.3
Indicator and estimator of the benefit of fishing and aquaculture

Indicator	Estimator of the benefit
Jobs	Number of those fishing
Households	Number of households concerned Fraction of the livelihood generated by the fishing activity
Production in kg	Total catch and production
Local consumption	Production exported from and imported into the CA
Nutritional contribution in protein	Percentage of the CA population needs produced locally
Economic value of the production	Monetary value (US dollar – local value) Share of the total economic value generated in the CA

TABLE 12.4
Productivity of aquaculture system in developing countries

Production system	Production volume (kilograms per hectare)
Tilapia, unfertilised ponds	320
Red Swamp Crayfish extensive rice paddies	750
Malaysian Prawn fed ponds	2 500
Tilapia fertilised ponds	3 200
Tilapia fed ponds	5 900
Tilapia intensive ponds	10 000
Indian Carp polyculture	13 600
Clarias flow-through ponds	40 000
Tilapia fed cages	500 000
Common Carp intensive cages	1 100 000
Clarias follow through tanks	8 500 000

Source: CA 2007, Chapter 12

Project. The total area devoted to fishing activities was reduced by 30 percent as a result of the project. Because of the significant increase of the catch in the head reservoir, production weight increased by 74 percent. Table 12.6 also presents the results of the survey on how many households are engaged full or part-time engaged in fishing.

Yield

The first step in estimating the economic value of fishing production is to estimate yields. Local data are often better than using outside references, but if data is unavailable references are needed to provide at least some order of magnitude for the yield capacity per hectare of water body. In Table 12.6, figures for India are provided for different categories of reservoirs, and for current harvest and potentially improved. Note that this potential is reasonable as 100 kg per ha is still a low figure compared to the figures shown in Table 12.5.

TABLE 12.5
Impact of the KOISP on production potential and monetary value of fisheries

Waterbody	Catchment area	Production (tonnes/year)	Value (SLRs 1 000)	Catchment area	Production (tonnes/year)	Value (SLRs 1 000)
Floodplain	6 200	124	50	0	0	0
Lagoons	1 500	150	225	1 500	150	60
Head reservoir	0	0	0	3 200	1 344	538
Tanks	1 608	1 013	405	1 608	1 013	405
Small tanks	300	189	76	200	126	50
River	0	35	14		0	0
Total	9 608	1 511	769	6 508	2 633	1 503
Change				-3 100	1 122	284

Note: 1999 has been used as reference year with an exchange rate of US$1 = SLRs70

Source: Nguyen-Khoa, Smith and Lorenzen, 2005a

TABLE 12.6
Value of fishing as a livelihood activity

Village	Location in catchment	Fishery	No. of households	No. of households (full and part-time)	% of households engaged in fishing
Ranawaranewewa	upper catchment	small tanks	196	15	8
Kudagama 1	new command area	new reservoir	240	15	6
Bandagiriya	old command area	ancient tank	1 500	200	15
Malakapupathana	old command area	ancient tank	282	17	6
Nadiganwila	banks of Kirindi Oya	ancient tanks and river downstream of reservoir	265	30*	11
Pallemalala	near coast	lagoon	350-388	102**	25
Udamalala	near coast	lagoon	435	30	7
Sippikulama	near coast	lagoon	450	140**	30

* Mainly opportunistic and "leisure" fishing in the river.

** Few fishing during prevailing drought

Source: Nguyen-Khoa, Smith and Lorenzen, 2005a

Monetary value

Average estimation of worldwide aquaculture production is US$12/kg (Tacon, 2003).

COST OF OPERATION

Cost of operation is normally low for fishing in water bodies, only when irrigation is closed then there needs to be a specific operation to deliver water to local water bodies, which will increase costs. For farms, cost is and should be parallel to irrigation deliveries.

TABLE 12.7
Yields/ha of water body estimated for India

Reservoirs	Present yield kg/ha	Potential yield kg/ha
Small	50	100
Medium	12	75
Large	12	50

Source: FAO, 1995

MANAGEMENT

No influence if homogenous spread.

DEMAND FOR OPERATION

The demand for operation is only important when irrigation is off and when the water bodies are reaching low levels.

TABLE 12.8
Summary for capture fisheries in water bodies and streams

	Main features
SERVICE	Various nature Delivery – support to natural streams and bodies.
CAPACITY	Water shortages, low levels, water quality
SENSITIVITY	Water shortages, low levels, water quality
PERTURBATION	Flood, drought, water shortages, pollution
WATER SHARE	A fraction of water evaporated from water bodies
BENEFITS	Reference US$12/kg of fish and aquatic products
COSTS	Only specific costs during irrigation closure
MANAGEMENT	No influence if homogenous spread
DEMAND for OPERATION	Only important when irrigation is off and water bodies reaching low levels

13. Cultural Services: Recreational, Social, Cultural and Tourism

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

Based on classification in the MEA, the category 'cultural services' encompasses recreational, social, cultural and tourism-related services. There are many human activities that may be attached to these services.

Cultural

- appreciation of nature;
- education;
- historical and archaeological appreciation;
- inspiration for art, craft and photography.

Recreational

- non-indigenous hunting, fishing, motorsports, swimming, picnicking;
- exploring;
- boating, kayaking and canoeing.

Social

- gathering;
- indigenous hunting.

Social value

Anyone who has travelled throughout an irrigated command area has witnessed the value derived from the various ecosystem services provided by irrigation water for the local inhabitants. Irrigation canals in many parts of South Asia are social places where people meet late afternoon to wash and bathe, but it is also a pleasant place to meet and socialize (Photo 13.1).

PHOTO 13.1
Social value of water – a typical afternoon scene along a canal in Sri Lanka

BOX 13.1
The vague classification of services for tourism

Classifying water services is highly subjective. There is no absolute classification: this can be illustrated by tourism.

In many countries tourism is classified as part of the industrial sector, given that it requires investment in infrastructure, capacity development, jobs are generated, external currencies. So tourism may be grouped with industrial services.

In terms of water services it would be more appropriate to attach 'tourism' to the group related to water bodies that mainly support tourism activities.

Finally, the MEA classification includes tourism with cultural services.

The social value of agriculture systems and water-related activities are linked to the social capital implied by some water activities. The social capital related to rice cultivation (paddy systems) is well known and documented (Groentfled, 2005). In this respect, specific agriculture and irrigation techniques that require strong cohesion for water circulation and maintenance of the terrace systems yield social capital (see Photo 13.2).

Cultural value/heritage

The traditional terrace system of a paddy field is another value that has a cultural and tourism importance. The fact that Asian societies are very attached to paddy cultivation stems from cultural and aesthetic values associated with the historical landscape.

Although recognition of the importance of agricultural heritage landscapes has been much later than for architecture, appreciation is growing. FAO has initiated a programme to protect and to raise awareness about Globally Important Agricultural Heritage Systems (GIAHS).

PHOTO 13.2
Terrace systems have a heritage value – the Philippines (left) and China (right)

Photo: GIAHS–FAO

Recreational

Many recreational activities in rural areas are related to water including bathing, swimming, boating, sailing, fishing, walking and picnicking. These activities are important to the population of the CA, not necessarily daily, but for special annual events such as religious ceremonies or family gatherings; for wedding or festivals.

PHOTO 13.3
Recreational – swimming in the canal is not authorized but...!

CAPACITY, SENSITIVITY AND PERTURBATIONS

Mostly capacity is linked to the presence of water in streams and water bodies and the water sustaining healthy natural ecosystems. The continuity of service, therefore, depends on the capacity to keep a minimum level of water in the streams and bodies when irrigation is off.

Cultural services are very sensitive to pollution and its consequences. There are well-documented cases of pollution of water bodies that have ruined all cultural services. Who wants to walk around a lake with dead fish on the shore?

WATER SHARE (ACCOUNTING)

The water share of cultural services is not marginal as it comes from water bodies and streams where evaporation is significant. Between 1 400 and 2 000 mm of evaporation per year are common, i.e. 14 000–20 000 m^3/ha. Of course, the amount of water that has evaporated should be partitioned among all users of the water body, as discussed in Chapter 3, Step 4.

BENEFITS OF CULTURAL SERVICES

With the exception of tourism, cultural services are probably the most difficult to assess in terms of tangible benefits. There are no rapid evaluation methods and there is no proxy for estimating the benefit of social, cultural and recreational services. An in-depth valuation approach, with a representative survey of the population and the use of non-market valuation methods is required.

Tourism is different, as this service can be measured in terms of employment, number of visitors, visitor expenditure, nights spent, etc. Of course the question of who benefits from what is always relevant as discussed in Box 13.2.

MANAGEMENT

Cultural services can be a driver of partitioning in the command area. Areas where cultural services are important may be considered as separate units because they provide special services.

DEMAND FOR OPERATION

The demand for operation is associated with the management of water bodies. Specific needs may be related to some cultural services, for instance keeping a minimum level in water bodies to accommodate tourism and recreational activities. Needs are also seasonal, linked to climate or to religious or social matters. In India, water from the River Ganges is sacred to the population and, therefore, managed with special care during special events (pilgrimages) to allow greater access to the 'Ganges' water'.

BOX 13.2

Bundala National Park Sri Lanka: Benefits from tourism yes, but for who?

Tourism is a major income-generating activity in Bundala National Park, which borders and the water is fed by the KOISP. The benefits reported from tourism activities are significant, more than 30 000 visitors annually, 50 percent are foreign tourists. However the local population feels they are not benefitting from the tourism. They also have to face the negative impacts on habitats (deterioration caused by four-wheel drive vehicles), wild animals are accustomed to people, making it harder for farmers to drive them away when they damage the crops.

Source: Matsuno, 1999

TABLE 13.1

Summary for cultural water services

	Main features
SERVICE	Water delivery – Support to natural streams and bodies
CAPACITY	Maintain minimum level and presence
SENSITIVITY	Water pollution
PERTURBATION	Water deficit Water pollution
WATER SHARE	A fraction of water bodies evaporation
BENEFITS	Data on tourism activities In depth valuation methods for other services (social, cultural, recreational)
COSTS	Cost of water bodies management Special cost for maintaining high flows and levels
MANAGEMENT	Can be a driver for partitioning
DEMAND for OPERATION	Specific needs for specific events

14. Environmental Services

The environmental services associated with irrigation systems are either directly linked to water or indirectly to the supporting services provided by water. Services that are directly linked to water include purification and water conservation, while services that are indirectly linked to ecosystem services are numerous as shown in Table 14.1.

TABLE 14.1
Environmental services against the MEA grid

Provisioning services	**Supporting services**
Environmental flows	Groundwater recharge
Fuel (natural vegetation)	Support to fishing
Biochemicals and natural medicines	Support to natural ecosystems and wildlife (biodiversity)
Habitat improvements (raw materials for construction)	Soil formation
	Soil conservation
Regulating Services	**Cultural services**
Sanitation and wastewater treatment	
Cooling effect on habitats, shade.	
Erosion control	

Today, additional advantageous and disadvantageous externalities are considered with regard to global concerns about climate change. Concern about greenhouse gas emissions (GHG) introduced a new global dimension to environmental services. For instance, the function of carbon sequestration, linked to agriculture and water practices, is increasingly considered in valuation procedures. However, all externalities need to be included, both positive and negative, for instance methane emission of paddy field should be included in the balance.

DESCRIPTION OF THE SERVICE AND USERS/ BENEFICIARIES OF THE SERVICE

Groundwater recharge or service from groundwater

One of the most important environmental services in a command area is groundwater recharge resulting from canal seepage and deep percolation from field applications. It is not unusual to see that more than 50 percent of irrigation water entering a command area is not consumed by crops but is lost to the groundwater system. In fact, these losses are often 'not real losses' as the water can be used or recycled by other users downstream.

Groundwater recharge falls into the category of indirect water services (see Figure 1.5). For this category a choice should be made between the following two options:

1. **Service as 'groundwater recharge'** – in this case the supporting service to groundwater is considered as the end service regardless of the downstream uses supported by this water (irrigation, domestic water, industry, etc).
2. **Services from groundwater** – in this case all services supported by groundwater are fully considered and the groundwater system is just a buffer in the cascade system of water uses.

The choice between options one or two will be influenced by local circumstances. Care must be taken not to count the services twice. In the example of KOISP in Sri Lanka discussed previously, option two was obvious as the shallow groundwater was not deep and the downstream uses clearly identified (perennial vegetation). In another project Fenhe district (Shanxi province, China) both options could have been chosen but option one was preferred because of uncertainty about the downstream uses of the groundwater recharge.

Sustaining low peak flows in natural streams: water purification

A direct service of water is the value of purification provided by in situ water. It is an important function in the basin. In the Adour Garonne basin (France) this function was estimated as US$1 billion annually i.e. 30 percent of the total value generated by water for the basin.

Water purification is the result of field practices, through fixing or removing some chemicals and silt load. For example, the role of paddy fields as pollution sinks has been well documented by studies addressing the multi-functionality of rice cultivation (Kim *et al.*, 2006). The basic mechanisms by which paddy fields act as sinks are:

- uptake of nutrients by the rice crop;
- nitrification and denitrification;
- phosphorus absorption by paddy soils.

Sustaining perennial natural vegetation

Indirect services are the biological support to habitats and biodiversity.

PHOTO 14.1
Supported Shahapur tank in Naryanpur system Karnataka, India: Bird sanctuary

Sustaining water bodies and wildlife

In KOISP, Sri Lanka an important service is linked to the support of wetlands and lagoons, and nearby national parks (Yala National Wild Life Park, Bundala Bird sanctuary). Bundala is the most important wintering area for migratory shorebirds, accommodating sometimes up to 20 000 birds (WWDR1. Ruhuna Basins, page 418).

Sustaining urban ecosystems, parks and recreation areas

More and more urban areas need water not only to sustain supply for domestic and industrial water but also to support restored or upgraded urban ecosystems, parks and recreational areas.

In the city of Taiyuan, the capital city of Shanxi province, China, irrigation water is critical for supplying water to large recreational areas, forest parks and urban wetlands for the city's three million residents. The amount of water remains low, at 3 percent of the total water input, but the value is extremely high for people. One aquatic park has been built on one reach of the Fenhe river, which is 21 km long and 300 m wide see Photo 14.2. The reach is isolated from the dry river bed by rubber dams.

Another example of this new type of 'urban restoration' water use is a wetland area situated in the middle of Taiyuan city, which is completely isolated from any other natural or semi-natural areas. This threatened area has now been restored and is sustained by irrigation water (Photo 14.3).

PHOTO 14.2
Aerial view of the Aquatic Fenhe Park in Taiyuan city

PHOTO 14.3
Natural wetlands restored by irrigation water, Taiyuan city

Preventing salt intrusion in river deltas

One function of water application at field level is to supply enough freshwater to prevent salt vertical lift. This occurs where river deltas are affected by seawater intrusion. Freshwater brought by floods, or any other means on top of the soils, are the only means to prevent salt rising by capillary action.

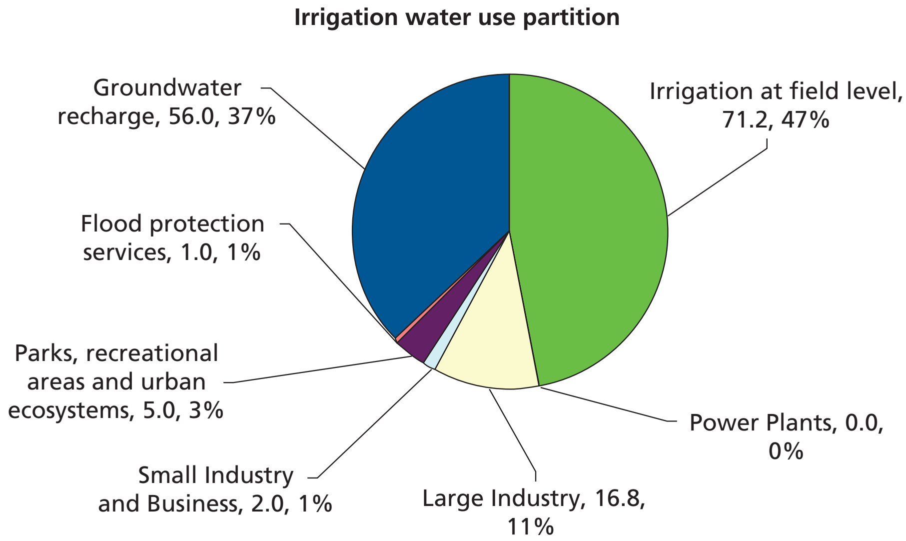
CAPACITY, SENSITIVITY AND PERTURBATION ASSOCIATED WITH THE SERVICE

The capacity of providing environmental services is basically linked to the presence of surface water flows, or lack thereof. During canal closure the services are no longer supported and the impact will depend upon the resilience of the ecosystems to a lack of water.

WATER SHARE (ACCOUNTING)

The share of water attributed to ecosystem services will equal a fraction of the evaporation from the water body, a fraction of water used by natural vegetation and sometimes direct delivery of raw water.

FIGURE 14.1
Water shares in Fenhe irrigation district – Shanxi, China



BOX 14.1
Rice cultivation to maintain the ecosystem balance of the river delta

In the river delta, a direct water service is to maintain the agriculture ecosystems by preventing salt intrusion. In Camargue, the delta area of the Rhone river in the south of France, the natural ecosystem was balanced by regular massive floods bringing fresh water load onto top soils, which was sufficient to keep salt at bay.

This equilibrium was brought to zero when the river was dammed and regulated in the 1950s. The salt rapidly built up in the upper layer of the soil, threatening all agriculture in the delta. A new equilibrium was only reached when rice cultivation was reintroduced. Fresh water percolation from paddy fields now plays the role of the floods, i.e. preventing salt intrusion.

VALUES AND COST

The value of water against the purification function of the natural ecosystems appears to be high, when documented and accounted for, as shown for one river in France (see Table 14.1), easily reaching one-third of total value.

It may be convenient (as proposed by several authors), to use relative values for non-marketable functions in the following ratio. **Monetary value/rice production value**. An example is used in Table 14.2.

The values reported in the literature for the benefits associated with the water purification are extremely variable from one country to another and even within the same country. Values are therefore inconsistent.

TABLE 14.2

Share of non-marketable environmental functions in the Citarum river basin West Java, Indonesia

Non-marketable or replacement cost of environmental functions	Share as percentage of the marketable/ tangible values (US$1 162/ha)
Flood mitigation	10
Conservation of water resources	28
Soil erosion prevention	0.01
Organic waste disposal	0.45
Rural amenity preservation	10
Heat mitigation	2.35
Total non-marketable functions	51

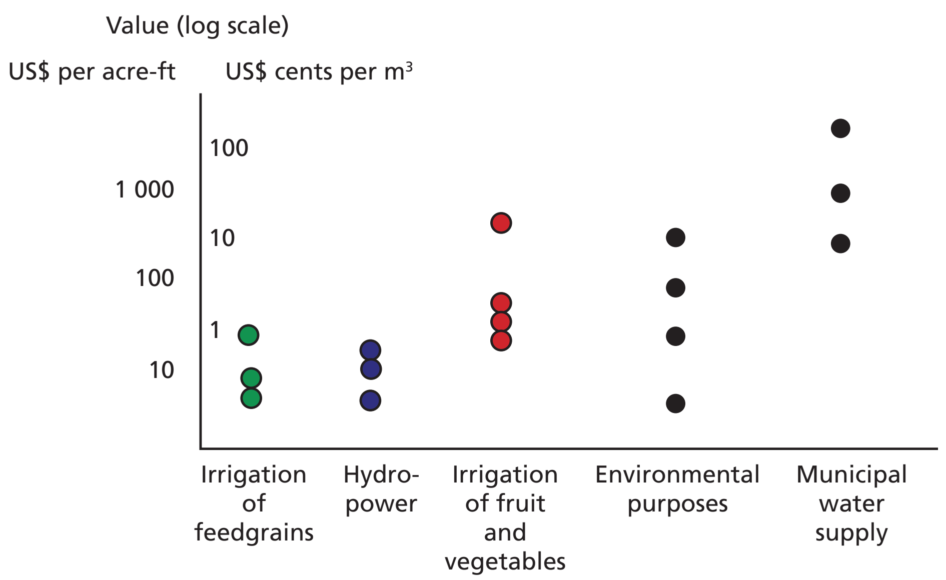
Source: Agus et al., 2006

For instance in Taiwan, C.C. Huang *et al*., (2006) estimated the value of water purification at a low 0.3 percent of the rice production value. In Indonesia, Agus, F. *et al*. (2006) report a value of 30 percent of the marketable rice grain product for conservation of water resources. In South Korea the value reported (Kim, *et al*., 2006; Kwon, and Eo, 2003) for water purification from paddy fields are much higher, varying from US$400 million to 6 billion (2005 value). Per hectare of paddy fields the latter would roughly represent US$400 and 6 000 annually.

As stated by Briscoe (1996) the value of environmental and ecological purposes varies widely but typically falls between the agricultural and municipal values (FAO, Water Report) as shown in Figure 14.2.

FIGURE 14.2

Typical market and non-market values for water use in the western United States of America



Source: Briscoe (1996) cited in FAO, 2004

TABLE 14.3
Summary for domestic environment services

	Main features
SERVICE	Various in nature Deliver – support to natural streams and bodies
CAPACITY	Time is usually a constraint
SENSITIVITY	Sensitivity of users
PERTURBATION	
WATER SHARE	Withdrawn amount Consumed fraction
BENEFITS	
COSTS	
MANAGEMENT	No management conditions
DEMAND for OPERATION	No demand conditions

MANAGEMENT

No management conditions.

DEMAND FOR OPERATION

No demand conditions.

15. Other Provisioning Services: Transport

Transport on waterways – with the huge development of roads and truck transportation, transport on waterways is less common in irrigated areas, however there are cases for which waterways remain the only option. This is particularly the case in frequently submerged lowlands (wetlands) and in river deltas. So the transport component of MUS can range from nil to extremely important (in between these extremes is rare).

Transport on inspection road – along canals is much more common. Although most of the time the canal bank roads are not to be used for private travel and are devoted to operation and maintenance activities. In reality these roads are heavily used by people, particularly when no alternatives are to be found. This de facto service transportation mode is not a service specifically related to water but to the infrastructure. This de facto service is often a constraint for the irrigation manager who faces difficulties in maintaining the roads that can be damaged by transportation such as trucks and tractors.

DESCRIPTION OF THE SERVICE AND USERS/BENEFICIARIES OF THE SERVICE

One example of significant transportation in water canals was found in Kim Dong district. Main products transported are sand, and other construction material. An estimated 60 000 tonnes of goods are transported every year in the Bac Hung Hai (BHH) canals running through Kim Dong district. The main management of BHH collects the fee for transportation, instead of management at the district or the subsystem level.

PHOTO 15.1
Main Ganga canal with transport facilities initially provided but no longer active (Lock on the right side of the cross-regulator)

CAPACITY, SENSITIVITY AND PERTURBATION ASSOCIATED WITH THE SERVICE

Canal capacity during closure for maintenance and during low discharge.

WATER SHARE (ACCOUNTING)

Maintaining high water levels in water bodies and streams can be achieved. However, water is lost through evaporation and sometimes from seepage and deep percolation if the water is not recycled.

BENEFITS AND COST

The benefit/value of transportation is very much contextual. It may range from zero to very high value when there is no other alternative for transporting people and goods. In the survey in the United States (FAO, 2004), see Table 15.1, it can be seen that transportation has a very high value in the United States (US$120 per 1 000 m^3), double that of irrigation.

TABLE 15.1
Value of water use in the United States by sector

	Values of water use in 1994 US$ per 1 000 m3 of water			
	Range of values	Average	Median	Number of observations
in situ				
Waste disposal	0–10	2.4	1	23
Recreational/habitat	0–2142	39	4	211
Navigation	0–400	118	8	7
Hydropower	1–91	20	17	57
Withdrawal				
Irrigation	0–995	61	32	177
Industrial	23–650	229	107	7
Thermal power	7–51	28	23.5	6
Domestic	30464	157	77	6

Source: FAO, 2004

MANAGEMENT

No management conditions

DEMAND FOR OPERATION

No demand conditions

TABLE 15.2
Summary for transport services

	Main features
SERVICE	Water level in waterways
CAPACITY	Limited by water availability
SENSITIVITY	Conflict with other uses
PERTURBATION	Conflict with other uses
WATER SHARE	Evaporation from water bodies and waterways. Seepages should normally be accounted for possible water reuse.
BENEFITS	Reference are contextual and should be reviewed locally only
COSTS	
MANAGEMENT	No management conditions
DEMAND for OPERATION	No demand conditions

16. Other Regulating Services: Flood Protection and Drainage

Flood protection is a regulating service that is the result of the capacity of irrigation systems for storing the peaks of water flows in main and intermediate reservoirs of the CA. In paddy field cultivation, terraces systems with bunds provide capacity for water storage from heavy rains, thus delaying and reducing peak flows downstream.

Drainage is an important service, particularly in irrigated command areas. It is well documented that lack of drainage in irrigated areas leads to waterlogging and soil salinization. Water stagnation close to habitations is usually undesirable because it encourages the spread of diseases.

An example can be found in the Shahapur command area, where drainage was diagnosed as a problem during the MASSMUS exercise in 2009. The soil substratum is impervious to water (granite) and irrigation is abundant. These two conditions favour stagnation of water, which is then the primary cause of some undesirable grass invasion, because of the low level of water in potholes.

DESCRIPTION OF THE SERVICE AND USERS/BENEFICIARIES OF THE SERVICE

Flood protection and drainage are services provided to avoid adverse impacts of water (waterlogging, salinity, water stagnation, floods). No water delivery is associated with these services. This service can imply that some areas may be deliberately submerged or flooded to protect other areas that are of higher value or more sensitive to damage and destruction.

PHOTO 16.1
Invasion of water grasses downstream from a village in Shahapur CA resulting from improper drainage

CAPACITY, SENSITIVITY AND PERTURBATION ASSOCIATED WITH THE SERVICE

Here the capacity for protecting designated zones from the adverse impact of excess water is discussed. Excess water impacts may be sudden and massive floods or long-term drainage problems. Capacity is then an issue of both diversion or evacuation and storing.

WATER SHARE (ACCOUNTING)

Drainage specifically enters into the water accounting process. It can be an internal source for recycling water; in this case it should not be accounted for as an extra source. It may be an outflow at the boundary of the CA, in which case it is important to have accurate measurements of the flows.

Flood protection does not enter into water accounting as such. However, when water in excess (runoff) is diverted and stored, it becomes an extra water resource and as such should be measured and accounted for.

BENEFITS AND COST

Flood mitigation has been evaluated in several countries where paddy cultivation is widely practised. Again, the figures are extremely diverse, in a study carried out in Indonesia a low value of US$111/year/ha is suggested. On the other side of the spectrum it was found that in Japan there was an estimated value of US$5 800. In the middle is Taiwan where Huang, *et al*. (2006) evaluated the flood mitigation function of paddy fields at 37 percent of the rice production value. Figures from Korea in various studies are also intermediate, they are more convergent than for other uses: roughly a value of US$700 to 1 100/year.

Of course, part of the variance can be attributed to the methods used. Substitute cost or damage avoided, methods may lead to significant differences in terms of benefits.

DEMAND FOR OPERATION

The demand varies with the type of equipment (manual, automatic, etc.). Specific operation procedures may be established within the CA to divert surplus water into facilities that can accommodate this water. It may be surface storage, agriculture areas that can withstand excess water. In developed countries pastureland, meadows, wetlands are used to hold surplus water. In Asia paddy fields are used for this purpose.

TABLE 16.1
Summary for flood protection and drainage services

	Main features
SERVICE	Diverting runoff to prevent/minimize consequences of floods Evacuate water from villages and towns as well as agricultural areas
CAPACITY	Storing capacity and safety Ditch capacity
SENSITIVITY	Sensitivity
PERTURBATION	Conflict between the capacity to store runoff and capacity to sustain water deliveries.
WATER SHARE	No
BENEFITS	Context specific
COSTS	Context specific
MANAGEMENT	No management conditions
DEMAND for OPERATION	Safety operation to avoid breaches Specific operation procedures might be set within the CA to divert surplus of water into areas of facilities that can accommodate excess water.

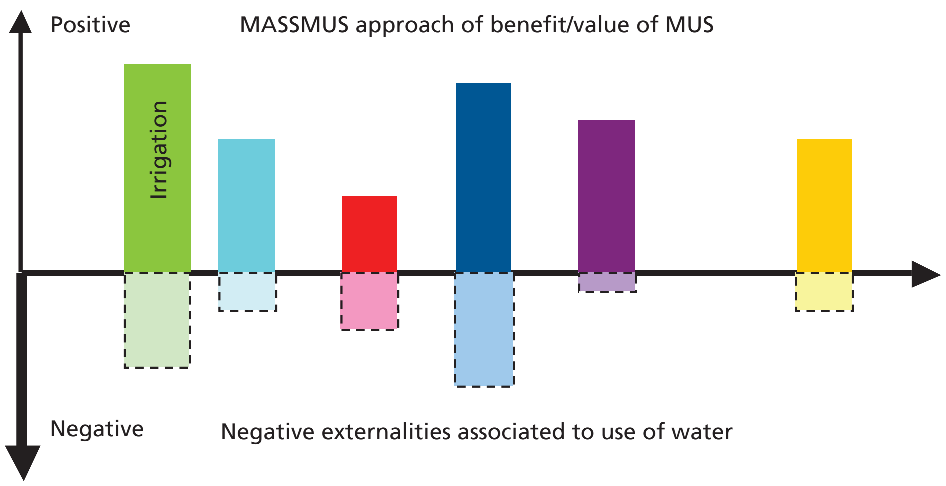
17. Externalities

The review of the services and uses of water, obvious and hidden, focusing on the benefit potentials or tangibles of these multiple uses cannot be concluded without a section on the externalities. Multiple uses are often a positive externality of the initial process (irrigation in this case), but externalities cannot be reduced to their positive aspects.

Any type of human activity or process generates benefits, impacts and externalities. Some externalities are positive, while others are negative. In the case of water management this document has thoroughly reviewed all possible positive externalities linked to water circulation within an irrigation command area. Inversely, all the activities generated can have adverse impacts on ecosystems, the natural resource base or people, who depend on the water for their livelihoods.

Any human activity is potentially harmful to the environment. Internalizing the externalities means subtracting the negative effect from the positive value and benefit.

FIGURE 17.1
Accounting for externalities: positive and negative



The purpose of this last chapter is not to elaborate the negative externalities generated by the MUS services, but to alert the reader to the need to constantly weigh the positive with the negative of the process. Clearly, the MASSMUS approach emphasizes positive externalities, however this does not mean negative externalities can be forgotten.

Externalities must all be accounted for – positive externalities may be turned into a 'specific use' with a specific status. Positive externalities contribute to the value generated by the system. Negative externalities may be accounted also because they generate negative values (cost), which reduce the total value created by the water resources.

Irrigation itself has its own negative externalities for example salinization, waterlogging and the spread of vector-borne diseases.

Aquaculture may have extremely negative effects on the environment when it is highly intensive with many chemicals and medicines being used in the process.

At least for each use incorporated into the MUS approach, there should be a query about possible negative externalities to achieve a balance view

Health impacts

Despite its positive effects on the rural economy and for farmers' income, irrigation may sometimes lead to negative impacts on the health of communities through vector-borne diseases. Keeping water in canals for long periods can affect the reproductive cycle of disease vectors. The link between system operations and community health can be strong.

The recommendations from health experts agree that there is the requirement of variability in canal flow regimes to reduce the breeding of mosquitoes. However, there is a clear conflict between these requirements for vector control and the objectives of irrigation management for stable water flows and steady deliveries. New operation techniques are required in areas where mosquito breeding is related to irrigation practices.

The example presented in Chapter 6 (Figure 6.4) illustrates how service should be linked to the water context (groundwater management). The downstream part (in red) of the NIS (Nepal) has never received an adequate supply of canal water and, therefore, has developed extensive pumping from the groundwater. However, this practice has resulted in arsenic contaminating irrigation and domestic water supplies. An alternative to groundwater must be found through improved canal operations. On the other hand, the upstream part of the system seems to be less vulnerable to arsenic and, therefore, pumping should be encouraged.

TABLE 17.1
Examples of possible negative externalities

Water uses – Services	Potential negative externalities to be considered
Irrigation (surface)	Waterlogging Salinization Water-born disease Pollution resulting from agriculture intensification
Livestock	Pollution from waste Surface water contamination
Aquaculture	Pollution
Domestic Water	Waste water drainage Direct water contamination.
Small Industry/business	Pollution
Homestead garden	
Perennial vegetation	Unintended and unaccounted water consumption
Hydropower plants	Barrier to fish passage Shocks in the natural ecosystem resulting from intermittent turbine use

Externalities and functions

Competition conflict over land use is not an externality. Competition for land or water is not considered an externality. For example, concerns about deforestation, when another use is to substitute forest cover, is not accounted for as externalities; but is part of the competition or conflict for land use. However, if a process leads to rapid exhaustion of land supporting capacity (e.g. soil fertility degradation), which in turn requires moving to other plots of land, degradation should be considered a negative externality.

Negative externalities need to be either eliminated or reduced and compensated for.

This section on externalities closes the long list of water uses/benefits/impacts.

MASSMUS epilogue

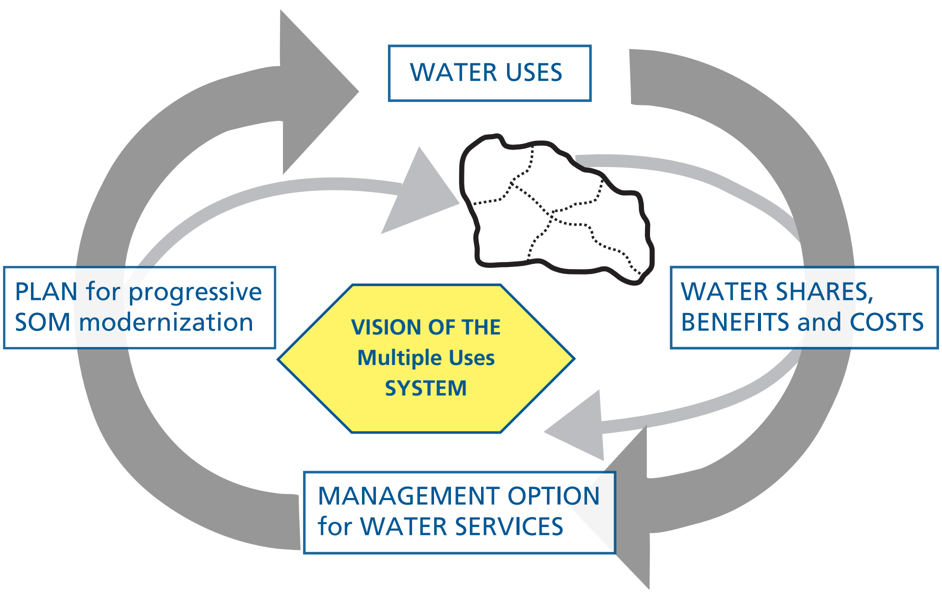
Reaching the end of this presentation of the MASSMUS methodology, it should be clear to everyone that incorporating MUS increases the complexity of water management. However no one can contest that MUS is a great opportunity to promote a robust sustainable water management from social, environmental and economic viewpoints.

The reality on the ground is that 'single use is the exception' and there is no alternative for managers but to embarking progressively on MUS. The key concept is a balance between a distant vision and a step-by-step process: the vision is the long-term destination stakeholders would like to move towards by taking progressive steps.

To end this document there is nothing better than the graph (Figure E.1), which sketches the natural cycle of the MASSMUS process and recalls the main features of the process:

- Step-by-step – most steps are required to move to the next.
- Iterative – one go, one cycle is not enough to exhaust the investigation, it is better to contemplate several cycles with an increasing focus.
- Scaling down – for large water system, the whole process should be duplicated for each managerial subunit defined at the preliminary stage.
- Vision – the whole process should aim towards a vision for the water system and the services. This vision should be discussed initially, set down and regularly refined by stakeholders.

FIGURE E.1
The MASSMUS iterative progressive process



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Annex 1

Rapid Appraisal Process for MUS System (RAP-MUS) [1]

BACKGROUND

The Rapid Appraisal Process (RAP) enables qualified personnel to determine key indicators of irrigation projects both systematically and quickly. The RAP can generally be completed within two weeks of fieldwork and office work – assuming that some readily available data on the project have been organized by project authorities in advance of the RAP.

Key performance indicators from the RAP help to organize perceptions and facts, thereby facilitating informed decisions regarding:

- the potential for water conservation within a project;
- specific weaknesses in project operation, management, resources and hardware;
- specific modernization actions that can be taken to improve project performance.

A parallel activity to the RAP is called benchmarking. As defined in preliminary documents by the International Programme for Technology and Research in Irrigation and Drainage (IPTRID), benchmarking is a systematic process for securing continual improvement through comparison with relevant and achievable internal or external norms and standards. The overall aim of benchmarking is to improve the performance of an organization as measured against its mission and objectives. Benchmarking implies comparison – either internally with previous performance and desired future targets, or externally against similar organizations, or organizations performing similar functions. Benchmarking is in use in both the public sector and the private sector.

Benchmarking incorporates various indicators, many of which are developed from the RAP. Both the RAP and the IPTRID benchmarking activity are still evolving. Therefore, the indicators in this annex will not always be identical to those in IPTRID documents. This annex also reflects current efforts by the World Bank to combine the processes.

The RAP for irrigation projects was introduced in a joint FAO/IPTRID/World Bank publication titled *Modern water control and management practices in irrigation – impact on performance* (FAO, 1999). The report provides an explanation of the RAP

1 *This document was initially written for large open channel network by* Dr Charles Burt Irrigation Training and Research Center (ITRC) California Polytechnic State University (Cal Poly) San Luis Obispo, California, USA 93407. *Adaptation to the specific case of Multiple Uses irrigation system and to Lift Irrigation system was made in 2009 and 2010* by Dr. Daniel Renault Senior Officer Irrigation Management Land and Water Division Natural Resources Department FAO HQ Rome

and also gives RAP results from 16 international irrigation projects.

The RAP makes use of a computer spreadsheet (Excel) with 12 internal worksheets. The investigators input the data collected into these worksheets.

This document describes the classical RAP and the special modules (sheets) developed for the lift irrigation system and the Multiple Use of water.

THE RAPID APPRAISAL PROCESS

The RAP for irrigation projects is a 1–2week process of collection and analysis of data both in the office and in the field. The process examines external inputs such as water supplies, and outputs such as water destinations (evapotranspiration, surface runoff, etc.). It provides a systematic examination of the hardware and processes used to convey and distribute water internally to all levels within the project (from the source to the fields). External indicators and internal indicators are developed in order to provide: (i) a baseline of information for comparison against future performance after modernization; (ii) benchmarking for comparison against other irrigation projects; and (iii) a basis for making specific recommendations for modernization and improvement of water delivery service.

The RAP has only recently been used for diagnosis of international irrigation projects. However, variations of the RAP presented here have been used since 1989 by the Irrigation Training and Research Centre (ITRC) at California Polytechnic State University on dozens of irrigation modernization projects throughout the west of the United States of America.

Traditional diagnostic procedures and research tend to examine portions of a project, whether they are the development of water user associations (WUAs) or the fluctuation of flow rates in a single canal lateral. Such research projects typically require the collection of substantial field data over extended periods.

The time and budgetary requirements of such standard research procedures are significant. Kloezen and Garcés-Restrepo (1998) state that: ‘three engineers worked full-time for more than a year to collect primary data and make measurements to apply process indicators at the level of selected canals and fields’ for just one project. Furthermore, they state that: ‘In addition, the work in Salvatierra was supported by an M.Sc. student...In addition, much time was spent on visiting the selected field and taking several flow measurements per field, per irrigation... Five more months were spent on entering, cleaning, and processing data.’ Although time-consuming research can provide valuable information about irrigation, decisions for modernization improvements must be made more quickly and must be comprehensive.

An essential ingredient for successful application of the RAP is adequate training of the evaluators. Experience has shown that successful RAP programmes require: (i) evaluators with prior training in irrigation; (ii) specific training in the RAP techniques; and (iii) follow-up support and critique when the evaluators begin their fieldwork.

An RAP will be unsuccessful if its accompanying computer spreadsheet files are merely mailed to local irrigation projects to be filled out. Evaluators must understand the logic behind all the questions, and they must learn how to go beyond the obvious when obtaining data. Ideally, if two qualified persons complete a RAP on a single irrigation project, the indicators that are computed by both persons will be very similar.

Typical baseline data for external indicators (such as water balances and irrigation efficiency) are either readily available or they are not. Individual irrigation projects have differences in the ease of access to typical baseline data on the command area (CA), weather, water supply, etc. In some projects, the data can be gathered in a day; in others, it may take weeks. Usually, the delays in data organization are related to finding the time to pull the data out of files and organizing them. If the data do not already exist, spending an additional three months on the site will not create them.

A quick and focused examination of irrigation projects can give a reasonably accurate and pragmatic description of the status of the project and of the processes and hardware that influence that status. This allows for the identification of the major actions that can be taken quickly in order to improve water delivery service – especially if the RAP is conducted in cooperation with the local irrigation authorities.

The question of what is 'reasonably accurate' in data collection and computations can always be debated. Confidence intervals should be assigned to most water balance data – reflecting the reality that there are always uncertainties in data and computation techniques. In irrigation matters, studies are typically concerned about 5–10percent accuracy ranges, not 0.5–1percent accuracy ranges (Clemmens and Burt, 1997). The problems encountered in irrigation projects are typically so gross and obvious to the properly trained eye that it is unnecessary to strive for extreme accuracy when attempting to diagnose an irrigation project. Furthermore, projects typically have such unique sets of characteristics that the results from a very detailed study of just a few items on one project may have limited transferability to other projects. In addition, even with very sophisticated and detailed research, it is difficult to achieve better than about 5–10percent accuracy on some key values, such as crop evapotranspiration of irrigation water.

For the RAP, it is necessary to begin with a prior request for information that can be assembled by the irrigation project authorities – information such as cropped areas, flow rates into the project, weather data, budgets, and staffing. Upon arriving at the project, the evaluators organize these data and interview project managers regarding missing information and their perceptions of how the project functions. The evaluators then travel down and through the canal network, talking to operators and farmers, and observing and recording the methods and hardware that are used for water control. Through this systematic diagnosis of the project, many aspects of engineering and operation become very apparent.

Experience has shown that an RAP is not suitable for the collection of some economic data. Data such as the overall cost of a project, per capita income, and the size of typical farm management units were not readily available in most of the projects described in FAO (1999).

In summary, where executed properly with qualified personnel, the RAP can provide swift and valuable insight into many aspects of irrigation project design and operations. Furthermore, its structure provides a systematic project review that enables an evaluator to provide pragmatic recommendations for improvement.

Some of the data collected during an RAP are also useful in quantifying various benchmark indicators established by the IPTRID. Most of the IPTRID benchmark indicators fall into the category of 'external indicators', whereas RAP indicators include both 'external' and 'internal' indicators. As discussed below, internal indicators are necessary for understanding the processes used within an irrigation project and the level of water delivery service throughout a project. They also help an evaluator to formulate an action plan that will eventually result in an improvement in external indicators. External indicators and traditional benchmarking indicators provide little guidance as to what must be done in order to accomplish improvement. Rather, they only indicate that things should be improved.

EXTERNAL INDICATORS FOR WATER SOURCES AND WATER DESTINATIONS

External indicators

External indicators for irrigation projects are ratios or percentages that generally have forms such as:

$$\frac{\text{Water Required}}{\text{Total Water Available}}$$

$$\frac{\text{Crop Yield}}{\text{Irrigation Water Delivered to the Fields}}$$

The IPTRID benchmarking indicators fall into the category of external indicators, and the RAP also generates a long list of external indicators.

The common attribute of external indicators is that they examine inputs and outputs for a project. External indicators are expressions of various forms of efficiency, whether the efficiency is related to budgets, water or crop yields. Moreover, they only require knowledge of inputs and outputs to the project. By themselves, external indicators do not provide any insight into what must be done in order to improve performance or efficiency. The identification of what actions must be taken to improve these external indicators comes from an examination of internal indicators, which examine the processes and hardware used within the project.

However, external indicators do establish key values – such as whether or not it might be possible to conserve water (without defining how that might be accomplished). As such, low values of external indicators often provide the justification for modernization of projects – with the anticipation that modernization or intervention will improve the values of those external indicators.

The RAP external indicators focus on items of a typical water balance. As such, values such as crop evapotranspiration, effective precipitation, and water supplies must be obtained. The primary purpose of Worksheets 1–3 in the spreadsheet that accompanies the RAP package is to estimate water-related external indicators.

Confidence intervals

A certain amount of error or uncertainty is inherent in all measurement or estimation processes. Therefore, the true or correct values for the water volumes needed to calculate terms such as ‘irrigation efficiency’ are unknown. Estimates must be made of the component volumes, based on measurements or calculations.

In reports that provide estimates of terms such as crop yield and water balance ratios, such as ‘irrigation efficiency’ and ‘relative water supply’, the uncertainties associated with these estimates should be acknowledged and quantified. Otherwise, planners may not know whether the true value of a stated 70percent efficiency lies between 65 percent and 75 percent, or between 50 percent and 90 percent.

One method of expressing the uncertainty in a single-valued estimate is to specify the confidence interval (CI) for that estimate. Where it is believed that a reasonable evaluation of data indicates that the correct value lies within 5 units of 70, then it should be stated that the quantity equals 70±5. More specifically, the essence of a CI should be illustrated as follows when discussing an estimated quantity: ‘The investigators are 95percent confident that their estimate of the irrigated area in the project is within ±7 percent of 500 000 ha (between 465 000 ha and 535 000 ha).’

Statistically, a CI is related to the coefficient of variation (CV), where: CV = (mean)/(standard deviation). The ‘CV’ has no units. In addition, CI = ±2 × CV where the CI is expressed as a fraction (%/100) of the estimated value. Stated differently, if the CI is declared to be 0.10, this means that the ±2 standard deviations cover a range of ±10 percent of the stated value.

Assuming a normal distribution of data, then in about 68 percent of cases the true value is found within plus or minus one standard deviation of the estimated value. Similarly, in about 95 percent of cases (from which comes the ‘95percent confident’ statement), the true value is found within plus or minus two standard deviations of the estimated value.

A logical question could be: ‘How confident are you of the CI that has been selected?’ The answer for an RAP is: ‘The CI is not precise, but it nevertheless gives a good idea of the evaluator’s sense for the accuracy of various values.’ It is better to provide a relative indication of the uncertainty in a value than it is to ignore the uncertainty and have people treat estimates as if they are absolute values.

In the RAP, the evaluator is asked to provide CI estimates for various data quantities. These CI estimates are manually entered into blank cells of Worksheet 4 (External Indicators). The computer spreadsheet then calculates automatically CI estimates for indicators that use these data.

There are two common conventions for computing the CI of a computed value (result). If two independently estimated quantities are added, the CIs are related by:

$$CI_r = \frac{\sqrt{m_1^2 CI_1^2 + m_2^2 CI_2^2}}{m_1 + m_2}$$

where:

- CI_r = CI of the result;
- CI_1 = CI of the first quantity added to form the result;

- CI_2 = CI of the second quantity added to form the result;
- m_1 = estimated value of the first quantity;
- m_2 = estimated value of the second quantity.

If two independently estimated quantities are multiplied together, the CIs are related by:

$$CI_r = \sqrt{CI_1^2 + CI_2^2 + \frac{CI_1^2 CI_2^2}{4}}$$

A rigorous estimate of CIs would require assigning CI values to each of the original data in the first three 'input' worksheets of the computer spreadsheet used for the RAP. However, for a typical RAP, it is not worth striving for more precision than can obtained by inserting CI estimates in the 'Indicator Summary' worksheet. For the convenience of the evaluator, the 'Indicator Summary' worksheet automatically computes the CIr for some pertinent quantities, utilizing various CI values provided by the evaluator.

INTERNAL PROCESSES AND INTERNAL INDICATORS

The broad goals of modernization are to achieve:

- improved irrigation efficiency (an external indicator);
- better crop yields (another external indicator, which is not used here);
- less canal damage from uncontrolled water levels;
- more efficient labour;
- improved social harmony;
- an improved environment as accomplished by fewer diversions or better-quality return flows.

In general, these goals can only be achieved by paying attention to internal details. The specific details addressed by the RAP are: (i) improving water control throughout the project; and (ii) improving the water delivery service to the users.

Therefore, Worksheets 5–11 have the following purposes:

- identify the key factors related to water control throughout a project;
- define the level of water delivery service provided to the users;
- examine specific hardware and management techniques and processes used in the control and distribution of water.

Many of these items are described in the form of 'internal indicators', with assigned values of 0–4 (0 indicating least desirable, and 4 denoting the most desirable).

A Summary for the internal indicators is found in Worksheet 12. Most of the internal indicators have subcomponents, called 'subindicators'. At the end of the spreadsheet, each of the subindicators is assigned a 'weighting factor'.

As an example of the use of internal indicators, Primary Indicator I-1 is used to characterize the actual water delivery service to individual ownership units

TABLE A1.1
Primary Indicator I-1 information

No.	Primary Indicator	Subindicator	Ranking criteria	Wt.
I-1	Actual water delivery service to individual ownership units (e.g. field or farm)			
I-1A		Measurement of volumes to the individual units (0–4)	4 – Excellent measurement and control devices, properly operated and recorded. 3 – Reasonable measurement and control devices, average operation. 2 – Useful but poor measurement of volumes and flow rates. 1 – Reasonable measurement of flow rates, but not of volumes. 0 – No measurement of volumes or flows.	1
I-1B		Flexibility to the individual units (0–4)	4 – Unlimited frequency, rate and duration, but arranged by users within a few days. 3 – Fixed frequency, rate or duration, but arranged. 2 – Dictated rotation, but it approximately matches the crop needs. 1 – Rotation deliveries, but on a somewhat uncertain schedule. 0 – No established rules.	2
I-1C		Reliability to the individual units (0–4)	4 – Water always arrives with the frequency, rate and duration promised. Volume is known. 3 – Very reliable in rate and duration, but occasionally there are a few days of delay. Volume is known. 2 – Water arrives about when it is needed and in the correct amounts. Volume is unknown. 1 – Volume is unknown, and deliveries are fairly unreliable, but less than 50% of the time. 0 – Unreliable frequency, rate, duration, more than 50% of the time, and volume delivered is unknown.	4
I-1D		Apparent equity to individual units (0–4)	4 – All fields throughout the project and within tertiary units receive the same type of water delivery service. 3 – Areas of the project receive the same amounts of water, but within an area the service is somewhat inequitable. 2 – Areas of the project receive somewhat different amounts (unintentionally), but within an area it is equitable. 1 – There are medium inequities both between areas and within areas. 0 – There are differences of more than 50% throughout the project on a fairly widespread basis.	4

(Table A3.1). Primary Indicator I-1 has four subindicators:

- I-1A. Measurement of volumes to the field;
- I-1B. Flexibility to the field;
- I-1C. Reliability to the field;
- I-1D. Apparent equity.

Each of the subindicators (e.g. I-1A) has a maximum potential value of 4.0 (best), and a minimum possible value of 0.0 (worst).

The value for each Primary Indicator (e.g. I-1) is computed automatically in the 'Internal Indicators' worksheet by:

1. Applying a relative weighting factor to each subindicator value. The weighting factors are only relative to each other within the indicator group; one group may have a maximum value of 4, whereas another group may have a maximum value of 2. The only factor of importance is the relative weighting factors of the subindicators within a group.
2. Summing the weighted subindicator values.
3. Adjusting the final value based on a possible scale of 0–4 (4 indicating the most positive conditions).

THE SPREADSHEETS FOR THE RAP

Table A3.2 describes the worksheets for the RAP.

GENERAL GUIDELINES FOR WORKSHEET USAGE

Names and types

The worksheet names within any Excel file are identified at the bottom of the screen. These must not be changed.

The Excel file has two general types of worksheets:

- Input worksheets. These worksheets request data:
  - In the first worksheet, the data are manipulated and/or used in computations on the far right-hand side of the data sheets, out of view of the input pages. (Some computations can be seen by scrolling the pages to the right.)
  - In the Worksheets 5–11, a few internal computations appear vertically in line with input data.
- Summary worksheets. These are Worksheets 4, 12, 13 and 14. The two important ones are 12 and 14. Worksheets 4 and 12 require a limited number of input values, but their primary function is to summarize various data, computed values, and indicators.

Cell colouring and input conventions

The colour convention for the first Input – Year ‘x’ worksheet is:

- Blank cell – indicates a place for data input.
- Shaded cell – contains a default or calculated value or an explanation, or indicates that no data entry is required. In general, any values within the shaded cells should not be changed unless one understands all of the programming.
- Red letters – indicate computed values.
- Blue values – indicate values that were transferred from elsewhere in the file. They may be computed or input elsewhere.

The colour convention for Worksheet 4. – External Indicators is:

- Blank cell – in the ‘Est. CI’ column only – requires the manual input of a value.
- Shaded cell – indicates values that are linked to previous worksheets or are calculated within this worksheet.

TABLE A1.2
Summary for the worksheets to be compiled as part of an RAP

Worksheets in spreadsheet	Worksheet description
1. Input – year 1	For an average water year, requires input (mostly monthly) of: - crop names - irrigation water salinity - crop threshold ECe values - field crop coefficients, by month - areas of crops - water supply - precipitation - recirculation and groundwater pumping - special agronomic requirements.
4. External indicators (ignore these, except to input needed 'CI' values)	Automatic computations of monthly and annual values of various water supply indicators. These are temporary values- except the user must input 'CI' values. The final, important values can be found in the Worksheet 14 'World Bank BMTI Indicators'.
5. Project office questions	Most of the data for this sheet are obtained from the project office. They include: - general project conditions - water supply location - ownership of land and water - currency - budgets - project operation, as described by office staff - stated water delivery service at various levels in the system.
6. Project employees	Requests information on employee training, motivation, dismissal, & work descriptions.
7. WUA	Data for WUAs that were not obtained in the 'Project Office Questions' are obtained here. This requires asking questions in the project office as well as having interviews with WUAs. Questions relate to: - size of WUAs - strength of organization - functions - budgets - water charges.
8. Main canal	Data for the main canal, including: - control of flows - general canal characteristics - cross-regulators - general conditions - operation rules - turnouts - communications - regulating reservoirs - the level of service provided to the next lower level.
9. Second-level canals	Same as main canal.
10. Third-level canals	Same as second-level canals.
11. Final deliveries	Information regarding the level of water delivery service to individual ownership units, and at the last point of operation by paid employees.

Worksheets in spreadsheet	Worksheet description
12. Internal Indicators	This worksheet summarizes the internal indicators that were calculated in the previous worksheets, plus asks for input regarding a few extra indicators. Weighted category indicators are computed for groups of subindicators.
13. Benchmark Indicators	This worksheet holds intermediate calculated values. Ignore this page.
14. World Bank BMIT Indicators	This, plus Worksheet 12, provides the final Summary for the exercise.

- Red letters – indicate values computed within this worksheet.
- Blue values – indicate values that were transferred from elsewhere in the file.

Conventions for Worksheets 5–13 are:

Blank cells with a light-lined border require input.

Blank cells with a dark-lined border indicate that the value is needed, but that it requires information that may only be available at a later time.

Any cell that is filled with a pattern or which is shaded should not receive input.

Shaded cells contain formulas and will show the results of automatic computations.

Cells with patterns are merely dividers between sections, or indicate that no data are needed.

The first input worksheet requires data for a single year, but it is important to provide data for multiple years (i.e. run the program several times with new data), because an examination of only a single year can be misleading for many projects that have wide fluctuations in climate and water supply.

WORKSHEET DESCRIPTIONS

Worksheet 1. Input – Year 1

The worksheet contains ten tables that require data, as well as various individual cells for specific information. Information requests are described below.

Before Table 1

Total project area: This is the gross project area (hectares), including fields that are supported by a project water delivery infrastructure ('command') and fields that are not supported by the infrastructure.

Total field area in the CA: This is the number of hectares that are supported by a project water delivery infrastructure. There may be some zones of this CA that never receive water because of infrastructure damage, shortage of water, etc.

Estimated conveyance efficiency for external water:

$$\text{Conveyance Efficiency} = \frac{\text{Volume of external irrigation water delivered}}{\text{Volume of external irrigation water at the source(s)}} \times 100$$

Where, in this case, the 'point of delivery' is where farmers take control of the water – that is, where the WUA and project authorities hand the water over. Sometimes, a turnout (off-take) represents the final point of delivery by an irrigation authority, yet that turnout supplies 100 fields. Conveyance losses include seepage, spillage, water lost in filling and emptying canals, evaporation from canals, and evapotranspiration from weeds along the canals. The conveyance efficiency includes losses that occur between the point of original diversion and the entrance to the CA, which in some cases may be many kilometres apart.

Estimated conveyance efficiency for internal project recirculation: This is the conveyance efficiency for water that originates within the project, by project authorities. That is, it includes water that the agency pumps from wells or drain ditches or other internal sources. It does not include any water that is imported into the project boundaries.

Estimated seepage rate for paddy rice: There will only be an answer here if paddy rice is grown in a project. This is the percentage of water applied to fields that goes below the rootzone of the rice. Seepage rates are often expressed in millimetres per day, in which case they must be converted to a percentage of the field-applied irrigation water. Many studies combine 'seepage' together with 'evapotranspiration' for rice, to arrive at a combined 'consumptive use'.

This convention is not used in the RAP because such a combination makes it very difficult to separate evapotranspiration (which cannot be recirculated or reduced) from seepage water (which can be recirculated via wells or drains). Furthermore, such a convention ignores the fact that deep percolation is unavoidable on all crops, not only on paddy rice. Therefore, the convention would apply to all crops, not just paddy rice.

Estimated surface losses from paddy rice to drains: There will only be an answer here if paddy rice is grown in a project. This is the percentage of irrigation water applied to fields, or groups of fields, that leaves the fields and enters surface drains. This does not include water that flows from one paddy into another paddy unless it ultimately flows into a surface drain.

Estimated field irrigation efficiency for other crops: This is an estimate for non-rice crops. The elements of inefficiency for paddy rice (deep percolation and surface runoff losses) have already been dealt with. The term 'irrigation efficiency' has a rigorous definition (Burt *et al*., 1997). However, the nature of an RAP is such that the values required for the rigorous application of the definition will not be available. Therefore, for the purposes of the RAP:

$$\text{Field Irrigation Efficiency} = \frac{\text{Irrigation Water Used for ET and Special Practices}}{\text{Irrigation Water Applied to the Field}} \times 100$$

Where:

- The only water considered in the numerator and denominator is 'irrigation' water. Water from precipitation is not included as this indicator is a measure of how efficiently irrigation water is used.
- 'Special practices' include water for leaching of salts, land preparation, and climate control. However, for each of these categories, there is an upper limit

on the amount that is accepted as beneficial use (and that can be included in the numerator). The RAP computations include an estimate of actual leaching requirement needs. The water assigned for land preparation for rice should not include excess deep percolation (caused by holding water too long on a field) or water that flows off the surface of a field.

- For crops such as rice, which are often farmed as a unit that includes several fields that pass water from one field to another, 'field' efficiency can be based on the larger management unit of several smaller field parcels.

In general, this value is a rough estimate. The spreadsheet computes a correct value of 'field irrigation efficiency' in Worksheet 4. External Indicators (Indicator No. 31), which should be compared against this assumed value. This value is only used for one purpose in the spreadsheet: to estimate the recharge to the groundwater from field deep percolation. If, upon completion of the RAP, this estimate is different from the computed estimate, the RAP user should adjust this assumed value (and/or the rice deep percolation and surface runoff values) until Indicator 2 approximately equals Indicator 31.

Flow rate capacity of the main canal (or canals) at diversion point (or points): This value should reflect the sum of the actual (as opposed to 'design') maximum flow rate capacities from each diversion point. Sometimes, the actual capacities are higher than the original design capacities, and in other cases they have been reduced owing to siltation or other factors.

Actual peak flow rate into the main canal (or canals) at the diversion point (or points): The purpose of this question is to define the maximum flow rate of irrigation water that enters the project boundaries. It should not include any internal pumping or recirculation of water.

Average salinity (ECe) of the irrigation water: Where possible, this 'average' should be the annual weighted average, based on the salt load (ppm × flow rate × time). It should be computed as a combination of the well water and surface water.

Table 1 – Field coefficients and crop threshold ECe

Water Year Month

The table provides 12 cells at the top of the Field Coefficient section into which the names of all 12 months are to be placed. Although the table could have had a default month of 'January' in the first cell, many projects have 'water years' that begin at other months, such as April in Southeast Asia, or October or November in Mexico. Place the appropriate month in the highlighted empty cell in order to begin the water year accounting.

Irrigated Crop Name

This column allows the user to input the names of the irrigated crops in the CA. A total of 17 crops are allowed, although the first three are already assigned to 'Paddy Rice', leaving 14 other names blank for the user. A CA may have more than 17 crops. However, many of these crops have small areas of cultivation, and for practical purposes they can be lumped together as a single crop category. Where a crop is double-cropped, then that crop name should be entered twice. The table already has default names for three paddy rice crops, because so many projects have three or more rice crops per year. It is not possible to override the paddy rice crops; it is not possible to substitute other names for these 3 entries because certain computations assume rice in these cells. Crop names only need to be entered once – in Table 1.

They are automatically carried into all other tables that require crop names. This ensures consistency between tables.

TABLE A1.3
Salt tolerance of various crops to soil salinity, after germination

Crop	Threshold ECe (ECe at initial yield decline) dS/m	Crop	Threshold ECe (ECe at initial yield decline) dS/m
Alfalfa	2.0	Onion	1.2
Almond	1.5	Orange	1.7
Apricot	1.6	Orchard grass	1.5
Avocado	1.3	Peach	1.7
Barley (grain)	8.0	Peanut	3.2
Bean	1.0	Pepper	1.5
Beet, garden	4.0	Plum	1.5
Bermuda grass	6.9	Potato	1.7
Broad bean	1.6	Rice, paddy	3.0
Broccoli	2.8	Ryegrass, perennial	5.6
Cabbage	1.8	Sesbania	2.3
Carrot	1.0	Soybean	5.0
Clover	1.5	Spinach	2.0
Corn (forage and grain)	1.8	Strawberry	1.0
Corn, sweet	1.7	Sudan grass	2.8
Cowpea	1.3	Sugar beet	7.0
Cucumber	2.5	Sugar cane	1.7
Date	4.0	Sweet potato	1.5
Fescue, tall	3.9	Tomato	2.5
Flax	1.7	Wheat	6.0
Grape	1.5	Wheat grass, crested	3.5
Grapefruit	1.8	Wheat grass, tall	7.5
Lettuce	1.3		

Source: After Maas and Hoffman (1977)

Salinity

There are two values for salinity:

- Average irrigation water salinity (ECw), dS/m. The average salinity of the irrigation water that comes into the project. The units of dS/m are equivalent to mmho/cm.
- Threshold ECe, dS/m. This is the salinity of a saturated soil-paste extract at which a crop yield will begin to decline. Example values are found in Table A3.3.

The leaching requirement (LR) for each crop is computed within the spreadsheet as:

$$LR = \frac{ECiw}{(5 \times ECe) - ECiw}$$

Where: ECiw = EC of the irrigation water (dS/m); and ECe = threshold saturated paste extract of the crop (dS/m). For example, if ECiw = 1.0 dS/m and the crop is grain corn (Table A3.3),

then: $$LR = \frac{1}{(5 \times 1.8) - 1} = .125$$

The extra water required for each crop, to remove salinity that arrives with the irrigation water, is then computed as:

$$\textbf{Extra water for salinity control} = (\text{ET of irrigation water}) \times \frac{LR}{1 - LR}$$

For example, if for a specific crop, ET of irrigation water = 100 000 MCM and LR = 0.125, then volume of water needed for salinity control = 14 286 MCM. However, deep percolation of rainwater will accomplish the same task (it washes accumulated salts out of the rootzone). Therefore, this RAP approximates the irrigation water requirement as: Volume of irrigation water needed for salinity control = Volume of water needed for salinity control - Rainfall deep percolation.

Field coefficients

Most irrigation specialists are familiar with the term ‘crop coefficient’. Crop coefficients have been widely used in estimates of crop evapotranspiration (ET) since the mid-1970s. The general formula used is: ETcrop = Kc × ETo, where: Kc = the crop coefficient; and ETo = grass reference ET. Guidelines for estimating ET and ETo are given in FAO (1998).

‘Reference’ values other than ETo are sometimes used, but they are being replaced rapidly with weather stations that provide the hourly data needed to compute ETo. This spreadsheet uses ETo as defined in FAO (1998) because:

- ETo is the standard ‘reference’.
- Most excellent ET research on a variety of crops uses ETo as the reference crop.
- ETo estimates tend to be more accurate than other reference methods, such as evaporation pans.

Where the only local data are from evaporation pans, it is advisable to consult with FAO (1998) in order to determine the proper conversion from monthly Epan to monthly ETo values. In Table A3.4, ETo = *Kp* × Epan.

This spreadsheet uses the term ‘field coefficient’ because often a ‘crop coefficient’ is only used during the crop-growing season, and often the common usage of ‘crop coefficients’ ignores the impacts of soil moisture contents.

In reality, the 'field coefficient, *Kc*' is the same as the 'crop coefficient, *Kc*' if the crop coefficient is properly adjusted – using FAO (1998) guidelines – to include factors such as:

- stress (reduced transpiration) caused by a dry rootzone;
- soil surface evaporation due to rainfall or irrigation.

The proper selection of field coefficients depends on a good understanding of Table 8 in the input spreadsheets (Precipitation, effective precipitation, and deep percolation of precipitation). The computation procedure that the spreadsheet uses includes:

- effective precipitation and irrigation water are assumed to be the only external sources of water for field ET;
- the field ET is computed on a monthly basis as: ET = *Kc* × ETo.

TABLE A1.4

Pan coefficients (Kp) for Class A pan for different pan siting and environment and different levels of mean relative humidity (RH) and wind speed

Class A pan description ->								
RH mean (%) ->		low (< 40)	medium (40–70)	high (> 70)		low (< 40)	medium (40–70)	high (> 70)
Wind speed (m/s)	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light (< 2)	1	.55	.65	.75	1	.7	.8	.85
	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1 000	.75	.85	.85	1 000	.5	.6	.7
Moderate (2–5)	1	.5	.6	.65	1	.65	.75	.8
	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1 000	.7	.8	.8	1 000	.45	.55	.6
Strong (5–8)	1	.45	.5	.6	1	.6	.65	.7
	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1 000	.65	.7	.75	1 000	.4	.45	.55
Very strong (> 8)	1	.4	.45	.5	1	.5	.6	.65
	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1 000	.55	.6	.65	1 000	.34	.4	.45

Source: FAO, 1998

Effective precipitation includes all precipitation that is lost through either evaporation (from the soil or plant) or transpiration, as computed by the formula above.

Therefore, in order to account for soil evaporation for those months when the crop is not in the ground, it is necessary to do two things simultaneously:

- The effective precipitation must be computed to account for that evaporation.
- A field coefficient (*Kc*) of greater than 0.0 must be applied to those months.

The following procedure is recommended for the RAP:

- For crops with no irrigation water used for pre-plant irrigation. If for a month the crop has not yet been planted, or a crop is not in the field, assume that for that month:
  - crop coefficient = 0.0;
  - effective rainfall that is reported for that month will only include water that is stored in the rootzone for ET after the seeds are planted.
- For crops that use irrigation water for pre-plant irrigation (e.g. rice field preparation, cotton pre-irrigation). Follow the above procedure until the irrigation water is first applied. Then do the following for each month until the crop is planted or transplanted:
  - crop coefficient > 0 to account for soil evaporation of both irrigation water and effective rainfall;
  - effective rainfall that is reported for that month will include water that is stored for ET after planting, plus the rainfall contribution to the soil evaporation prior to planting.

For example, it is possible to consider a case in which:

- A pre-plant irrigation is applied to a field on the first day of the month.
- The crop will not be planted for another month.
- The soil remains bare and free from weeds for this month.
- The soil remains 'dark' for three days after standing water disappears from the soil surface.

Table A3.5 indicates how to compute an average monthly Kc that takes the soil evaporation properly into account. Rules to follow include:

- The minimum value of *Kc* is typically 0.15.
- Where a soil surface is dark in appearance from moisture, even if there is no standing crop, a crop coefficient of 1.05 is appropriate.
- Most unstressed field crops (cotton, rice and corn) have a crop coefficient of about 1.1 once they have achieved 100 percent canopy cover.

Table 2 – Monthly ETo values

ETo values (in millimetres) by month should be entered. See the above discussion regarding crop coefficients. Ideally, ETo should be computed on an hourly basis using the Penman–Monteith method (FAO, 1998).

Table 3 – Surface water entering the command area boundaries (MCM)

All values for this table should be in units of million cubic metres (MCM), and should only include water that can be used for irrigation. In other words, flows from a river flowing through a CA that has no diversion structures or pumps would not be included. The table allows for three general categories of surface inflows:

- Irrigation water entering from outside the CA. The MCM should be the total MCM at the original diversion point (or points). Therefore, technically speaking it is not the MCM entering the CA. This category of 'irrigation water' is the 'officially diverted' irrigation water supply.

TABLE A1.5

Example computation of an average monthly Kc value for a month following a pre-plant irrigation, but prior to planting

Day	*Kc*	Explanation
1	1.05	Irrigation – wet soil surface.
2	1.05	2nd day of irrigation - wet soil surface.
3	1.05	1st day after irrigation. No standing water. Soil surface still dark.
4	1.05	2nd day after irrigation. Soil surface still dark.
5	1.05	3rd day after irrigation. Soil surface still dark.
6	0.70	4th day after irrigation.
7	0.50	5th day after irrigation.
8	0.30	6th day after irrigation.
9	0.15	7th day after irrigation.
10	0.15	8th day after irrigation.
11	1.05	Rain – wet soil surface.
12	1.05	2nd day of rain – wet soil surface.
13	1.05	1st day after rain. Soil surface still dark.
14	1.05	2nd day after rain. Soil surface still dark.
15	1.05	3rd day after rain. Soil surface still dark.
16	0.70	4th day after rain.
17	0.50	5th day after rain.
18	0.30	6th day after rain.
19	0.15	7th day after rain.
20	0.15	8th day after rain.
21	1.05	Rain – wet soil surface.
22	1.05	2nd day of rain – wet soil surface.
23	1.05	1st day after rain. Soil surface still dark.
24	1.05	2nd day after rain. Soil surface still dark.
25	1.05	3rd day after rain. Soil surface still dark.
26	0.70	4th day after rain.
27	0.50	5th day after rain.
28	0.30	6th day after rain.
29	0.15	7th day after rain.
30	0.15	8th day after rain.
Average *Kc* =	0.71	for this month of 30 days.

- Other inflows from External Source #2. This source can be defined by the RAP user, and can be a consolidation of several physical sources – but all placed in one category. However, these inflows must be accessed by users within the CA as an irrigation supply – either through diversion or through pumping from rivers.
- Other inflows from External Source #3. This has the same qualification as External Source #2.

The key concepts for Table 3 are:

- Table 3 only includes surface volumes that enter from outside the CA boundaries.
- The surface volumes are only included if they are volumes of water used for irrigation. For the purposes of the RAP, External Sources #2 and #3 are considered irrigation water if they consist of water that individual farmers or groups of farmers divert or pump. Many projects have such supplemental supplies that do not enter the CA through designed and maintained canals, yet these supplies are important parts of the overall irrigation supply in the CA.

The important value here is the volume of water that enters the CA, not the volume of water that is pumped from drains (as that may also include recirculation of spills and field runoff).

Table 4 – Internal surface water sources (MCM)

Table 4 values do not represent original supplies of water (as the surface sources were already accounted for in Table 3). Rather, this is the volume of water that is recirculated or pumped from surface sources within the project. This may be water that originated from the irrigation canal and was spilled, deep percolated, or ran off from fields. The origin of the water is not the important thing in Table 4. Rather, the important feature for Table 4 is which entity diverts or pumps this non-canal water.

Table 5 – Hectares of each crop in the command area, by month

Table 5 provides information on how much area is used for each crop during each month.

The *Kc* values for each crop are found in the row immediately above the row into which it is necessary to input the hectares of that crop. If a *Kc* value greater than 0.0 exists for a month for that crop, it is necessary to input the number of hectares associated with that crop, for that month.

Table 6 – Groundwater data

These questions only need to be answered where groundwater is used by farmers or by the project authorities.

Groundwater accounting in irrigation projects frequently ignores external sources of groundwater, and the fact that much of the groundwater may simply be re-circulated surface water. The RAP eliminates the double counting of re-circulated water, which is what happens where groundwater is treated as an independent supply.

Table 6 recognizes that an aquifer may extend well beyond the confines of the CA.

The questions are divided into two categories: pumping from the aquifer within the CA; and pumping from the aquifer but outside the CA. Both areas must be considered if the aquifer is to be examined properly. The external indicators and benchmarking indicators do not utilize the external pumping information. However, the pumping from outside the CA is frequently completely dependent upon seepage and deep percolation from within the CA. In such a case, a 'water conservation' programme within the CA to minimize seepage may actually eliminate the water source for groundwater pumpers outside the CA. There may also be considerations such as contamination of the groundwater as it passes through old marine sediments – increasing the salinity of groundwater as compared with surface water.

The 'net' groundwater pumping within the CA can only be greater than or equal to zero (given the way the spreadsheet is designed). For the computations:

- estimates of deep percolation from fields are made;
- estimates of seepage from canals are made.

When combined, these two represent the recharge of the aquifer from external irrigation water.

Estimates are then made of the groundwater pumping that occurs within the CA – either by project authorities or by individual farmers. This groundwater pumping volume is then discounted for estimated losses. The result is an estimate of the groundwater that actually contributes to evapotranspiration.

The volume of groundwater that is used for ET is compared with the recharge from surface water supplies. If the recharge is greater than the ET of groundwater, then the 'net' groundwater pumping = 0.0. If the ET of groundwater is greater than the recharge, the difference is the 'net' groundwater pumping. In most projects, the 'net' groundwater pumping will equal zero because typically the aquifer is recharged with the imported surface irrigation water.

Although groundwater pumping is an important aspect of recirculation of irrigation water, it is not a 'new' supply of water any more than recirculation of surface water would be. Recirculation of any type will increase the irrigation efficiency of the project. However, it will not have any impact on the irrigation efficiency of the field units unless the recirculation occurs on the fields themselves.

Table 7 – Precipitation, effective precipitation, and deep percolation of precipitation
The monthly gross precipitation (in millimetres) is required at the top of the table. These values are generally easy to obtain.

The other values may be a bit of a mystery to most users although the concepts of effective precipitation and deep percolation are common concepts. The problem the users will have is in identifying proper values. Simple assumptions about deep percolation and the percentage of rainfall that is effective do not work for spreadsheets such as these, which are designed to be applied over a wide range of geography, each having vast differences in climates and crops.

Effective precipitation is defined as precipitation that is destined for ET (evaporation or transpiration) either this month or in the future.

Effective precipitation and deep percolation can be input in this table for any or all months, regardless of whether a crop is in the field that month. The deep percolation of rainfall is used for only one computation purpose: as a computed reduction of the amount of irrigation leaching water that is necessary to wash salts from the rootzone.

In general, values for 'effective precipitation' and 'deep percolation' are not available as monthly values, and they are almost never available for individual crops. Nevertheless, it is important to make an estimate of these values.

As an aid to the spreadsheet user, the calculated ETfield values (in millimetres) are carried forward from previous tables (these tables are found on the far right-hand side of the pages of this worksheet, and include computations using ETo and *Kc* values). Once the spreadsheet user inputs an estimate of the percentage of effective precipitation, a corresponding depth of effective precipitation will appear in the next row.

In general, if there is a light rainfall during a month yet the ETfield is high, there will be very little deep percolation of rainfall. Conversely, if there is a large amount of rainfall and very little ETfield, then more deep percolation can be expected. Deep percolation also depends on the soil type (sandy soils have more deep percolation than do clay soils). The deep percolation cannot exceed the quantity: Precipitation - Effective precipitation.

Table 8 – Special agronomic requirements (mm)
Only a few crops will have values in this table. The most notable crop is paddy rice.

In the following example for a rice crop, the assumption is that the rice field needs to be flooded prior to planting:

- flooding – 1 March;
- planting – 15 March.

The field stays covered with a small depth of water the entire time, or at least the soil is very wet the entire time. Therefore, the 'field coefficient, *Kc*' equals 1.05. It is further assumed that there is a monthly ETo of 120 mm during March.

Furthermore, it is assumed that the field coefficient, *Kc*, has been computed following the example at the beginning of this annex. The difference between this example and the earlier one is that this example is very simple – the soil is always wet, so the *Kc* is always equal to 1.05.

If the crop coefficient for March were entered as 1.05, then ET for the whole month of March would be computed separately. Therefore, Table 9 would not include any ET amount that occurred between 1 March and 15 March.

However, if the crop coefficient for March were entered as 1.05/2 = 0.53, this would indicate that the spreadsheet user only wanted to count the ET starting on 15 March as 'crop ET', and the ET between 1 March and 15 March would be included in Table 8. It is recommended that the first approach be used (using a *Kc* of 1.05 for the month).

Assuming that the first approach is used (*Kc* = 1.05 for March), then the value in Table 8 must only include two things:

- the deep percolation amount of irrigation water;
- the amount of irrigation water that runs off the field, or group of fields, into surface drains.
- If there had been rainfall during March, some of the runoff and deep percolation

would have been rainwater. Table 8 only includes irrigation water amounts, so any rainfall amounts must be subtracted from total seepage and runoff.

Table 9 – Crop yields and values

Three types of input are needed:

- the local exchange rate (US$/local currency);
- typical average yields of each crop, in tonnes per hectare;
- the farmgate selling price of each crop, in local currency per tonne.

Table 10 –Estimated Shares of Water uses and benefits

This table is automatically constructed from the worksheet 7.a MUS. It yields to two figures one for the water share and one for the partition of value/benefits.

Tables 11 and 12 - Preparatory steps for the figures

These tables are used to prepare for the figures. Values in the tables are normally calculated from other tables and worksheets, but they may need some manual adjustments in particular when specific grouping of uses have to be performed.

Worksheet 4. External indicators

This worksheet is a temporary holding place for some values and computations. For the user, the primary usage of this worksheet is to enter confidence interval values.

INTERNAL INDICATOR SECTION

Worksheets 5–12 require a good field visit to the project by qualified evaluators. They focus on how the project actually works – what the instructions are, how water is physically moved throughout the canal/pipeline system, what perceptions and reality are, and other items such as staffing, budgets and communication. A quick look (rapid appraisal) of these items will immediately identify weaknesses and strengths in the project. Action items are virtually always readily apparent after the systematic RAP has been conducted.

Worksheets 5–12 contain a large number of pages. However, only about 25 percent of the lines require an answer (the other lines are explanations or blanks), and computations are only necessary for a few items such as budget questions. Furthermore, the questions for the main canal are identical to those for the second-level canals and the third-level canals. Once an evaluator understands the questions for the main canal, the remainder of the pages are easily answered after a field visit.

Worksheet 5. Project office questions

Most of the questions in this worksheet should be filled out by the irrigation project employees prior to the visit, as this includes many simple data values such as salaries, number of employees, and stated project policies.

However, the evaluator must answer some of the questions during the visit.

This worksheet includes questions that address the possibility of chaos existing in a project. ‘Chaos’ exists when the reality in a project does not match what project authorities believe occurs. Therefore, the evaluator must ask the project authorities what levels of water delivery service the main canal delivers, what various operators do, and how water reaches individual farmers. These 'stated' conditions are later compared against what the evaluator actually observes in the field.

In general, it is easiest to modernize irrigation projects that have a minimum of chaos. If the project authorities are either not aware of actual field conditions, or if they refuse to recognize certain problems, it is then very difficult to make changes.

This workshe*et al*so introduces the concept of assigning a rating of 0–4 to project characteristics, with 0 being the worst rating and 4 being the best. In the majority of cases, the evaluator reads a series of descriptions, and assigns a rating to each of that 'internal indicators' that are later summarized in Worksheet 12 (Internal indicators).

Some indicator values (such as 'O&M adequacy') are calculated automatically based on previous answers. The rating scale for these values can be found by highlighting the calculated value and reading the formula in the cell.

This worksheet has some drainage and salinity information questions at the very end. These are used in various benchmarking indicators.

Where there is an 'umbrella' WUA (elected by smaller WUAs) that manages the project, then that 'umbrella' WUA is considered part of the 'project office'.

MUS is addressed in the lines 224 to 243 with 3 sections. The first section identifies the number of MUS: those resulting from design and those resulting from practice. The second section specifies the stated management attitude against MUS. The third specifies the stated quality of service provided to other uses.

Worksheet 6. Project employees

Most of these questions require a qualitative assessment of conditions in the project, with the evaluator giving a rating of 0–4 for each question. Topics include:

- adequacy of employee training;
- availability of written performance rules;
- power of employees to make independent decisions;
- the ability of the project to dismiss employees with cause;
- rewards to employees for good work.

Worksheet 7.a. MUS

This worksheet is the special module added to the RAP to address specifically the Multiple Uses of Water. An overall MUSD ranking has to be done after the field visits to characterize the actual integration of MUS in the Management Operation and Maintenance [lines 8-13].

Then for each uses of water the same grid of elements applies. Based on initial MASSMUS applications, some distinctions are sometimes proposed for one use of water, i.e. water domestic is split into several categories: bulk water to cities – water to small towns and villages – water to villages and individuals.

For each use or sub-use information concerning the following items are required: characteristics of importance (users, volume used consumed) the means of supply and the characteristics of services, the fraction consumed and returned, existence of conflicts with other uses, users' organisation and governance, service remuneration and value/benefits associated with the use.

When local information is missing calculation of values and water consumption are proposed with the help of tables of references based on literature reviews and on some initial MASSMUS application. This section of references will be regularly updated and enriched by the outputs from new MASSMUS applications. Users are invited to check regularly the FAO website for updated version of RAP-MUS at the following link: http://www.fao.org/nr/water/topics_irrig_mus.html

Worksheet 7.b. WUA

In the worksheets, the abbreviation WUA stands for water user association. Some irrigation projects have a large WUA that operates the whole project canal system, but the final water distribution is done by many smaller WUAs. In such a situation, the WUA questions pertain only to the smaller WUAs.

Many of the questions are identical to those in Worksheet 5 (Project office questions).

The answers must reflect average conditions throughout the whole irrigation project, rather than any single WUA. Therefore, several WUAs must be visited in order to answer the questions properly.

Worksheet 8a. Lift Station

This worksheet is the special module added to the RAP to make it specific to Lift Irrigation System.

The worksheet requires the visit of the lift station, the description of the inlet, the outlet (head of the main canal) and data that should be collected by managers on the running parameters of the lift station.

The worksheet is organized into seven sections:

- General Description of the Lift Station
- Description of the pumping equipment
- Maintenance and Management Indicators
- Capacity analysis
- Operation of the lift station
- Monitoring of the lift station
- Energy balance and efficiency

Section 1 General description of the Lift Station: INLET - PUMP - OUTLET

The inlet and outlet sections must be described physically, hydraulically and geometrically: water levels in the chamber (variation and average) should also be entered. The raising main pipeline is described: diameter, length, fittings and roughness.

Section 2 Description of the Pumping Equipment

The type and main characteristics of the pumps should be entered. Capacity of the pumps at BEP (Best Efficient Point) should be entered.

Particularly for lift station with high varying water levels it is important to enter the entire characteristic curves (H-Q; Power-Q and Efficiency-Q). In sheet 8a. this is done in boxes aside of the main columns: user are asked to enter a set of 6 values given by the pump manufacturers and covering a wide range of situations. The values are automatically adjusted using polynomial expressions the coefficients of which must then be entered manually into a separate table. These expressions of the characteristics are then used to calculate any functioning point according to the variation of water levels and discharges.

Section 3 MAINTENANCE AND MANAGEMENT INTERNAL INDICATORS

This section looks at the hardware and software at the station in a very similar way as that of made for the canal system.

- Control of Flows From Pumping Station Offtakes
- Operation (Pumping Station)
- Capacity 'bottlenecks' in the Pumps

Section 4 CAPACITY ANALYSIS

This section looks at the capacity of the lift station at BEP (entered) and at various configurations corresponding to the water level conditions and corresponding calculated head losses. Calculation of head losses in the pipelines is made using the Colebrook-White expression. Computation of discharge is made using the tool/goal/seek function that must be activated manually for each reference line.

Section 5. LIFT STATION OPERATION

- Control of Flows From Pumping Station
- Operation (Pumping Station)
- Capacity 'bottlenecks' in the Pumps

Section 6 Monitoring of Lift Station running

Key information on the process for recording data at the lift station.

Section 7. Energy balance & Efficiency

Indicators of energy efficiency are automatically from data entered in previous sections.

Worksheet 8b. Main canal

This worksheet begins with six questions about general conditions throughout the project. The answers will have a large CI (defined earlier in the section covering external indicators). However, because there are large differences between various projects, the answers are meaningful.

The remainder of the questions are identical to those for the second-level and third-level canals. While most of the questions are self-explanatory, a few points warrant special explanation.

The wave travel time is the is the lag time between making a change in flow rate at one point in a canal and having the change stabilize at another point downstream.

Concerning the functionality of various structures and instructions, evaluators must always consider the operations from the point of view of the operator, and ask themselves: 'If I were to walk up to this structure, how would I know what to do and would it be easy to do?' For example, where the objective is to maintain a constant water level with a structure:

- What does 'constant' mean – within 1 cm or within 5 cm?
- How many times a day would the structure need to be moved, and even with that movement would it be possible to achieve the desired result?
- Is the structure dangerous or difficult to operate?

If an operator is told to deliver a flow rate into a canal, yet there is no flow rate measurement device (or the device is inaccurate, improperly maintained, improperly located, or requires significant time to stabilize), then it will be almost impossible to accurately achieve the desired result.

Therefore, the evaluator should not simply listen to explanations. The evaluators must put themselves into the operator's shoes. It is not sufficient to know that the operator moves something and then looks at something; the evaluators must understand whether those 'somethings' do indeed give the proper answer.

The format of Worksheet 8 is:

- General observations are recorded.
- Ratings are given to various aspects of operation, maintenance and process. Some of these ratings depend on the general observations that are recorded in the same worksheet. Other ratings stand on their own.

It may appear that some of the general observations are not necessary because they are addressed later in the form of ratings. However, they have been included in order to force the evaluators to make a more systematic examination of various features – which are summarized in later ratings.

The questions about actual service are key. RAP evaluators must recognize that the RAP has been designed under the assumption that all employees of an irrigation project have their jobs for one reason only – to provide service to customers.

By analysing a project by 'levels' (office, main canal, second-level canal, third-level canal, distributaries, and field), a huge project can be understood in simple terms. The operators of the main canal have one objective only – everything they do should be done to provide good water delivery service to their customers, the second level canals (and perhaps a few direct turnouts from the main canal). This 'service concept' must be understood and accepted by everyone, from the chief engineer to the lowest operator. Once it is accepted, then system management becomes very simple. Personnel on each level are only responsible for the performance of that level.

Main-canal operators do not need to understand the details of that day's flow-rate requirements on all the individual fields. In order to subscribe to the service concept, operators generally need to know that their ultimate customer is the farmer. However, the details of day-to-day flow rates do not need to be known at all levels.

Rather, the main-canal operators have one task to accomplish – to deliver flow rates at specific turnouts (offtakes) with a high degree of service. Service is described in the RAP with three indices:

- flexibility, composed of:
  - frequency,
  - flow rate,
  - duration;
- reliability;
- equity.

For very simple field irrigation techniques, reliability and equity are crucial. Without good reliability and equity, there are generally social problems, such as vandalism and non-payment of water fees. Thus, reliability and equity are cornerstones of projects that have good social order.

In order to have efficient field irrigation practices, some minimum level of flexibility is required. Even with the most basic irrigation methods, such as paddy rice, the flow rates are completely different at the beginning of the season (for land preparation) compared with when the rice crop is established. Moreover, not everyone plants at the same time, meaning that the irrigation project must have some flexibility built into it.

In order to obtain a high project efficiency, the canal system must have sufficient flexibility built into it to be able to change flows frequently in response to continually changing demands and weather. However, most irrigation projects are not very flexible. Furthermore, most irrigation projects have low project efficiencies.

Finally, evaluators need to consider that a major purpose of the RAP is to identify what can be done in order to improve project performance. Modern field irrigation methods, e.g. sprinkler and drip, require a much higher degree of flexibility and reliability than do traditional surface irrigation methods. The evaluators must always be asking themselves during the RAP: 'I do not only want to recommend how to rehabilitate the project – I want to recommend steps that will move the project closer to a higher efficiency and better water management as the future will certainly demand. Will these structures and operating instructions and personnel be capable of meeting the new requirements, and if not, what adjustments must be made?'

Therefore, the examination of the main canal must be thorough. The evaluators need to start at the source, and work their way to the downstream end of the canal. This is not to say that every single structure must be analysed. However, evaluators must examine the key structures along the complete length of the canal.

Common challenges that evaluators have to overcome are:

- The project authorities want to spend a disproportionate amount of time at the dam, discussing dam maintenance, the watershed, and politics. Actually, the only items of interest at the dam are: (i) the storage; and (ii) how discharges are computed and actually made and measured.
- Evaluators will be told: 'the canal is all the same'. The explicit or implied conclusion is that the evaluators only need to examine portions of the canals near

the headworks. It may be true that the canal is indeed identical along its complete length. However, in general, there are significant differences in maintenance, slope, structures, etc. along its length. Only by physically travelling along the canal will the evaluators learn about those differences.

- The operation will be explained by project authorities that are accompanying the evaluators. This is a difficult challenge. The office visit (Worksheet 5) is designed to obtain the perspective of the office staff and bosses. A purpose of the field visit is to talk to the actual structure operators and review their notes – without having their bosses interrupt and give the 'official' answer. In many cases, it is necessary to separate the bosses from the operators, so that the operators are not cautious with the answers they give. Therefore, the 'rules of the game' must be understood before the field visit is made.

Another challenge arises in the selection of which canals to visit. Sometimes, a project will have two or more main canals, and dozens of 'second-level' canals. However, in general, operator instructions, hardware, and maintenance levels will be similar on all of the canals at a specific level. Visiting more canals is helpful, but it is not necessary to visit all of the canals in a project.

Different main canals each have a few specific engineering/hydraulic challenges. One canal may have a bottleneck (restriction) at a river crossing, and another canal may have a peculiar control problem – even though everything else seems the same. If the RAP evaluators can provide good recommendations for such specific hydraulic problems (that are not covered specifically in the RAP forms), the credibility of the evaluators will be enhanced, and RAP recommendations will have a better chance of being accepted. Therefore, the evaluators should take ample pictures and notes during the visit.

Basic advice for evaluators as they tour the canals (main, second, third, etc.) is summarized in Box A3.1.

Worksheet 9. Second-level canals

See the discussion for Worksheet 8. Second-level canals are those that receive water from the main canals. In general, the second-level canals are operated differently from the main canals.

Worksheet 10. Third-level canals

See the discussion for Worksheet 8. In many medium-sized projects, the 'third level' does not exist; therefore, this worksheet would not be filled out in such cases.

Worksheet 11. Final deliveries

There are two possible points that are considered in this worksheet. One is the Individual Ownership Units – the smallest unit that is owned by a single individual (where private ownership is allowed) or that is managed by a farmer. The Individual Ownership Unit may be larger than a single field where one farmer receives water and then distributes the water over several fields from a single turnout (very common in the United States of America). The key feature of the Individual Ownership Unit is that, at this point, there is no cooperation needed between individual farmers.

BOX A1.1
Advice for evaluators

Understand everything. Understand how the operators think things should work. Question everything. If you do not understand explanations, continue to question the explanations until you understand the perspective of the operators. But go beyond that. Every structure has a function. Do not be satisfied with attempting to visualize how that function can be accomplished more easily or better; question the very reason why the structure has been assigned that function. Perhaps in a modernization plan, a structure that is currently operated under flow-rate control should instead be operated under upstream water-level control. In other words, question the very nature of the strategies of operation – not just individual structures. The RAP is not an examination of individual structures – it is a comprehensive examination of a whole process…in which structures have functions. One must understand the pieces (operators, rules and structures) in order to understand the process, but the RAP also questions the assumptions behind the specific processes themselves. The RAP requires evaluators who can look beyond the individual pieces; it requires evaluators who can visualize how the pieces can be manipulated and re-arranged as parts of a complete process that provides good service and high efficiency.

The second point is the Point of Management Change. In projects with a high density of turnouts, the Point of Management Change may be the same as the point of Individual Ownership Units. In other words, the irrigation project authority (or the WUA) employee delivers water all the way to the field level. The Point of Management Change is the 'hand-off' point between paid employees and volunteers or farmers.

In some projects, the irrigation authorities place great emphasis on the number of farmers within a project. It is necessary to go beyond this statistic when examining the present operation, because the project authorities may relinquish control of the water to groups of 200 farmers – who are expected to somehow provide equitable and reliable water distribution among themselves. Therefore, there are two important indicators for this discussion:

- The number of fields (Individual Ownership Units) downstream of the Point of Management Change. The greater is the number, the poorer is the reliability, equity and flexibility of water delivery service. Furthermore, any number greater than 1 or 2 indicates that drip and sprinkler irrigation are almost impossible to support.
- The number of turnouts that are operated per employee. This is much more meaningful than the 'number of farmers per employee', because employees may never provide water directly to individual farmers.

Worksheet 12. Internal indicators

This worksheet contains three types of values:

- Summaries of the various internal subindicators that were rated in the previous worksheets, and then computed weighted values for each primary indicator. The shaded columns on the right-hand side provide information about the values, the weighting factors, and the worksheet location for detailed rating criteria of the subindicators. All of these values are given a rating of 0–4, with 4 being highest and most desirable.

- Subindicators and primary indicators, the values of which are input directly into this worksheet (as opposed to being transferred from previous worksheets). These are indicators I-32, I-33 and I-34. These values all have a rating of 0–4.
- A few indicators (I-35+) that do not conform to the rating scale of 0–4. Rather, these are direct ratios of values or individual values that have special significance.

Worksheet 13. IPTRID indicators

This worksheet is an intermediate worksheet that should not be used. Instead, refer to Worksheet 14, as described below.

Worksheet 14. World Bank BMTI indicators

This worksheet contains the 'Benchmarking Technical Indicators', or BMTI values, as of October 2002 for the water year described. The definitions of the various BMTI values are given in Tables A1.6–A1.9.

TABLE A1.6
Definitions of Benchmarking Technical Indicators: water balance indicators

Indicator	Definition	Data specifications
Total annual volume of irrigation water available at the user level (MCM) (also called 'irrigation water delivered').	Total volume of irrigation water (surface water plus groundwater) directly available to users, MCM – using stated conveyance efficiencies for surface and groundwater supplies. It includes water delivered by project authorities as well as water pumped by the users themselves. Water users in this context describe the recipients of irrigation service; these may include single irrigators or groups or irrigators organized into water user groups. This value is used to estimate field irrigation efficiency; it is not used to estimate project irrigation efficiency.	Calculated from the stated value of system water delivery efficiency (from the dam or diversion point to the final project employee delivery point). Includes farmer pumping, because this is a 'delivery' in the sense that it is irrigation water that is available to the farm/field.
Total annual volume of irrigation supply into the three-dimensional boundaries of the command area (MCM).	This is the irrigation water that is imported into the project boundaries, to include river diversions, reservoir discharges, and net groundwater extraction from the aquifer. This value is used to estimate project irrigation efficiency; it is not used in the computation of field irrigation efficiency.	Determination of this value requires a detailed water balance where there is groundwater pumping, because the net extraction must be estimated.
Total annual volume of irrigation water managed by authorities (MCM).	This is the irrigation water that is imported into the project boundaries by the authorities, plus any internal groundwater pumped by the authorities. The value is not used to compute any efficiencies, as some of the internal pumping may be recirculation of original source water. However, this is the volume of water that the project authorities administer, so it is used for the computations related to costs.	
Total annual volume of water supply (MCM).	Total annual volume of surface water diverted and net groundwater abstraction, plus total rainfall, excluding any recirculating internal drainage within the scheme.	This is the irrigation water that is imported into the project boundaries, to include river diversions, reservoir discharges, and net groundwater extraction from the aquifer. Plus, this includes total rainfall.

Indicator	Definition	Data specifications
Total annual volume of irrigation water delivered to users by project authorities.	Total volume of water delivered to water users by the authorities over the year that was directly supplied by project authorities (including WUA) diversions or pumps. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups. This does not include farmer pumps or farmer drainage diversions.	This can be measured directly, or is more commonly estimated based on an assumed conveyance efficiency.
Total annual volume of groundwater pumped within/to the command area (MCM).	Total annual volume of groundwater that is pumped by authorities or farmers that is dedicated to irrigated fields within the command area. This groundwater can originate outside of the command area.	An answer must be provided even if the user does not precisely know the volume of groundwater pumped. The uncertainty can be handled by assigning a large confidence interval, if necessary.
Total annual volume of field ET in irrigated fields (MCM).	Total annual volume of crop ET. This includes evaporation from the soil as well as transpiration from the crop. Depending on how the user entered the data, this may include off-season soil evaporation.	This is computed based on crop coefficients and ETo values.
Total annual volume of ET – effective precipitation (MCM).	The volume of evapotranspiration that must be supplied by irrigation water. Regardless of how one enters data for ET (above), if one follows the guidelines in this manual, one obtains the same final answer of (ET – effective ppt.) – which is the net irrigation requirement.	The user gives an estimate of the effective rainfall, by month, and by crop. Effective rain contributes to the ET.
Peak net irrigation water ET requirement (CMS).	The net peak daily irrigation requirement (ET – effective rainfall) for the command area, based on actual cropping patterns for this year (CMS).	Calculated as the peak monthly (ET – effective rainfall) value, divided by the number of days in that month.
Total command area of the system (ha).	The physical hectares of fields in the project that that are provided with irrigation infrastructure and/or wells.	
Irrigated area, including multiple cropping (ha).	The hectares of cropped land that received irrigation. If a 1ha field has two irrigated crops per year, the reported irrigated area would be 2.0 ha.	
Annual irrigation supply per unit command area (m3/ha)	(Total annual volume of irrigation supply into the command area) / (Total command area of the system)	Total annual volume of irrigation supply into the command area: see earlier definition. Total command area of the system: see earlier definition.
Annual irrigation supply per unit irrigated area (m3/ha)	(Total annual volume of irrigation supply) / (Total annual irrigated crop area)	Total annual volume of irrigation supply: see earlier definition. Total annual irrigated crop area: see earlier definition. Includes multiple cropping.
Conveyance efficiency of project-delivered water (%). (Weighted value using stated values)	(Volume of irrigation water delivered by authorities) / (Total annual volume of project authority irrigation supply)	Volume of external irrigation water delivered by authorities: total volume of irrigation water supply that is delivered to water users by the project authorities over the year. Water users in this context describe the recipients of irrigation service; these may include single irrigators or groups or irrigators organized into water user groups. Total annual volume of project authority irrigation supply: see earlier definition.
Estimated conveyance efficiency for project groundwater (%).	(Annual volume of project groundwater delivered to users × 100) / (Annual volume of groundwater pumped by authorities)	Annual volume of project groundwater delivered to users: This refers to a weighted value of conveyance efficiency for groundwater that is pumped by authorities from wells both inside and outside of the command area, but which is delivered within the command area. Annual volume of groundwater pumped by authorities: self-explanatory.

Indicator	Definition	Data specifications
Annual relative water supply (RWS).	(Total annual volume of water supply) / (Total annual volume of field ET in irrigated fields)	Total annual volume of water supply: see earlier definition. Total annual volume of field ET: see earlier definition.
Annual relative irrigation supply (RIS).	(Total annual volume of irrigation supply into the 3-D boundaries) / (Total annual volume of ET – effective precipitation)	Total annual volume of irrigation supply into the 3-D boundaries: see earlier definition. Total annual volume of ET – effective precipitation: see earlier definition.
Water delivery capacity.	(Canal capacity to deliver water at system head) / (Peak irrigation water ET requirement)	Canal capacity to deliver water at system head: actual gross discharge capacity of main canal (canals) at all diversion points (CMS). Peak irrigation water ET requirement:: see earlier definition (CMS).
Security of entitlement supply (%).	The frequency with which the irrigation organization is capable of supplying the established system water entitlements.	System water entitlement: the bulk volume (MCM) or bulk discharge of water (CMS) to which the scheme is entitled per year.
Average field irrigation efficiency (%).	((ET - Effective precipitation + LR water) × 100) / (Total public and private water delivered to fields)	All values are expressed in 12 month volumes.
Command area irrigation efficiency (%).	((ET + Leaching needs - Effective ppt.) × 100) / (Surface irrigation imports + Net groundwater)	All values are expressed in 12 month volumes.

TABLE A1.7

Definitions of Benchmarking Technical Indicators: financial indicators

Indicator	Definition	Data specifications
Cost recovery ratio.	(Gross revenue collected) / (Total MOM cost)	Gross revenue collected: total revenues collected from payment of services by water users. Total MOM cost: total management, operation and maintenance cost of providing the irrigation and drainage service excluding capital expenditure and depreciation/renewals.
Maintenance cost to revenue ratio.	(Maintenance cost) / (Gross revenue collected)	Maintenance cost: total expenditure on system maintenance. Gross revenue collected: total revenues collected from payment of services by water users.
Total MOM cost per unit area (US$/ha).	(Total MOM cost) / (Total command area serviced by the system)	Total MOM cost: see earlier definition. Total command area serviced by the system: see earlier definition.
Total cost per staff person employed (US$/person).	(Total cost of personnel) / (Total number of personnel)	Total cost of personal: total cost of personnel employed in the provision of the irrigation and drainage service, either in the field or office (including secretarial and administrative staff). Includes WUA employees and project employees. Total number of personnel engaged in irrigation and drainage service: total number of personnel employed in the provision of the irrigation and drainage service, either in the field or office (includes secretaries, administrators). This includes WUA employees and project employees.
Revenue collection performance.	(Gross revenue collected) / (Gross revenue invoiced)	Gross revenue collected: total revenues collected from payment of services by water users. Gross revenue invoiced: total revenue due for collection from water users for provision of irrigation and drainage services.
Staff persons per unit irrigated area (Persons/ha).	(Total number of personnel engaged in irrigation and drainage service) / (Total irrigated area serviced by the system)	Total number of personnel engaged in irrigation and drainage service: total number of personnel employed in the in provision of the irrigation and drainage service, including secretarial and administrative staff – in WUAs plus project employment. Total irrigated area (ha): see earlier definition.

Indicator	Definition	Data specifications
Number of turnouts per field operator.	(Total number of turnouts [offtakes]) / (Total number of personnel engaged in field irrigation and drainage service)	Total number of personnel engaged in irrigation and drainage service: total number of field personnel employed in the provision of the irrigation and drainage service, including supervisors. Total number of turnouts: the number of turnouts (offtakes) to fields, farms, or groups of farmers, plus offtakes to laterals and sublaterals, that are physically operated by the field personnel.
Average revenue per cubic metre of irrigation water delivered to water users by authorities (US$/m3).	(Gross revenue collected) / (Total annual volume of project irrigation water delivered)	Gross revenue collected: total revenues collected from payment of services by water users. Total annual volume of irrigation water delivered: see earlier definition.
Total MOM cost per cubic metre of irrigation water delivered to water users by the project authorities (US$/m3).	(Total MOM cost) / (Total annual volume of irrigation delivered by project authorities)	Total MOM cost: total management, operation and maintenance cost of providing the irrigation and drainage service excluding capital expenditure and depreciation/renewals. Total annual volume of irrigation water delivered by project authorities: see earlier definition.

TABLE A1.8

Definitions of Benchmarking Technical Indicators: agricultural productivity and economic indicators

Indicator	Definition	Data specifications
Total annual value of agricultural production (US$).	Total annual value of agricultural production received by producers.	
Output per unit command area (US$/ha).	(Total annual value of agricultural production) / (Total command area of the system)	Total annual value of agricultural production: total annual value of agricultural production received by producers. Total command area of the system: the command area is the nominal or design area provided with irrigation infrastructure that can be irrigated.
Output per unit irrigated area, including multiple cropping (US$/ha).	(Total annual value of agricultural production) / (Total annual irrigated crop area)	Total annual value of agricultural production: see earlier definition. Total command area of the system: see earlier definition.
Output per unit irrigation supply (US$/m3).	(Total annual value of agricultural production) / (Total annual volume of irrigation supply into the 3-D boundaries of the command area)	Total annual value of agricultural production: see earlier definition. Total annual irrigated crop area: see earlier definition.
Output per unit water supply (US$/m3).	(Total annual value of agricultural production) / (Total annual volume of water supply)	Total annual value of agricultural production: see earlier definition. Total annual volume of water supply: see earlier definition.
Output per unit of field ET (US$/m3).	(Total annual value of agricultural production) / (Total annual volume of field ET)	Total annual value of agricultural production: see earlier definition. Total annual volume of field ET: see earlier definition.

TABLE A1.9
Definitions of Benchmarking Technical Indicators: environmental performance indicators

Indicator	Definition	Data specifications
Water quality: average salinity of the irrigation supply (dS/m).	Salinity (electrical conductivity) of the irrigation supply.	Weighted (by volume) value, using monthly data. Should include both surface water and groundwater supplies.
Water quality: average salinity of the drainage water (dS/m).	Salinity (electrical conductivity) of the drainage water that leaves the command area.	Weighted (by volume) value, using monthly data.
Water quality: average biochemical oxygen demand (BOD) of the irrigation supply (mg/litre).	Biological load of the irrigation supply expressed as BOD.	Weighted (by volume) value, using monthly data. Should include both surface water and groundwater supplies.
Water quality: average BOD of the drainage water (mg/litre).	Biological load of the drainage water expressed as BOD.	Weighted (by volume) value, using monthly data.
Water quality: average chemical oxygen demand (COD) of the irrigation water (mg/litre).	Chemical load of the irrigation supply expressed as COD.	Weighted (by volume) value, using monthly data. Should include both surface water and groundwater supplies.
Water quality: average COD of the drainage water (mg/litre).	Chemical load of the drainage water expressed as COD.	Weighted (by volume) value, using monthly data.
Average depth to shallow water table (m).	Average annual depth of the shallow water table calculated from water table observations over the irrigation area.	This is an average value for the area of high water table.
Change in shallow water table depth over time (m) (+ indicates up).	Change in shallow water table depth over the last five years.	This is an average value for the area of high water table.

HOW TO INTERPRET RAP RESULTS

The RAP, by itself, is only a diagnostic tool. It allows a qualified evaluator to examine an irrigation project systematically in order to determine the external indicators and the internal indicators.

The external indicators give an indication of whether it is possible to conserve water and enhance the environment through improved water management. The internal indicators give a detailed perspective of how the system is actually operated, and of the water delivery service that is provided at all levels.

The interpretation of the results requires one or more irrigation specialists who have a clear understanding of the options for modernization. Without a thorough knowledge of these options, the recommendations can be ineffective and even counterproductive.

The basic rules are:

- In almost all projects, modernization requires both hardware and management changes.
- In general, it is quite possible to provide high levels of water delivery service to turnouts without good water control if the system is very inefficient and there is a very abundant supply of water. However, if the system must also be efficient, the only way to provide good water delivery service is to have excellent control of the water.

- In almost all projects, water delivery service needs to be improved in order to meet the basic objectives of lower labour costs, reduced spill, improved crop yields, and less environmental damage. The RAP process allows the evaluator to target the appropriate level (or levels) on which to begin modernization.
- In general, there are many very simple changes that can be made in operational procedures, and numerous others that require only a moderate investment in capital for hardware changes.
- All changes must be accompanied by quality control and excellent training.
- There must be a clear understanding the difference between CA irrigation efficiency and field irrigation efficiency. In projects without internal recirculation, the CA irrigation efficiency is generally lower than the field irrigation efficiency. However, in projects with internal recirculation of water, the CA irrigation efficiency may be greater than the field irrigation efficiency.

The CA irrigation efficiency benchmarking indicator combines many of the previous indicators into a single indicator value:

$$\frac{\text{Crop ET - Effective precipitation + Leaching irrig. water needed}}{\text{Surface irrigation water into the project + Net groundwater pumping}} \times 100$$

This expression of irrigation efficiency does not conform to the precise requirements defined by Burt *et al*. (1997), but it is close enough to give a reasonable estimate of the CA irrigation efficiency.

A CA irrigation efficiency of 100 percent is impossible. In general, efficiencies greater than 60 percent require internal recirculation of losses – either as surface water recirculation or from groundwater pumping, or both.

In short, improvement in command area irrigation efficiency can be achieved in two ways: (i) reduce first-time losses; and (ii) recirculate first-time losses.

First-time losses occur in two areas:

- Conveyance losses. These include:
  - spillage from canals and pipelines;
  - seepage from canals;
  - phreatophtye water consumption.
- Field losses. These include:
  - conveyance losses in field channels;
  - surface runoff from fields;
  - deep percolation in fields, caused by: standing water in rice fields, non-uniformity of irrigation water application, and excess duration of irrigation water application.

There is considerable merit in reducing first-time losses because these can have a direct effect on required canal capacity, fertilizer loss, pesticide losses, local waterlogging, etc. In most projects, seepage from canals is targeted, although often other components of first-time losses are more important and cause greater damage to the environment.

Options for the recirculation of first-time losses:

- Surface recirculation. Surface drains, creeks, and rivers pick up first-time losses that originated as:
  - seepage or deep percolation that returns to creeks from a high water table;
  - surface runoff from fields;
  - spillage from canals.
- Pumping from the groundwater. This recirculates first-time losses that originated as:
  - seepage;
  - field deep percolation.

In some cases, recirculation is the least expensive and quickest option for improving project irrigation efficiencies.

A common mistake in modernization is the elimination of first-time losses with the belief that this will improve project irrigation efficiencies. However, where such first-time losses are already recirculated within the project, there may not be any true water conservation.

However, other benefits can be obtained from the elimination of first-time losses:

- easier operation of the distribution system from lining;
- better crop yields through better first-time water management;
- less contamination of water by fertilizers and pesticides.

At the beginning of the RAP input sheets, the RAP user is asked to provide estimates of field irrigation efficiency for rice and other crops. These estimates should account for all conveyance losses, field deep percolation, and surface runoff downstream of the delivery point from the project authorities. However, Worksheet 14 (World Bank BMTI indicators) gives a better estimate of field irrigation efficiency – based on a water balance of the project. This value should be compared with the stated value in Worksheet 1 in order to see whether the stated value corresponds to the water balance values. In general, the water balance values are much closer to the truth.

How to use field irrigation efficiency values

Where the field irrigation efficiency is low, it should not necessarily be concluded that the farmers need better education on how to irrigate properly. In many projects, such training is worthless because project authorities dictate the schedule and amounts of water delivery, and the farmers have almost no choice in the matter.

Low field irrigation efficiencies are typically an indication of a water delivery system that is unreliable, inequitable and/or inflexible. Generally, the water delivery system must be improved before significant field efficiency improvements can take place.

However, there is one practice that can be implemented immediately without changing the water delivery system. This is land grading. Most of the world’s irrigation projects use surface irrigation, and good land grading is important for good in-field distribution uniformity of water.

Where the project irrigation efficiency is greater than the field irrigation efficiency, then there is considerable recirculation within the project.

Project irrigation efficiency is the key indicator as to whether there is an opportunity to conserve water. Field irrigation efficiency gives no indication of this by itself, because a large share of the field losses is often re-circulated.

'Water conservation' in a hydrological basin (as opposed to a specific irrigation project) can only be achieved where one of the following occurs:

- Water flows to salt sinks (ocean, localized salty groundwater) are eliminated.
- Excess evapotranspiration (ET) is reduced (weed and phreatophtye and drain ET is reduced).

Even where good water management does not conserve water in the basin, it does has appreciable benefits, including:

- improving downstream water quality;
- improving the timing of water usage;
- reducing the flow-rate requirements into a project;
- reduction in pumping (sometimes);
- improving crop yields through better timing of applications and reduced fertilizer leaching.
- improving the quality and quantity of flows in rivers and streams immediately downstream of irrigation diversion points.

Summary for the interpretation process

In general, the process of interpretation is as follows:

- Field irrigation efficiencies are examined. Good field efficiencies depend on receiving good water delivery service at the field.
- Project irrigation efficiencies are examined. It is very common for irrigation project personnel to want higher flow rates into the project, although the inefficiencies may be quite high. An important alternative to increasing the water supply is to improve efficiencies.
- Conveyance efficiencies are noted, and compared against field irrigation efficiencies. Both of these are considered in light of any recirculation (groundwater or surface water) that may occur. The comparison helps to determine where efforts might be made.
- The attributes of water delivery service are examined for each level.
- The appropriateness of hardware and operator instruction is reviewed.
- The existence of recirculation systems is noted. In many projects, installing surface water recirculation systems in strategic areas is a simple way to improve performance and water delivery service.
- Where employees spend their time is an important indication of where changes can be made. For example, many projects have a large staff of hydrographers who continually take current meter readings at many locations in the main canals. In general, this inaccurate (owing to the inherent nature of unsteady flows and point-

in-time measurements) work can be eliminated completely if a new strategy for water delivery is adopted.

- With modernization, some actions can be taken in parallel with others, but some actions require a foundation. For example, automation with electronic programmable logic controllers (PLCs) first requires excellent access to sites, excellent communications, and a strong infrastructure for electronic troubleshooting and repairs. They also require a project that has an excellent maintenance record. In other words, PLC automation requires a substantial foundation that is often lacking in irrigation projects. PLC implementation without that foundation is almost guaranteed to fail.

Typically, the key steps for modernization are:

1. Eliminate the discrepancy between 'actual' and 'stated' service. Where project managers refuse to accept reality, it is best to spend time and money on other projects.
2. All levels of staff must understand and adopt the 'service mentality'. While this is not achieved overnight, modernization concepts are rooted in this mentality. Without it, attempts to modernize a project will typically have minimal benefit.
3. Examine instructions that are given to operators, and modify them as needed. A classic example in many Asian projects is where the objective of cross-regulators is to maintain an upstream water level, but the gate operators must move the cross-regulators in strict accordance with instructions (of specific gate movements) from the office – based on computer programs or spreadsheets. A simple check in the field will show that water levels are not maintained properly. The instructions for the operators must be changed, and they are very simple: 'Maintain the upstream water level within a specified tolerance of a defined target'.
4. The first three items are the easiest, but they may also be the most difficult with some senior staff. If the first three items cannot be achieved, it is best to either walk away from a project, or else dismiss the senior staff. Changes in the first three items may take some training, study tours, etc.
5. The next steps, more or less in order of sequence, are to improve the following areas:
    - Understanding of what actually happens in the system. Experts can evaluate a project quickly and because of their background, understand almost immediately the cause/effect relationships and the probable level of service. The operators and supervisors often do not see things the same way. It is very helpful to install simple dataloggers and water-level sensors at key locations in order to record spills, flow-rate fluctuations, and water-level fluctuations. This is almost always revealing for operators who can only visit a location once per day.
    - Communications at all levels. This starts with person-to-person communications (often by radio).
    - Mobility of staff. In general, a small yet mobile staff is much more efficient than a large, immobile staff. This is because a small mobile staff is not responsible for just one or two structures, but must understand how various structures and actions affect other areas. Mobility may be improved by better roads, motorcycles, trucks, etc.
    - Flow-rate control and measurement at key bifurcation points. 'Measurement' and 'control' are not the same. Both are needed. There are many combinations

of structures and techniques that provide rapid and accurate control and measurement of flow rates. This is typically a weak area for many irrigation projects.

- Existence of recirculation points or buffer reservoirs in the main canal system. 'Loose' water control may be very adequate in the main system – provided there exists a place to re-regulate about 70 percent of the way down a canal.
- Improved water-level control throughout the project. The flow-rate control and measurement (above) pertain only to the heads of canals and pipelines. Downstream of the head, it is important to easily maintain fairly constant water levels so that turnout flow rates do not change with time, and so that the canal banks are not damaged. With the proper types of structures, this is easy to do without much human effort.
- Re-organization of procedures for ordering and dispersing water. In most modern projects, one group is responsible for operating the main canal; another is responsible for the second level, and so on. Each group then has a very specific service objective. If a main canal is broken into 'zones' with different offices controlling different 'zones', there is almost always conflict between the zones. Re-organization of the operators is typically necessary. In addition, the whole procedure for receiving real-time information from the field and responding promptly to requests must typically be revamped for most projects.
- Remote monitoring of strategic locations. Such locations are typically buffer reservoirs, drains, and tail-ends of canals.
- Remote manual control of flow rates at strategic locations. These are the heads of the main canal, and heads of major offtakes (turnouts) from the main canal.
- Provision for spill, and the recapture of that spill, from the ends of all small canals.

The above points do not mention canal lining and maintenance equipment. Maintenance equipment must be adequate, and canal lining can reduce maintenance and seepage. However, these topics have been discussed for many decades, and the large sums of money spent on canal lining have generally not brought about modernization. This is because modernization is not just a single action. The items under point 5 represent a departure from traditional thinking of 'concrete civil engineers' and a focus on operations.

Another 'missing' item is a discussion about downstream control and sophisticated canal control algorithms. This is because an irrigation project must walk very well before it runs, and these technologies might be considered as 'high risk'. Sophisticated controls should be selected only after other options have been ruled out, and never before an adequate support infrastructure exists. There is no 'magic pill' for modernization and improved irrigation performance, and simple options often provide excellent results.

It is good to listen to the operators and try to detect a few things that give them a lot of problems. It is sometimes possible to solve some of these problems quickly. By solving these problems for the operators, they will become advocates of further modernization efforts.

CONCLUSIONS

When conducted and analysed by a qualified irrigation engineer, the RAP provides indicators that explain the results and processes of an irrigation project. Many of these indicators can be used for benchmarking purposes, allowing for a comparison between projects and pre-/post-modernization performance. In a short period of only a few weeks, the RAP provides sufficient information to target key action items for modernization. Therefore, it serves as a valuable tool for countries to prioritize investments in different projects, and to prioritize specific actions within individual irrigation projects.

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Annex 2

Economic Valuation Techniques[2]

Economic value is the willingness to pay for a good or service minus what it costs to supply it. When determining the willingness to pay for environmental services we try to reveal how much purchasing power—measured in dollars—people are willing to relinquish in order to be provided with a service, or how much compensation they would be willing to accept in order to forgo that service.

The following are different techniques for valuation that can be utilized for determining the economic values of the uses and functions of MUS:

- Market Price Method
- Productivity Method
- Hedonic Pricing Method
- Travel Cost Method
- Cost Avoided/Substitute Cost Method
- Contingent Valuation Method
- Benefit Transfer Method

Market Price Method

Estimates economic value for environmental goods/services that are bought and sold in commercial markets.

EXAMPLE:

To estimate the value of raw materials, such as rope, we can look at the economic benefit generated to producers and consumers from the sale of the rope.

Net economic benefit: [producer surplus] + [consumer surplus]

Producer surplus:

[price of rope] x [quantity of rope sold] – [cost of supplying rope]

To determine consumer surplus the demand function Must be known.

Consumer surplus:

2 This brief has been written by Sabina Pendse MSc from Yale University USA Volunteer at FAO NRL in 2009.

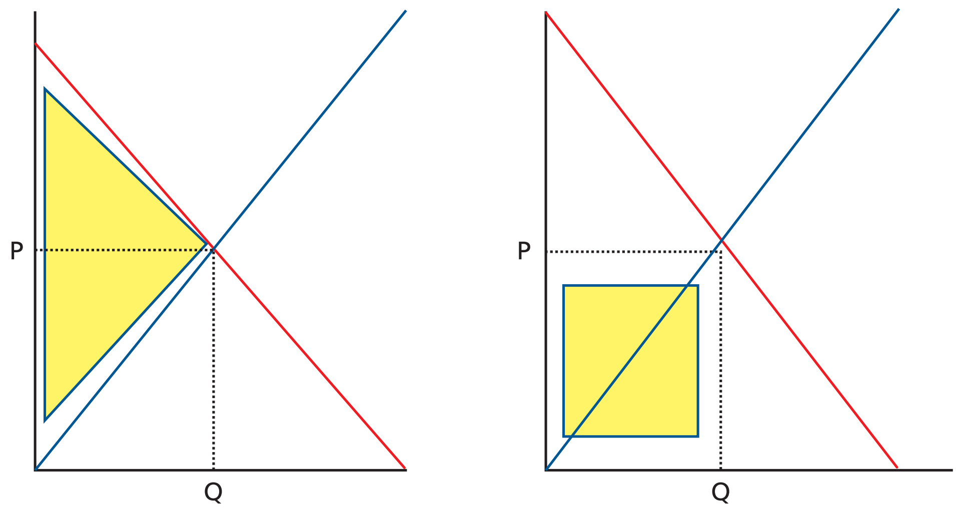
[maximum amount consumer is willing to pay]-[what consumer actually pays]

PROS: The Market Price Method uses actual, observed data and values are well-defined.

CONS: This method of valuation can only be used for market goods. Only completely accurate in perfectly competitive market with no market failures.

Note the difference between net economic benefit and gross product:

FIGURE A2.1
Demand and supply functions



Productivity method

Estimates economic values for environmental goods/services that contribute to the production of goods/services that are bought and sold in commercial markets.

EXAMPLE:

To estimate the value of water in irrigate crop production, we look at the productivity of water in regards to the profit made from the crops:

[price of crop] x [quantity of crop sold] – [costs of all inputs except water (labor, capital, etc)] / quantity of water

PROS: This method is relatively basic, and the data are not complicated.

CONS: This method can only be used with goods/services that contribute to production of commercial goods. Also, production cost data may be difficult to obtain.

Hedonic Pricing Method

Estimates economic values for environmental services that directly affect market prices of some other good.

EXAMPLE:

To estimate the value of a homestead garden we can look at variation on housing/real estate prices that reflect the value of specific attributes.

[price of home with homestead garden] –[price of home without homestead garden]

*Note that the only difference between the two homes should be the presence of a homestead garden, size, location, quality should be the same.

PROS: This method is based on data of actual consumer behavior, and property values are usually a good indicator of value.

CONS: This method only works where there is a reliable, robust real estate market present and when data is comparable. It also depends on awareness and information asymmetry of environmental attributes. This method also requires a lot of data collecting and manipulation.

Travel Cost Method

Estimates economic values for environmental goods/services associated with environmental sites by assuming the value is reflected in willingness to pay to travel to visit the site.

PROS: This method is good because it bases values of actual, observed data of choices made by consumers.

CONS: The most accurate use of this method requires robust data and statistical techniques. May be difficult to determine the opportunity cost of travel time.

Cost Avoided/Substitute Cost Method

Estimates economic values for environmental goods/services based on costs of damages avoided, cost of replacing goods/services, or costs of providing substitute services.

EXAMPLE:

To estimate the value of flood control of an irrigation canal, one could use the amount it would cost for a substitute—building a reservoir or levee. One could also estimate the value by calculating the value of property protected. This can be found in property value data, or for a simpler version, lost profits from crop yields from flooded land.

PROS: This method often requires less data and fewer resources than most other methods.

CONS: This method works best when there is an exact, or close, substitute good or service available. This method is only appropriate when there is clear evidence that consumers would demand the alternative service, and would demand the same amount of benefits to be provided.

Contingent Valuation Method

Estimates economic values for environmental goods/services by asking people to directly state their willingness to pay based on hypothetical situations.

EXAMPLE:

To estimate the value of animal habitat, people can be surveyed to see their willingness to pay for land conservation in a specific hypothetical scenario.

PROS: This method is the most widely accepted method for valuation, and can be used to value any good or service.

CONS: This method can often be biased by survey respondents state preferences not accurately reflecting choices they would make. This method also requires a lot of time to create and collect survey data.

Benefit Transfer Method

Estimates economic values for environmental goods/services by using benefit estimates from previous studies.

EXAMPLE:

To estimate the economic value of water quality in a stream, you can use values determined in other studies from similar locations, context.

TABLE A2.1

Best valuation techniques for each use/function

Uses/Functions	Direct Use Value	Indirect Use Value	Non Use Value	Valuation Techniques
Delivery to Farms	X			MP/P, CV, H, BT, D
Domestic Water Supply	X	X		MP/P, CV, BT, D
Water for Cattle (animals)	X			MP/P, CV, BT, D
Forest Resources	X			MP/P, CV, BT, D
Fishing	X			MP/P, CV, D, BT
Hydropower	X			MP/P, CV, D, BT
Groundwater Recharge		X		D, BT, CV
Flood Control		X		H, CV, D, BT
Recreation/Tourism	X			MP/P, TC, CV, BT
Transport	X			MP/P, CV, D, BT
Soil Conservation		X		H, D, BT
Forest Functions (shade, cooling effect, etc)		X		H, CV, BT, D
Hygiene and Sanitation		X		H, D, CV, BT
Social functions (linked to the infrastructure/management)		X		CV, BT
Biodiversity	X	X	X	MP/P, D, CV, BT
Cultural			X	CV
Aesthetics			X	CV, BT

MP = Market Price, P = Productivity, H= Hedonic Pricing, D = Costs Avoided, TC = Travel Cost, CV = Contingent Valuation, BT = Benefit Transfer.

PROS: This method can be easily and rapidly applied to make gross estimates.

CONS: This method is less accurate than other methods and relies on the adequacy of previous studies. Also, this method requires that the previous studies are in similar locations and have similar site and user characteristics.

Annex 3

Livestock references

Financial benefits of livestock

The following tables are extracted from Renwick *et al* (2007)

TABLE A3.1
Large livestock

Country	Context	PPI$	Drinking Water Use		Reference
			lpcd	$/m3	
LARGE LIVESTOCK					
Kenya	Mixture of cattle and goats Laikipia - site 1	61.00	17.3	3.54	Mizutani, Muthani, Kristjanson, Recke (2005)
	Laikipia - site 2	61.00	17.3	3.54	
	Laikipia - site 3	-8.00	10.9	-0.74	
	Amboseli	21.00	26.2	0.80	
	Average	**34.00**	**18.1**	**1.88**	
	Cattle sheep and goats avg holding - 4.5 TLU/capita	45.00	30.0	1.50	Radney (2007)
South Africa	Cattle	40.00	30.0	1.33	Dovie, Shackleton, Witkowshi, (2006)
India	Adult male cattle	15.88	30.0	0.53	Priya Deshhingkar, et. Al (2007)
	Adult female cattle	13.24	30.0	0.44	
	Adult female cattle crossbred	15.88	30.0	0.53	
	Cattle young stock	6.62	20.0	0.33	
	Buffalo	15.88	40.0	0.40	
	Buffalo young stock	89.00	20.0	4.45	
	Buffalo dairy (no water source)	317.00	71.0	4.46	Upadhyay (2004)
	Buffalo dairy (secure watersource)	109.00	54.0	2.02	
	Cattle dairy (secure source)	5.00	14.0	0.36	

TABLE A3.2
Large livestock

Country		Context	PPI$	Water Use		Reference
				lpcd	$/m3	
India	Andhra Pradesh and Madhya Pradesh	Adult male cattle	15.88	30		Priya Deshhingkar, John Farrington, Pramod Sharma. Laxman Rao, Jayachndra, Reddy, Ade Freeman and Dantuluri Sheeramaraju (2007)
		Adult female cattle	13.24	30		
		Adult female cattle crossbred	15.88	30		
		Cattle young stock	6.62	20		
		Buffalo	15.88			
		Buffalo young stock	6.62			
		Goat	1.32	4.5		
		Sheep	1.32	4.5		
		Poultry - 100 adult poultry	0.07	.3		
	Compared two areas: one with secure water and another without					Upadhyay (2004)
	Source	Buffalo - dairy	317	71		
		Cow - Dairy	109	54		
	No-source	Buffalo - dairy	89	20		
		Cow - Dairy	5	14		

TABLE A3.3
Goats and chicken

Country	Context	PPI$	Water Use		Reference
			lpcd	$/m3	
GOATS					
South Africa	Goats	3.40	4.50	0.76	Dovie, Shackelton, Witkowski (2006)
India	Goats	1.32	4.50	0.29	Priya Deshhingkar, et al (2007)
India	Sheep	1.32	4.50	0.29	Priya Deshhingkar, et al (2007)
CHICKENS					
Bangladesh	Chicken (scavenger based systems - 13 chickens): $10.90/mo	10.00	0.30	33.33	Dovie, Shackelton, Witkowski (2006)
Tanzania	Family poultry flock comprised of five adults	7.60	0.30	25.33	Chitukuro and Foster (1997)
Senegal and Gambia	Out of an average flock size of 21 birds **$130/yr - $6 bird**	6.00	0.30	20.00	Balde (2006)

Annex 4

Information on Fish and Rice

(Extract from Halwart and Gupta, 2004).

TABLE A4.1

Comparison between environmental requirements of fish and rice

Parameter	Normal Range	
	Rice	Fish
1. Depth of water	Minimum saturated soils with no flooding: Ideal: Continuous flooding starting at 3 cm depth gradually increasing to max of 15 cm by 60th day. Complete training 1 to 2 weeks before harvest (Singh et al. 1980)	0 to 41.5 m from nursery and 0.8 to 3.0m for grow out. (Pillay 1990)
2. Temperature	Water and soil temperature of up to 40°C and fluctuations of up to 10°C in one day apparently with no deleterious effect	25°- 35°C for warmwater species Stable temperature preferable. Feeding may slow down at temperatures below or above normal range. Metabolic rate doubles with every 10°C rise
3. pH of water	Neutral to alkaline	6.5 - 9.0 (Boyd 1979)
4. Oxygen	Important during seeding stage for development of radicals	Preferably at near saturation or saturation level (5.0 - 7.0 PPM depending on temperature)
5. Ammonia	High levels of ammonia common immediately after fertilisation	Un-ionised ammonia highly toxic. Ionised form generally safe
6. Transparency or torpidity	Immaterial	Important for growth of natural food. Very high level of suspended soil particles may impair respiration
7. Culture period	90 to 120 days for HYV; up to 160 days for traditional varieties	120 - 240 days depending on species and market requirement

TABLE A4.2
Production reported for fish in rice-fish farming

	Fish Yield (kg-ha^{-1})						
	Bangladesh	China	India	Indonesia	Philippines	Thailand	Vietnam
Concurrent							
Monoculture							
High Range	188-239[a]				223-263[n]		
Low Range	125-156[a]	2 000-3 100[d]		143[k]	43.7-59.7[o]		48-79[t]
Polyculture							
High Range	187-605[b]	750-1 500[e]	500-2 000[h]	2 000-3 5 000[l]	606-636[p]	468-1 472[r]	677[u] 187 prawn =21 fish
Low Range	116-396[b]	150-300[f]	500-700[h]		78-303[o]	87.7-363.3[s]	
Rotational							
Monoculture							
Range				80-367[m]	406-527[q]		
Polyculture							
Maximum		>1 500					
Range		300-450[f]	815-2 135[i]				
Concurrent- Deepwater							
Polyculture							
Range	1 320-3 211[c]	300[g]	3-1 100[j]				

TABLE A4.3

Summary for Cost and return reported for fish in rice-fish farming. All figures in USD/ha/crop or per year

Rice + Fish System, Year, Preiod (Source)	Rice + Fish		Rice Only		% More or (Less)
	Amount	Total	Amount	Total	
Bangladesh					
Ditch/Sump, boro (dry) 1994, (Gupta et al. 1998)					
Rice income	749		690		8.5%
Fish income	195				
Rice expenses	(302)		(326)		(7.4%)
Fish expenses	(72)				
Net Returns		570		364	56.6%
Ditch/Sump, aman (wet) 1993, (Gupta et al. 1988)[a]					
Rice income	464		444		4.5%
Fish income	183				
Rice expenses	(121)		(137)		(11.6%)
Fish expenses	(31)				
Net Returns		495		307	61.2%
China					
WRDG Grow-out 1987, one crop, (Yan et al. 1995)					
Rice income	559		562		(0.9%)
Fish income	864				
Rice expenses	(131)		(158)		(17.1%)
Fish expenses	(202)				
Net Returns		1 090		404	169.8%
Unsp. Grow-out 1988, one crop, (Lin et al. 1995)					
Net Returns[b]		588		405	45.2%

Legend: WRDG - Wide Ridge

a) Original figures in Bangladesh Taka (BDT), converted to USD at the 1994 rate of USD 1.00=BDT39.00. Gross rice income not given but was derived using net benefit from rice and rice expenses.

b) Original figures in Chinese Yuan (CNY), converted to USD at the 1987-88 rate of USD1.00=CNY3.72

TABLE A4.3

Summary for cost and returns from rice+fish and rice-only culture, selected Southeast Asian countries, All figures in USD-ha-1crop-1 or USD- ha-1yr-1 as indicated and are rounded to the nearest unit

Rice + Fish System, Year, Preiod (Source)	Rice + Fish		Rice Only		% More or (Less)
	Amount	Total	Amount	Total	
Indonesia					
Minapadi-Minapadi-Fish vs Rice-Rice-Fallow 1988, one year (Yunus et al, 1992)[a]					
Rice income	1 518		1 663		(8.7%)
Fish income	490				
Rice expenses	(621)		770		(19.4%)
Fish expenses	(122)				
Net Returns		1 244		576	116.0%
Philippines					
Trench 1986, one crop, (Sevilleha 1992)					
Rice income	674		700		(3.7%)
Fish income	126		-		
Total expenses	(506)		(469)		7.9%
Net Returns		294		231	27.3%
Trench 1986, one crop, (Sevilleha 1992)					
Rice income	1 098			757	45.0%
Fish income	607				
Rice expenses	(322)			(390)	(17.4%)
Fish expenses	(242)				
Net Returns		1 141		367	210.9%
Pond Refuge 1991-92, one year, (Israel et al.1994)[b]					
Rice income	2 077		1 579		31.5%
Fish income (incl. own consumption)	1 126				
Total expenses	(1 860)		(1 143)		62.7%
Net Returns		1343		436	208.0%
Thailand					
Unspec. 1984-85, one year, (Thongpan et al. 1992)					
Net Returns		121		160	(24.4%)
Viet Nam					
BW/DWR. 1988. one year, (Mai et al. 1992)					
Net Returns from Rice Monoculture				38	
Net Returns from Rice and Shrimps: fed		105			176.3%
Net Returns from Rice and Shrimps: not fed		58			(34.9%)
Ricefield w/homestead, pond and dike (Rothuis et al. 1998)					
Rice income	888		1 060		(16.2%)
Fish income	89		6[d]		1 383.3%
Income from homestean and dike	175		119		47.1%

Rice + Fish System, Year, Preiod (Source)	Rice + Fish		Rice Only		% More or (Less)
	Amount	Total	Amount	Total	
Rice variable expenses	(544)		(600)		(9.3%)
Fish Variable Expenses	(66)		(3)		2 100%
Homestead/dike variable expenses	(98)		(91)		7.7%
Total farm fixed cost	(176)		(157)		12.1%
Net Returns		268		334	(19.8%)

Legend: BW/DWR - Brackishwater Deep Water Rice

a) Extrapolated to 1 ha from weighted average of 6 farms of 0.35-1.0 ha for rice-rice-fallow and 0.5-1.5 ha for minapadi-minapadi-fish

b) Original figures in Philippine Peso (PHP), converted to USD at the 1991 rate of USD 1.00=PHP27.48.

c) Original figures in Viet Nam Dong (VND), converted to USD1.00=VND11 000 as given by authors

d) Even farmers not adopting rice-fish farming maintained a small fishpond accounting for the fish

Annex 5

Examples of partitioning of domestic use in two irrigated command areas

(Extracted from Van der Hoek, 1999)

TABLE A 5.1

Main sources of water for different domestic uses of households (n=156) in the Kirindi Oya Irrigation and Settlement Project, Sri Lanka (van der Hoek et al 1999)

	Standpipe		Well		Canal		River		(tank)		Other		Total
Uses	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**(%)**
Drinking, cooking	109	(70)	46	(29)	0	(0)	1	(1)	0	(0)	0	(0)	(100)
Washing utensils	100	(64)	47	(30)	3	(2)	4	(2)	1	(1)	1	(1)	(100)
Laundering	48	(31)	23	(15)	57	(36)	12	(8)	16	(10)	0	(0)	(100)
Bathing	49	(31)	22	(14)	55	(35)	13	(8)	16	(10)	1	(1)	(100)
House cleaning	43	(28)	19	(12)	4	(2)	3	(2)	3	(2)	3	(2)	(48)
Sanitation	92	(59)	44	(28)	9	(6)	5	(3)	6	(4)	0	(0)	(100)

Note: Only 75 (48%) of the 156 households reported using water for house cleaning

TABLE A 5.2

Main sources of water for different domestic uses of households (n=364) in the Hakara 6R, Pakistan (van der Hoek et al 1999)

	Village tank		Seepage from canals, fields		Water supply scheme		Canal (direct)		Total
Uses	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**(%)**
Drinking	64	(18)	265	(72)	28	(8)	7	(2)	(100)
Cooking	87	(24)	233	(64)	35	(10)	9	(2)	(100)
Washing utensils	178	(49)	125	(34)	43	(12)	18	(5)	(100)
Laundering	166	(46)	82	(22)	42	(12)	74	(20)	(100)
Bathing	174	(48)	120	(33)	43	(12)	27	(7)	(100)
House cleaning	78	(21)	39	(11)	28	(8)	3	(1)	(41)
Sanitation	181	(49)	141	(39)	42	(12)	0	(0)	(100)

Note: Only 148 (41%) of the 364 households reported using water for house cleaning

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FAO IRRIGATION AND DRAINAGE PAPER

Multiple uses of water services in large irrigation systems

Auditing and planning modernization
The MASSMUS Approach

This publication expresses the rationale for multiple use of water services for large irrigation systems and demonstrates how managers can optimize, rather than simply tolerate, multiple uses. It also illustrates how consideration and appropriate management of multiple uses can benefit an irrigation system by improving performance and enhancing sustainability. The aim is to provide readers - irrigation managers and designers - with guidelines, steps to follow and leads that will allow them to perform multiple uses or services investigations in their own irrigation systems unearthing all services, the obvious and the hidden, and to document them using local data and surveys. The approach focuses on large-scale agency managed systems, however the revealed MUS approach and concepts are equally relevant to small-scale farmer managed systems.

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