Improving irrigation water use efficiency:

A synthesis of options to support capacity development

June 2020

Blue Peace

IN THE MIDDLE EAST

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This report was published in 2020 as part of the project, "Disseminating Knowledge to Improve Agricultural Water Use Efficiency in the Middle East", implemented under Blue Peace in the Middle East (BPME), an initiative co-funded by the Swiss Agency for Development and Cooperation (SDC) and Turkish Water Institute (SUEN).

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ABOUT BLUE PEACE IN THE MIDDLE EAST

The Blue Peace in the Middle East Initiative is a structured and dynamic network of prominent institutions from partner countries in the region with the long-term vision of transforming water from a potential source of conflict into a potential instrument of cooperation and peace through concrete actions. In partnership with Swiss Agency for Development and Cooperation (SDC), SUEN functions as the Coordination Office since 1st January 2019 of the regional initiative.

ABOUT TURKISH WATER INSTITUTE (SUEN)

SUEN is a think tank established to develop water policies, provide consultation to decision makers, coordinate between organizations and institutions and enhance scientific research and strategic ideas with a focus on creating a common platform for water governance. SUEN works in close cooperation with national and international water-related institutions on issues such as sustainable water management, developing water policies, sustainable energy and capacity building for addressing local and global water problems.

PREFACE

The demand to increase water use efficiency in irrigated agriculture is laudable particularly when water is scarce, and agriculture, which already accounts for 70% of the world's freshwater withdrawals, has a reputation for inefficiency. Clearly, we need to reduce the amount of water we use for irrigation while at the same time increasing food production and productivity to feed a growing population. But using the traditional metric of water use efficiency as a means of monitoring progress may not be so helpful, indeed it can be misleading.

Efficiency is a useful concept for monitoring effective use of resources, such as energy, but the idea does not work so well when applied to water and irrigated agriculture. Measuring water use efficiency as a ratio of crop water use to the amount diverted from a river is attractive in its simplicity. It is widely used, it has long been accepted among irrigation professionals and practitioners, and is engrained in irrigation books and literature. But times are changing, and when water is scarce, such simplicity can lead to serious misunderstandings about how water is used and managed in agriculture and can lead to inappropriate decision-making with serious financial consequences. It may seem counter intuitive to many, but there are a growing number of examples of investments in technologies designed to 'improve water use efficiency' which have actually increased water use on farms rather than producing water savings.

In this synthesis I have tried to unravel the myths which surround the term 'water use efficiency' and to provide an evidence-based foundation on which to build solutions to make real water savings while increasing food production and productivity. As with many complex problems there is no silver bullet. The answer lies not just with switching technologies, but also in making significant changes to the way we manage irrigation water. However, I have continued to use the term 'water use efficiency' because it is so engrained in people's minds. But I hope the reader will use the term wisely with an in-depth understanding of what it actually means in practice and so avoid falling into the simplicity trap.

The main aim of this synthesis is to support the much needed capacity, particularly in the Middle East, for improving water use efficiency in irrigation by providing the foundation from which others can produce a series of in-depth training manuals and programmes appropriate to different audiences and circumstances. It is aimed at professionals involved in irrigated agriculture: engineers, agronomists, land/soil managers, those who plan, design, and operate irrigation systems, and particularly those who provide education and training for professionals, technicians, and farmers.

Melvyn Kay
May 2020

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GLOSSARY

Adaptive management: in complex situations there may never be sufficient information to come to an optimum decision. In such situations managers may decide to take a flexible planning approach, backed by strong monitoring and information management systems, that allow constant adaptation and upgrading of plans and activities.

Adequacy: describes the amount of water needed to fill the soil in the crop root zone. This is measured by the ratio of the average depth of water added to the root zone (mm) to the average depth required (mm).

Consumptive use: water withdrawn which evaporates or transpires from vegetation and is no longer available for societal/economic use. **Beneficial consumption:** water evaporated or transpired for the intended purpose such as transpiration from an irrigated crop. **Non-beneficial consumption:** water evaporated or transpired for purposes other than the intended use, such as evaporation from water surfaces, riparian vegetation, waterlogged land.

Closed river basin: a river basin is described as closed when there is no longer enough water to meet both social and environmental needs and demand exceeds supply (see also 'open river basin').

Conveyance efficiency: is the ratio of the volume of water delivered to the farms to the volume diverted from a river or reservoir.

Distribution efficiency: for an irrigation scheme describes water losses in the tertiary (or distribution system) that delivers water from the conveyance network to individual farms/fields. This part of the system is mostly under the control of farmers or WUAs. Distribution efficiency is the ratio of the volume of water delivered to the farm to the volume diverted from the conveyance network.

Deficit irrigation: is an irrigation strategy that is used during drought-sensitive growth stages of a crop. Outside these periods, irrigation may be limited or even unnecessary if rainfall provides a minimum supply of water.

Efficiency: refers to using less resource to produce a product with least waste of time and effort. Insulating buildings improves energy use efficiency and driving fuel-efficient cars consume less fossil fuel.
In agriculture efficiency refers to using less water to produce a crop or undertake a production process.

Farm efficiency: is the ratio of the volume of water required by the crop to the volume of water delivered to the farm.

Gross water requirement: the amount of water diverted to meet crop evapotranspiration including losses from percolation/seepage.

Integrated water resource management (IWRM): the co-ordinated development and management of water, land, and related resources to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Farm irrigation efficiency: describes the efficiency of the whole scheme and is the product of the conveyance efficiency, distribution efficiency, and farm irrigation efficiency.

Non-consumptive use: can be recoverable and non-recoverable. Recoverable is water that can be captured and reused, such as flows to drains that return to the river system and percolation from irrigated fields to aquifers; return flows from sewage systems. Non-recoverable is water lost that cannot be used, such as flows to saline groundwater sinks, deep aquifers that are not economically exploitable, or flows to the sea.

Open river basin: a river basin is described as open when there is more than enough water to meet both social and environmental needs and supply exceeds demand.

Uniformity: water must be evenly spread across the field if crops are to grow and yield uniformly. For sprinkler irrigation, uniformity is commonly described using the Christiansen Coefficient of Uniformity (CU). For surface and drip irrigation Distribution Uniformity (DU) is an alternative measure.

Water accounting: is the systematic quantitative assessment of the status and trends in water supply, demand, distribution, accessibility and use in specified domains, producing information that informs water science, management and governance to support sustainable development outcomes for society and the environment.

Water auditing: connects water accounting and water governance. It builds on water accounting to advise water governance. By examining trends in water supply, demand and productivity, water auditing examines features of water governance such as institutions, public and private expenditure, laws and the wider political economy of water in specified domains.

Water management: concerns the active management of water on a daily, weekly, seasonal, and annual basis using combined operations involving people, infrastructure, finance, and other inputs and resources.

Water productivity: is the ratio of output (physical, economical, or social) to the amount of water depleted in producing the output. It is measured in kg/m^3 or US$/$m^3$.

Water governance: is the range of political, social, economic, and administrative systems that are in place to develop and manage water resources and the delivery of water services, at different levels of society. Governance comprises the rules, mechanisms, and processes through which water resources are accessed, used, controlled, transferred, and related conflicts managed.

Water saving: is understood to be genuinely saved water that is made available for use elsewhere in a river basin.

Water scarcity: is excess of water demand over supply and is largely driven by human, economic, and societal factors.

Water shortage: is a natural phenomenon when demand exceeds supply during periods of drought.

Water use: any deliberate application of water to a specified purpose. The term does not distinguish between uses that remove water from further use (evaporation, transpiration, flows to sinks) and uses that have little quantitative impact on water availability (navigation, hydropower, most domestic uses).

Water use efficiency as measured for UN Sustainable Development Goal (SDG) 6: this is indicator 6.4.1 within SDG 6 and is defined as the gross value added per unit of water used, expressed in US$/$m^3$. The rationale is to provide information on efficiency of the economic and social use of water resources. It can help to formulate water policy by focusing attention on those sectors or regions with low water-use efficiency in terms of monetary value.

Water use efficiency as measured for a river basin: this is defined as the ratio of the amount of water used in a river basin to the amount of water available in the basin.

Water withdrawals: refers to water diverted from rivers, lakes, and aquifers for societal/economic use.

1 Introduction

This synthesis is designed to support capacity development to improve water use efficiency in irrigation as part of the project, Blue Peace in the Middle East: Regional Collaboration on Water. It provides a foundation for developing a series of in-depth training manuals and programmes that are appropriate for different audiences and circumstances.

It is aimed at professionals involved in irrigated agriculture: engineers, agronomists, land/soil managers, and others who plan, design, and operate irrigation systems, and particularly those who provide education and training across the sector to professionals, technicians, and farmers.

1.1 Agriculture's water management challenge

Water scarcity is one of the major global challenges facing sustainable development and is the main driving force behind the need to improve the way in which we use this limited resource. This is not just a physical problem, it is also caused by institutional, economic, and infrastructure-related constraints and is linked to pressures that emanate from population growth and mobility, socio-economic development, dietary changes, and climate change.

Since 2012, the World Economic Forum [1] has put water at the top of the world's agenda as one of the five greatest risks facing the world. It is also a major concern within the United Nation's 2030 Development Agenda. By 2050, if society continues to pursue the current *business as usual* model, the global demand for water could exceed supply by over 40%, which would put at risk 45% of global GDP, 52% of the world's population, and 40% of grain production [2].

THE UN 2030 DEVELOPMENT AGENDA

Water scarcity is a major concern within the United Nation's 2030 Development Agenda. Water flows through all 17 Sustainable Development Goals (SDGs). SDG 6, known as the 'Water Goal' – focuses attention on sustainable management of water for all. Indeed, the UN Deputy Secretary General described SDG 6 as the 'docking station' for all the SDGs and the 2030 Agenda (speech at Stockholm World Water Week 2018). SDG6 recognises the limited nature of renewable water resources, the inefficiencies of traditional 'silo' approaches to managing water and the need for an integrated approach to water resources planning and management (IWRM) for people, industry, energy, agriculture, and the environment. This is now accepted by all UN Member States. In many countries, planning for IWRM is well advanced, but implementation is still in its infancy. There is no 'one size fits all' solution and countries must seek their own unique way of meeting their water challenges based on local physical, social, and economic circumstances.

Source: [3]

Water used in agriculture is seen as one of the main causes of water scarcity. It accounts for almost 70% of global freshwater withdrawals, mostly for irrigation, and has a reputation for being a low-value, wasteful, and inefficient use of water.

The global average agricultural water use efficiency is estimated to be 55% with national figures ranging from 40-65% as measured by crop water use divided by water withdrawals [4]. The implication is that much of the water abstracted never reaches the crops because water is lost through leakage, evaporation, misuse in canal systems and from runoff and seepage on farms due to poor irrigation practices. Apart from wasting water, poor irrigation practices create problems, like salinity, waterlogging, soil erosion, and pollution through the misuse and leaching of agri-chemicals. Whilst these problems have technical solutions, many of them persist because of weak and poorly integrated services that were designed to support irrigated farming.

On the plus side, although water demand for agriculture continues to increase, it is a sector where significant water savings can be made by reducing water wastage and increasing agricultural productivity. The recent UN publication reviewing progress on SDG 6, the 'water goal', [3] suggested that agriculture, mostly irrigation, as the largest user offers the greatest potential for saving water. *"Saving just a fraction can significantly alleviate water stress in other sectors, particularly in arid countries where agriculture consumes a considerable amount of the available water resources"*

However, reducing water wastage will not be an easy task. Traditional approaches to reducing wastage are being challenged. Recent studies show that switching to what are seen as more efficient technologies for example, may in fact increase water use rather than reduce it.

In water-scarce river basins, studies show that what appear to be losses from seepage and inefficient irrigation practices are not always truly lost. Rather they return to the river and groundwater and provide a source of supply for other farms downstream. As such, irrigation's reputation for inefficiency, and the traditional means of improving it, is not always justified.

Clearly, irrigated agriculture has a vital role in sustainable development. It contributes to national food security, provides rural and urban employment, contributes to economic growth, and can help to bring renewable water supplies into balance with increasing demand. The challenge is to improve water use efficiency and increase water productivity, which in other words means reducing the amount of water wasted in irrigation and producing more food with less water – *more crop per drop.*

Improving water use efficiency is not just about technology. Changes are needed in the way irrigation systems are planned, designed, and managed, and particularly for public sector irrigation schemes, changes in the institutional structures which govern them. Inevitably local and national politics and culture also play a significant role in the future success of irrigation.

BOX 1 IRRIGATION IN THE MIDDLE EAST

In the Middle East, the climate is semi-dry and dry and countries rely on irrigated farming for food security and employment. Freshwater withdrawals for irrigation can reach 75-85% of available resources. According to FAO AQUASTAT1, in 2015 total irrigation in the region was 19,207,142 ha, surface irrigation accounted for 16,339,334 ha (85%), sprinklers for 1,950,727 ha (10%) and drip for 917,081 ha (5%).

[1] http://www.fao.org/nr/water/aquastat/tables/index.stm

1.2 About this synthesis…

This synthesis focuses on improving water use efficiency on both large irrigation schemes and individual farms and is set in the context of national and river basin planning, particularly when water is scarce and there is competition for water (Figure 1).

Of necessity it is generic in nature in view of the many ways that irrigation has developed across the Middle East. It will be for individuals to assess local circumstances and apply the most appropriate options to provide the best outcomes for their circumstances.

It will also be essential for those involved in training and disseminating information to differentiate the information so that it is suitable for different audiences. From farmers to policymakers, each group will need to understand what irrigation means for them, the issues, and the options available. Each will need different kinds of training materials and levels of detail appropriate to their requirements and interests. This will be for individual organisations to explore and develop the most appropriate ways of doing this. An extensive reference list is provided so that various aspects of water and efficiency can be studied in more detail.

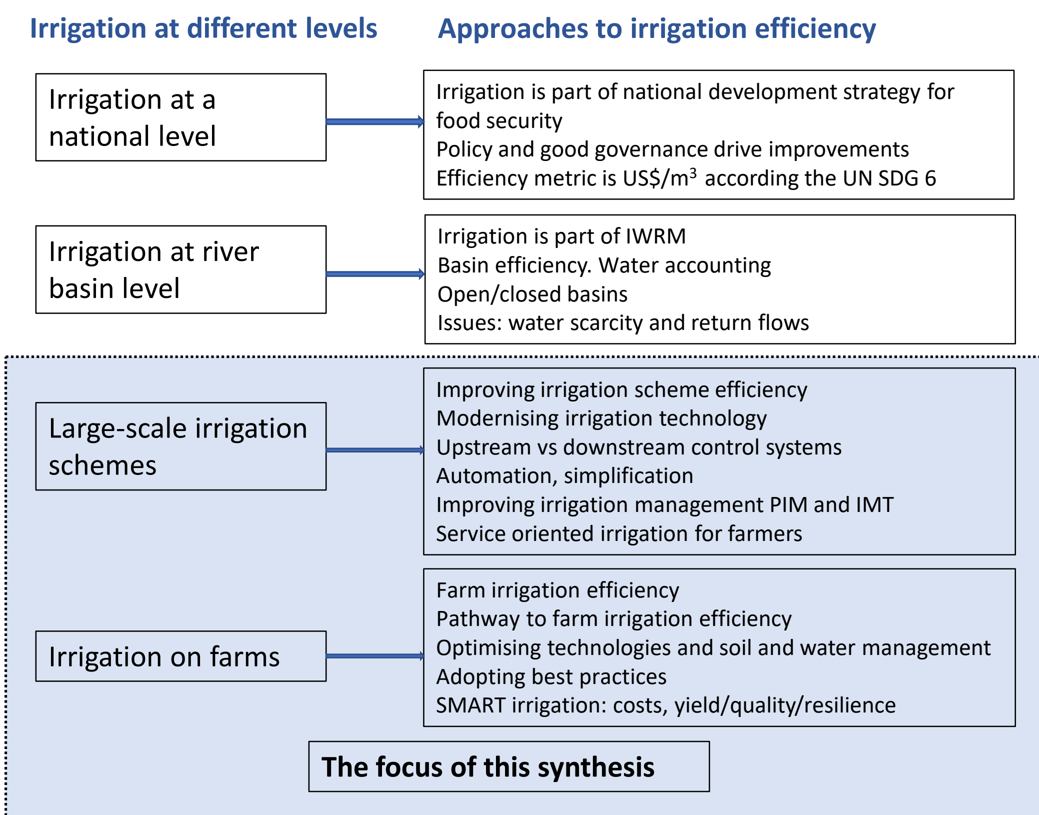


Figure 1 How irrigation is perceived at different levels and the key elements of improving water use efficiency

A plethora of literature

There has been a plethora of publications over the past 50 or so years about improving irrigation efficiency and how to make best use of available water since the classic handbooks produced by the US Department of Agriculture in the 1950s and 1960s and the FAO in the 1980s. The physics of irrigation has not changed but irrigation practices and our knowledge and understanding of how irrigation schemes are designed, built, and operated has substantially increased. Although much has been published since, information on improving irrigation efficiency is scattered and sometimes buried in the grey literature rather than in mainstream publications and books. It is not always accessible in a trust-worthy format that is technically credible and independent of bias.

In many countries, governments, research organisations, and businesses have produced information focused on their specific requirements, like irrigation scheduling, different methods of irrigation, and choice of equipment. The US extension services, for example publishes extensively on irrigation practices. But the information is naturally focused on US conditions and although much can be gleaned from their publications, care is essential to ensure the technologies are applicable and adaptable to irrigation schemes elsewhere. Technologies used on large commercial, mechanised farms in a developed country may be appropriate for smallholder farms in the developing world. Equipment manufacturers are also prone to present information that is most favourable to their products.

An integrated approach

Although this synthesis focuses on irrigation it cannot ignore that irrigated farming is an integral part of water management within a river basin. Water scarcity is now driving water and water-using sectors to cooperate and take an integrated approach to basin water planning and management.

This aligns with the call for integration in the UN Water Goal (SDG 6) in which agriculture and irrigation must play a major role. But agriculture as a sector has work to do in putting its own house in order. It is a highly fragment industry, largely organised around commodities rather than resources and is a complex mix of rainfed and irrigated cropping. Irrigation also suffers from fragmentation as engineers have traditionally focused on infrastructure while agronomists have concentrated on cropping. A more enlightened approach is needed that builds links not just between engineering and agronomy, but among the many disciplines that can influence improvements in water use efficiency. It is hoped that this synthesis will help to build those important links for the benefit of all water users.

In summary...

Chapter 2 sets out to clarify what water use efficiency means in irrigation. Most people are familiar with the term efficiency. But, for a variety of reasons this simple concept does not transfer easily to water and irrigation, there is confusion and misunderstandings, and these can lead to inappropriate decision-making. This is particularly true when water is scarce, as is the case in many countries today. This chapter traces how the concept of efficiency was developed, how it was applied to both large-scale irrigation schemes and individual farms, and how this is now changing rapidly with the advent of water scarcity, understanding the importance of returns flows, and water accounting.

Chapter 3 focuses on improving the efficiency of large-scale irrigation systems and the options available to modernise both technology and management. It introduces the concept of irrigation services that are changing traditional supply-oriented irrigation schemes to ones that respond to farmer irrigation demands. This is not just about sophisticated electronic systems, rather there are also simple options that can make significant improvements.

Chapter 4 focuses on efficiency on-farms. The tasks of farmers are different to those of irrigation agencies and system operators and they have different goals in mind. This chapter describes ways of improving the efficiency of irrigation methods, the pros and cons of switching technologies from surface to sprinkler and drip irrigation, and improving soil and water management practices.

Chapter 5 is about developing capacity to plan, design, and manage irrigation systems. Developing capacity is not just about training people and improving their technical and managerial skills, it is also about strengthening organisations and institutions that enable people to work effectively together. This is a neglected aspect of irrigation development as politics and investment favours building infrastructure which is more visible and easier to measure progress. International attention is gradually shifting towards capacity development and this chapter describes both long-term strategy options and more immediate steps that can be taken to prepare people for potential long-term changes in irrigated farming.

1.3 Importance of terminology

Floods and droughts are constantly in the news today and worryingly, the terminology around water is often confusing and misleading [6]. Myths about water that misrepresent facts and basic science are commonplace. There is even confusion in scientific publications and among water professionals about what water use means – is it consumptive or non-consumptive, can water be re-used, or is it really lost and unrecoverable?

Water engineers and hydrologists usually have a clear scientific understanding of differences between consumptive use of water in agriculture and public water supply which can be re-used for other purposes, and that improving efficiency does not always result in more water being available for others to use. It is incumbent on engineers and scientists to consistently use language that is clear and universally understood by the public, decision-makers, and those who formulate legislation and implement decisions. Misunderstandings about water use and management can lead to inappropriate decision-making with serious financial consequences. For this reason, a glossary of terms is included to help clarify terminology used in the report.

Most people are familiar with the term efficiency. But, for a variety of reasons this simple concept does not transfer easily to water and irrigation

2 Understanding Water use efficiency

Most people are familiar with the term 'efficiency' and what it means. It is about using less of some resource and the implication is that this is a good thing to do. But this simple concept does not transfer easily to water and irrigation and can produce misleading results.

We insulate our homes to reduce the amount of energy we consume and drive fuel-efficient cars that consume less fossil fuels. This simple concept is also used in the water sector on the basis that if we all use less water, there will be more for others to use. But, for a variety of reasons this simple concept does not transfer easily to water and irrigation.

The concept of water use efficiency in irrigation has only emerged in the latter half of the 20th century which also saw significant growth in irrigation worldwide and across the Middle East in particular. Engineering dominated irrigation development because of the need for infrastructure – hydraulic structures, pumping stations, reservoirs, canals, and pipelines were all essential elements of irrigation schemes for diverting and controlling water flow to irrigate the land. In the early to mid-1900s global population was less than half of what it is today. Water resources were generally more plentiful, and abstraction from rivers and groundwater for domestic water supply, industry, and irrigation were largely planned as separate entities usually by different government ministries – water resources, public works for domestic supply, agriculture, energy, and environment – with little attention to coordination. There seemed to be enough water for everyone. At the same time, the study of river basin hydrology was in its infancy and was often covered by a few chapters added to more rigorous texts on hydraulics. Only later, when water shortages occurred, did the interest in coordinated water planning grow, which is now the essence of integrated water resources management (IWRM) and is the backbone of the current UN 2030 Development Agenda and the Sustainable Development Goals (SDGs).

2.1 Irrigation scheme efficiency[2]

Although irrigation has been widely practised for thousands of years, it was during the second half of the 20th century that the science and practice of irrigation engineering developed with its own rules, design procedures, and terminology. Governments gave civil engineers the task of planning, designing, and building irrigation schemes. The scale of the task was huge with many thousands of farmers needing water to grow crops, and large engineering infrastructure needed to control and distribute water from major river systems. Typically, irrigation systems comprised primary (main) canals that convey water from a source to an irrigated area, secondary (branch) canals that deliver water from a primary canal to different parts of the area (commands), and tertiary (distributary) canals that distribute water to individual or groups of farms (Figure 2). The names of canals differed from country to country, but their functions were similar. Within farms, water courses or farm channels were constructed to transfer water from the tertiary canals to the fields.

[2] The early part of this chapter draws substantially from [6]

Hydraulic structures controlled the flow into the system so that farmers would receive a share of the water available. On some schemes, drains were installed to remove excess water from farms to avoid water-logging and salinity when too much water was supplied or there was heavy rainfall. On large schemes, the primary and secondary canals were usually operated by a government irrigation agency staffed by professional engineers who understood hydraulics and whose role was to manage water flows in canal systems and distribute water to farmers. On some schemes this management role extended to tertiary canals, on others the tertiary canals were managed by farmer groups such as Water User Associations (WUAs). Farmers were then responsible for water management on their farms. Extension services supported farmers with cropping and on-farm irrigation practices to encourage them to improve their efficiency and productivity. Some large schemes were privately operated such as state farming enterprises and commercial irrigated sugar cane estates. The private sector would often encourage smallholder farmers (out-growers) to produce cane as well and in return they provided inputs and technical support.

The system capacity was based on crop water requirements and this was established using formulae, such as the Penman equation [7], or information gathered from lysimeter experiments from local agricultural research stations. Engineers recognised that not all the water diverted into a scheme would be usefully consumed by the crops and that some would be wasted through seepage and evaporation and misuse both in the distribution system and on the farms. Losses were an acceptable part of the design process of an irrigation scheme and were accounted for by using a simple ratio for the volume of water consumed by the crops to the volume of water that would need to be diverted to make sure the crops would be fully irrigated.

This ratio, developed in the 1950s, became known as the irrigation efficiency and was used to establish the capacity of an irrigation scheme as the basis for design [8].

$$\textit{Irrigation efficiency (\%)} = \frac{\textit{Volume of water consumed by crops}}{\textit{Volume of water diverted from source}} \times 100$$

High efficiency implied low water losses, thus more water would be available for other purposes, and the implication was that this was good. It was also important from a cost point of view. Irrigation infrastructure was costly, and engineers wanted to avoid over-designing structures, canals, pumps and pipes to irrigate a given area.

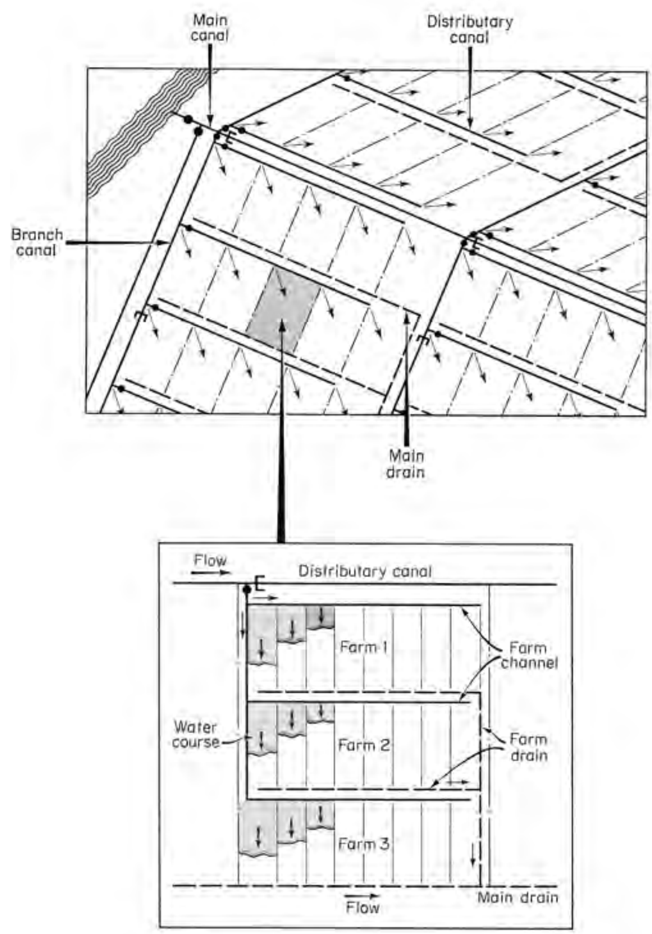


Figure 2 Typical large-scale irrigation scheme supplying water to groups of farms

At that time little was known about actual water losses in irrigation schemes and so large safety margins were applied when planning and designing new schemes. Typically, an irrigation efficiency of 50% was acceptable as a basis for scheme design. Thus, half the water diverted into an irrigation scheme was deemed wasted or lost. But allowing for this *inefficiency* also provided additional capacity should the scheme be expanded in the future and possible changes in cropping that may increase water demand. Note that this approach was for design purposes, for sizing canals and hydraulic structures, and would not necessarily represent the actual efficiency when the scheme came into operation. Designing systems in this way continued throughout most the 20th century.

Providing farmers with plenty of water in the early days of a new scheme helped to build confidence between farmers and scheme managers, but it also encouraged a culture of inefficient irrigation practices that was difficult to rectify when water demand increased and farmers were expected to grow more crops with less water. There were, however, draw backs to this approach. The tendency to over-design canals, structures, and reservoirs increased the costs of schemes. Accepting low efficiency also created harmful side-effects, like rising groundwater levels and soil salinisation. Costly sub-surface drainage was then required to control water tables and salinity levels.

In 1978, the results of a major field study to measure irrigation efficiencies was published jointly by the International Commission on Irrigation and Drainage (ICID)[3], the University of Agriculture, Wageningen, and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen [9].

This study significantly improved understanding of water losses in irrigation systems and where they occurred. The system was divided into three distinct efficiency components:

Conveyance efficiency: water losses in the main and secondary canals/pipes (the conveyance network) that were mostly under the control of an irrigation agency.

$$\text{Conveyance efficiency} = \frac{\text{Volume delivered to the farm distribution system } (m^3)}{\text{Volume diverted from a river/reservoir } (m^3)}$$

Distribution efficiency: water losses in the tertiary (or distribution system) that delivers water from the conveyance network to individual farms/fields. This part of the system was mostly under the control of farmers or WUAs.

$$\text{Distribution efficiency} = \frac{\text{Volume delivered to the farms } (m^3)}{\text{Volume diverted from conveyance system } (m^3)}$$

Farm irrigation efficiency: water losses within farm canals/pipes that carry water around the farm and in applying water to the crops using surface, sprinkler, or drip irrigation. This part of the system was usually under the control of individual farmers.

$$\text{Farm irrigation efficiency} = \frac{\text{Volume required by the crop } (m^3)}{\text{Volume delivered to a farm } (m^3)}$$

The efficiency of the irrigation scheme as a whole was assessed by combining these three components:

$$\text{Irrigation scheme efficiency} = \text{Conveyance efficiency} \times \text{distribution efficiency} \times \text{farm irrigation efficiency}$$

All the above efficiencies can be expressed in % terms by multiplying each fraction by 100.

[3] The International Commission on Irrigation and Drainage (ICID) was established in 1950 as a scientific, technical and voluntary not-for-profit non-governmental international organization (NGO) www.icid.org

More performance indicators

Since this early work, many papers and reports have been published on assessing the performance of large-scale irrigation schemes. Bos, who was involved in the early work on efficiency in the 1970s [9] brought together much of this work in 1997 [10] and updated and published it as a book in 2005 [11]. This is a comprehensive work on performance indicators and, based on field research, Bos suggests these are *sufficiently mature to be recommended for practical use*. It was published with the support of ICID and the International Water Management Institute (IWMI). The publication includes the basic indicators described in this section for water delivery and water use efficiency, but it now includes performance indicators for maintenance, sustainability, environmental aspects, socioeconomics, and management. It provides a framework for performance assessment (Figure 3), which includes operational and strategic performance assessment, diagnosing irrigation performance, and managing data for performance assessment. Bos argues that the process of performance assessment hinges around the capacity of system managers to answer two simple questions:

Am I doing things right? Which is about routine implementation of an agreed level of service.

Am I doing the right things? Which addresses long-term strategic performance and whether a scheme is fulfilling its wider production development objectives.

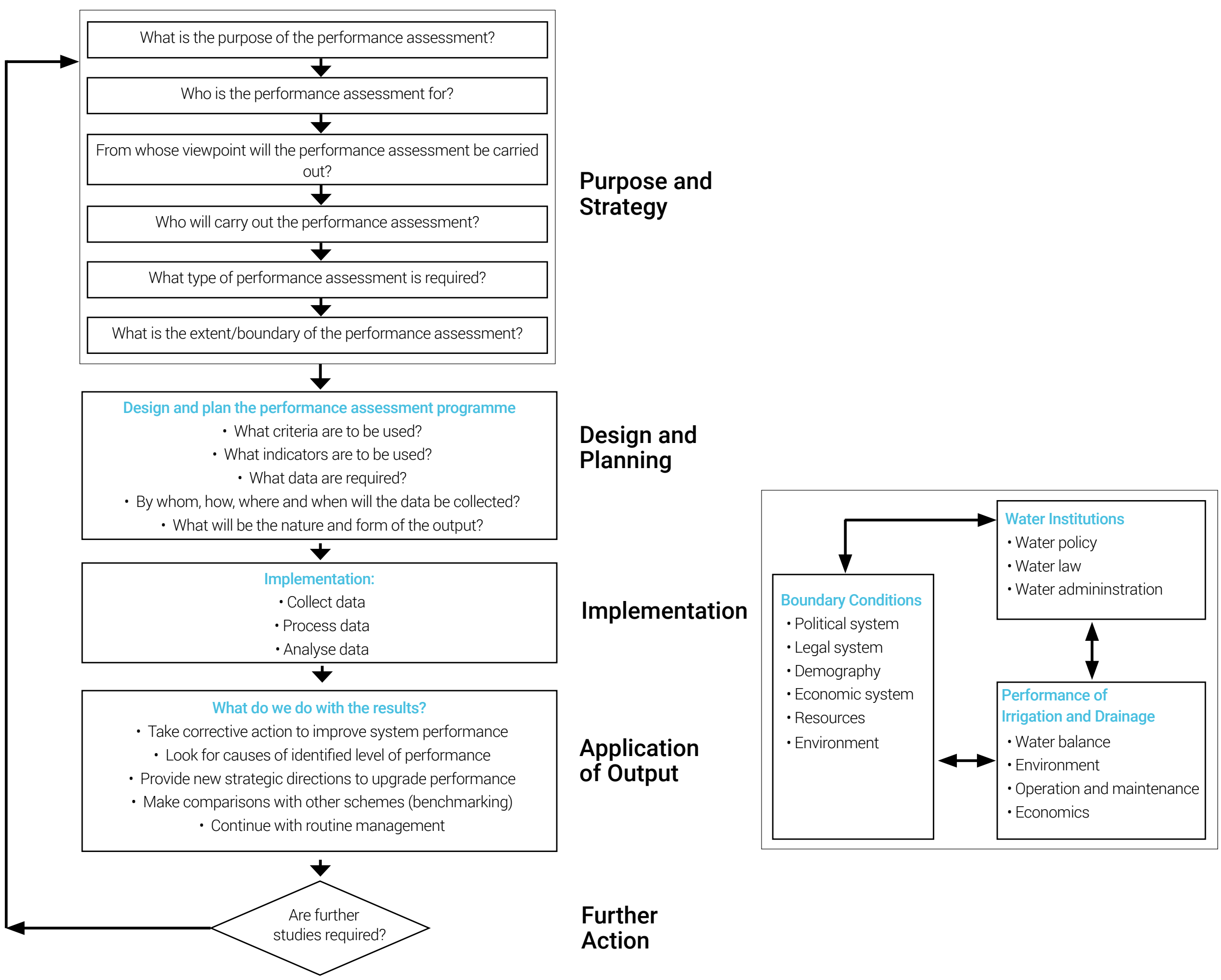


Figure 3 Framework for performance assessment of a) irrigation and drainage schemes b) in relation to the wider institutional context [11]

2.2 Farm irrigation efficiency

Whilst *farm irrigation efficiency* (referred to in section 2.1) provided an overall assessment of water losses within farms, both farmers and scheme managers wanted to know more about how individual farms were performing. How much water was lost in the farm canals/pipes and how much was lost when water was applied to fields using different irrigation methods. Thus, farm irrigation efficiency was divided into two distinct components:

Farm conveyance efficiency refers to water losses in farm canals/pipes that convey water around the farm.

$$\textit{Farm conveyance efficiency} = \frac{\textit{Volume delivered to the fields } (m^3)}{\textit{Volume delivered to the farm } (m^3)}$$

Water *application efficiency* refers to water losses when water is applied to the land. Initially the formula used was adapted from the early concepts of irrigation efficiency, and so efficiency was measured as a ratio of the volume of water consumed by the crop to the volume of water applied directly to the field.

$$\textit{Water application efficiency} = \frac{\textit{Volume consumed by crops } (m^3)}{\textit{Volume applied to land } (m^3)}$$

Refinements were suggested, such as adding a leaching requirement on the demand side for irrigation schemes in arid regions to avoid salinity problems [12].

But this was an overly simplistic measure of efficiency and it did not fully describe the irrigation performance in the field or on the farm.
An efficient irrigation requires:

- Uniformity: so that every part of the field received the same amount of water
- Adequacy: there is enough water to satisfy the needs of the crop.

The water application efficiency formula did not measure uniformity or adequacy. It was also misleading. In 1950, Hansen pointed out that if the amount of water supplied to a crop was less than the amount the crop needed (i.e. the crop was under-irrigated), water application efficiency as defined, would increase and could approach 100% even though the irrigation was clearly inadequate (Figure 4).

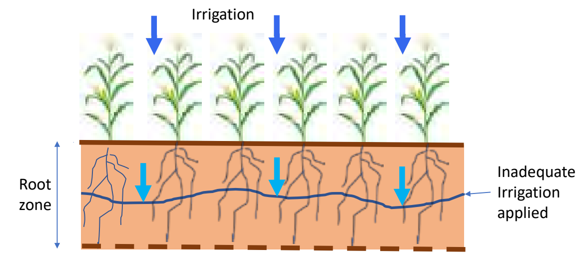


Figure 4 Inadequate irrigation, but the efficiency approaches 100%

To overcome these inadequacies addition formulae where introduced. Water distribution efficiency was established to show how uniformly water was distributed throughout the crop root zone. The more uniform the distribution, the more uniform the crop response and growth. Uneven water distribution affects crop growth and productivity (Figure 5).

The formula used to measure distribution efficiency was:

$$\textit{Water distribution efficiency} = 100\left(1-\frac{y}{d}\right)$$

Where *d* is the average depth of water stored in the root zone; and *y* is the average numerical deviation in depth of water stored from the average depth stored *d*.

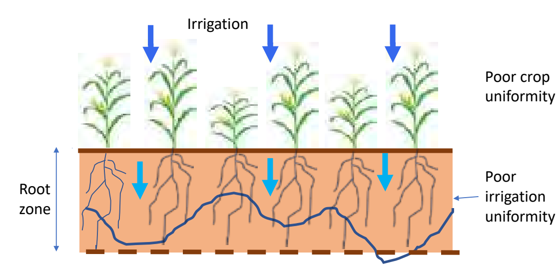


Figure 5 Impact of poor irrigation uniformity on efficiency and crop growth

Attempts to measure adequacy produced a formula for water storage efficiency:

$$\text{Water storage efficiency} = \frac{\text{Water stored in root zone } (m^3)}{\text{Water needed in root zone } (m^3)} \times 100$$

Figure 6 is an example of using the three formulae to measure efficiency, each giving a different perspective on the same irrigation. Water application efficiency is 100% as there are no losses although the irrigation is inadequate; water distribution efficiency is 80% but this does not flag a serious deficiency at one end of the field; and water storage efficiency is 75% demonstrating that the irrigation did not fill the crop root zone. These data can be confusing, difficult to measure in practice, and not easy to interpret. Sensible observation can help to spot the problems. In this case the crop is much smaller where the irrigation is poor, and this is where the farmer must focus to overcome the problem.

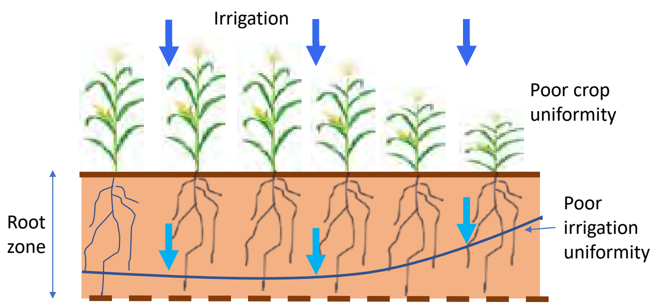


Figure 6 Three different ways of measuring efficiency: Water application efficiency = 100%; Water distribution efficiency = 80% Water storage efficiency = 75%

2.3 Water productivity

The *more crop per drop* approach focuses on the amount of product per unit of water. This is referred to as *water productivity* (WP) and it often substitutes for water use efficiency as a more direct measure of benefits from irrigation. It is not an efficiency expressed as a percentage, rather it refers to the ratio of the net benefits from irrigated crops to the amount of water used to produce the benefits. This may include both irrigation water and effective rainfall.

$$\text{Water productivity } (ton/m^3) = \frac{\text{Crop yield or biomass (ton)}}{\text{Amount of water consumed } (m^3)}$$

The benefit from irrigation is usually measured in terms of crop yield in tons/m^3 or kg/m^3 of water consumed. Though benefits can be measured in terms of Kilocalories, proteins, income, and jobs – reflecting various interests such as *nutrients per drop, capita per drop, and jobs per drop*.

Increasing WP can occur without increasing irrigation efficiency and may be the result of using fertiliser. An example of WP based on yield: if a crop uses 5,000 m^3 of water and the yield is 100 tons/ha, the water productivity would be 20 kg/m^3. If a similar crop uses the same amount of water but yields 120 tons/ha, the WP would be higher at 24 kg/m^3.

2.4 Does irrigation efficiency need an ISO?

Although this chapter has so far described several well-established ways of measuring efficiency, there is as yet no universally accepted approach or an international standard (ISO) on irrigation efficiency[4]. The nearest to a standard is the publication on irrigation efficiency supported by the International Commission on Irrigation and Drainage (ICID) [11]. The lack of enforceable standard metrics means that quoted efficiency values may not be comparable and without

[4]ISO has published ISO 46001:2019 Water efficiency management systems — Requirements with guidance for use. Though this is primarily aimed at the public water supply sector

qualification they are open to misunderstanding, confusion, and abuse. For example, an irrigation equipment manufacturer, may simply claim their equipment is highly efficient, it can save say 20% of irrigation water, and increase yields by 30%. Such statements sound impressive at face value but are highly contentious and if not challenged to provide more details of what is being measured, can lead to poor decision-making. Percentages quoted without qualification of what is being measured are meaningless, the question to ask is 20% of what?

2.5 How others view efficiency

Just to add to this confusion, not everyone in the water sector uses the definitions of water use efficiency so far described. People working at different levels in water resources planning and management take different approaches to measuring efficiency and use different metrics to assess performance.

At a global and national level: National governments measure water use efficiency as part of their commitment to the UN 2030 Development Agenda as set out in SDG 6 - the water goal. Water use efficiency is measured as national economic output in US$ *(more US$ per drop)* which is a useful indicator for governments to show where water is being used most effectively for sustainable economic growth. But it is of little value to an irrigation scheme manager or farmer who wishes to assess how water is withdrawn from rivers and used on an irrigation scheme or a farm. The average global efficiency measured in this way is 15 US$/m^3, but the range is significant from 2 to 1000 US$/m^3. Countries with high GDP and low water use fare better than those with high water use, such as in irrigation, and low value of production [13].

Another example of potentially misleading statistics is the SDG6 indicator for measuring water stress as the ratio of freshwater withdrawal as a proportion of available freshwater resources.

Globally, more than 2 billion people live in countries experiencing high water stress. Yet the global average water stress indicator is only 11% which would suggest that water was not such a big problem. However, the average figure hides serious water stress greater than 70% in 22 countries and above 100% in 11 countries that now rely on desalination for freshwater supplies [3].

At a river basin level: Water resources managers will be more concerned with efficiency of a river basin, rather than individual schemes or farms (water used in the basin vs renewable water resources available). They will use water accounting procedures (see section 2.7) to assess where water is being used or consumed in a basin, how much water is still available in different parts of a basin, and whether a basin is still open for further water withdrawals. What happens on individual farms may be of little interest to them. Indeed, basin level efficiency may by quite high even when the efficiency on individual farms is low (see Box 2).

At irrigation system level: Irrigation managers will be primarily concerned with the efficiency of their conveyance and distribution systems, and on-farm irrigation efficiencies. They will be concerned to reduce water losses from seepage, evaporation, and *administrative* losses from poor water management.

At the farm level: Farmers will usually be more concerned about saving money and increasing farm income rather than saving water. They may also be willing to invest in water efficiency measures if this saves money by increasing water productivity and farm incomes. They will be less interested in the overall water management picture if they have a reliable water supply and water charges are not significant.

Farmers will tend to measure efficiency in terms of water productivity (*more crop or US$ per drop*). In some countries, farmers are now being incentivised to increase nutrition rather than just yield (*more nutrition per drop*). A by-product of farmers investing in productivity is that it may also save water, which is of more interest to the system managers than the farmers (less water withdrawals).

BOX 2 WHAT MATTERS – BASIN EFFICIENCY OR FARM EFFICIENCY?

In a drive to improve water use efficiency in a water scarce river basin, several large irrigated farms were converted from *(inefficient)* surface irrigation to *(efficient)* drip irrigation. The water saved was diverted to nearby towns for domestic use. But further downstream environmental organisations noticed that an important lake and wetland started to dry up. The reason for this was the lake was maintained by groundwater flow which benefitted from seepage from the inefficient surface irrigation. Thus, one group's attempt to improve farm irrigation efficiency created another group's water shortage downstream. Scale matters when assessing water use efficiency – is it the water use efficiency of the basin or individual farms that matters?

Water scarcity changes the way we need to think about water use efficiency

2.6 When water is scarce

Water scarcity changes the way we need to think about water use efficiency. In the past when water was plentiful, irrigation schemes were largely planned and designed with little reference to the demands of other water users and the wider implications for the aquatic environment in a river basin. Today, many river basins are reaching full development (known as closed basins – see Box 3) as demand is increasing from urban populations, and society wants to preserve and protect environmental flows. Once demand exceeds supply there is competition for water, and irrigation schemes can no longer be planned in isolation, rather irrigation schemes must be assessed within a broader hydrological (basin) context that takes account of other uses – public, industry, energy, and environment.

Ideas about water use efficiency as described so far in this chapter have assumed that each user can assess performance in isolation without the need to consult with other water users. However, this is no longer a valid assumption from a water-saving perspective [14].

Accounting for return flows

When water is scarce and a river basin is closing, water losses take on a new level of importance and attention must now focus on what happens to them. Where does the 'lost' water go? Previously, runoff, seepage from canals, and deep percolation were considered as losses and no longer available for irrigation. Though in many river basins this water is not truly lost. It percolates down into the groundwater or returns to the river and may be available for others to use downstream (Figure 7). For this reason, losses are referred to as *return flows*. Taking account of return flows means that one farmer's water losses become another farmer's water source downstream [16]. Water is only truly lost when it flows into the sea or seeps deep into inaccessible aquifers (or sinks).

BOX 3 OPEN AND CLOSED RIVER BASINS

River basins are sometimes referred to as *open* or *closed*. When there is enough water to satisfy demand, even in the dry season and water continues to flow out into the sea, a basin is described as open. Examples include the Euphrates-Tigris Basin. However, as demand for water increases and available supplies dwindle, eventually there will be no usable water flowing out to sea. At this point the basin becomes *closed*. When basins approach closure there are often *top-ender tail-ender* problems, as those living at the tail end of the system tend to get less water of poorer quality than those at the head of the system. This can cause lots of problems for water managers. Over 20% of the world's population live in urban communities along the coast and large rural populations rely on agricultural lands in the river deltas; all demanding more and cleaner water supplies.

New demands for water in a closed basin can only be met if someone in the basin is willing to give up some of their supply. Another option is to re-open the basin by increasing storage to capture water when flows are more plentiful, and transferring water in from adjacent basins.

Source: [15]

Accounting for return flows means that one farmer's water losses become another farmer's water source downstream

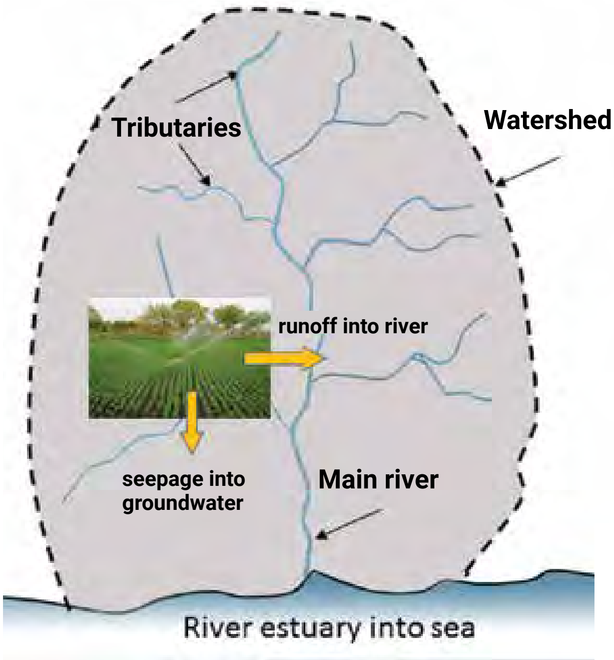


Figure 7 Inefficiencies on-farm are not lost, they benefit farmers downstream

There are many examples that demonstrate the importance of accounting for *return flows.* Much of the irrigation in the Nile delta in Egypt, for example, relies on seepage and runoff from 'inefficient' irrigation practices upstream. The challenge to increase irrigation efficiency remains but how is this best done while taking account of return flows?

Governments often advise their farmers to invest in more water efficient technologies to save water. Their intention is to reduce farm water withdrawals and make more water available for others to use. The reality however, is rather different. The effect of increasing on farm efficiency is to reduce the return flows on which others downstream rely for their water source. In theory the water saved would remain in the main river or canal system for others to use. In practice, research in several countries, both developed and developing has shown that farmers who invest in water efficiency tend to use the water saved to increase their irrigated area and increase their production [16] and [17].

They tend not to release the water for others to use as planners may have expected. When farmers keep the extra water for themselves, downstream farmers suffer from the reduced flows. In such situations it is questionable whether investing in on-farm efficiency will result in any water savings from a basin perspective. One solution is to restrict water withdrawals and introduce water quotas, but this may require legislation and the institutional structures to measure water volumes and enforce the rules.

Accounting for return flows raises an important question for farmers. If return flows are being usefully used downstream, should individual farmers invest in on-farm efficiency measures? The answer lies in assessing the benefits to the farm. Examples would be reducing energy costs for pumping less irrigation water. In the US, a legal case between the states of Montana and Wyoming demonstrated just how serious investing in irrigation efficiency and accounting or return flows can be when water is scarce (see Box 4).

Assessing the value of return flows is difficult and depends on the river basin. Return flows from farms located at the head of the river basin will benefit farmers downstream. But return flows from farms near the river estuary will have little benefit as they may flow into the sea and be lost. Thus, farms near the estuary would benefit from the more conventional water-saving measures such as reducing seepage in canals and improving their irrigation systems and practices (see chapter 4).

Not all return flows are useful. Research in Iran [19] points out that water quality is an important factor in assessing the amount and value of return flows. Particularly in arid regions when water is usefully used for leaching purposes (see Box 5).

BOX 4 MONTANA V WYOMING: SPRINKLERS, IRRIGATION EFFICIENCY, AND RECAPTURING RETURN FLOWS

In 2012, a legal case in the US demonstrated the serious impacts of increasing irrigation efficiencies to reduce return flows. The Yellowstone river basin in the US is nearly equally divided between Montana and Wyoming and in 1950 the two States made an agreement to apportion the available water for irrigation and other purposes. However, in 2007 following severe drought between 2000 and 2006, Wyoming invested in sprinkler and drip irrigation to increase irrigation efficiency to make better use of their limited water allocation. But Montana had long benefitted from the return flows from the *inefficiencies* in Wyoming and the impact of increasing efficiency was to reduce the return flows to the detriment of Montana. Montana alleged that sprinklers increase water consumption from 65% of water diverted to 90%, thereby reducing return flows from 35% of the diverted water to only 10%. Montana argued that Wyoming should have imposed administrative requirements to offset adverse these effects on Montana.

This was a complex legal case and dealt with the laws of the so-called doctrine of recapture. Can farmers recapture their water losses by increasing their irrigation efficiency when others downstream have long benefited from those losses? The court held that such improvements were permitted under the Yellowstone River Agreement.

Source: [19]

BOX 5 IRRIGATION SCHEME IN IRAN ACCOUNTS FOR RETURN FLOWS

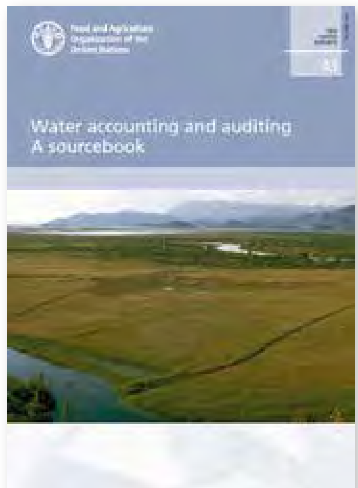
A study of the Moghan irrigation scheme covering 72,000 ha in northwest Iran compared 'classical' irrigation efficiency, which assumed that all water not used by the crop is lost, and the 'neoclassical' approach which accounts for return flows. But not all return flows are usable and depend on the water quality, which can vary throughout the irrigation season particularly when additional water is usefully used for leaching purposes. Using the classical approach, the irrigation efficiency of the scheme was only 37.9%. But using a measure of efficiency, that included return flows and taking account of water quality, was 72% for the scheme and 91% of the return flows were usefully used in the study area.

Source: [78]

When water accounting is combined with data acquired using remote sensing it can be a powerful tool for a more accurate and realistic assessment of crop water consumption on irrigation schemes

2.7 Water accounting

When there is competition for water any analysis must take in the broader hydrological context and this requires a rigorous framework that takes account of return flows and enables proper comparison and assessment of the various water users. *Water accounting* provides that framework [20].



In 2018, FAO [21] [22] likened water accounting to household accounting which is common in everyday life. Money is a precious and limited asset and so it is vitally important to know how much is coming into the home and how much is being spent. Budgets and bank accounts all help to keep track of income and expenditure. Businesses also need accounts and accountants to budget and monitor cash flows to ensure profitability and sustainability. It is thus paradoxical that we do not give similar detailed attention and priority to accounting for water as a precious and limited resource.

Water accounting is a hydrological water balance of inputs and outputs and can help us to make sense of how much is available and how it is allocated to make sure the taps do not run dry. But it is much more than this. Water accounting is about understanding the hydrological cycle, assessing spatial and seasonal variations in rainfall with unpredictable extremes of floods and droughts. It must take account of medium and long-term changes in demand across all water users – communities, farming, energy, industry, and the environment – and inform water infrastructure investment such as pumping, storage, and planning for climate change.

Water accounting is not just for hydrologists. It can help to identify problems across different water-using sectors within river basins and build resilience to climate change. It can help to create a common language to interpret and communicate water resources data to the many different people involved in managing water who come from different backgrounds, cultures, interests, and levels of education.

This process is being actively promoted by the FAO as a planning tool in countries where irrigation is a major user of water and the challenges of producing more crop per drop are not always fully recognised or well understood by other water users.

When water accounting is combined with data acquired using remote sensing and geographical information systems, it can be a powerful tool for a more accurate and realistic assessment of crop water consumption on irrigation schemes and individual farms rather than relying on measurements of water withdrawals (see Box 6).

Water accounting also provides a foundation for effective water governance and sustainable development by providing information for sound decision-making.

Water auditing and governance

Water auditing provides the connection between water accounting and water governance. Water governance is widely accepted as the major weakness in water resource management in most developing countries. According to the World Bank [23], the issue that makes water governance so particularly challenging is, *the uncertainty about the amount and quality of water available from year to year, in terms of both stocks and flows.*

Like financial audits, water auditing provides the qualitative judgements to the water account. It is the means of placing findings, outputs, and recommendations of water accounting into the broader societal context of water management, water supply, and water services delivery.

BOX 6 WATER ACCOUNTING IN LITANI RIVER BASIN IN LEBANON

The Litani River basin is a key river basin in Lebanon and it is experiencing water scarcity. The population has doubled since 2010 due to the Syrian refugee crisis to some 750,000 and water availability is now only 800 m^3/cap/year. The growing population, climate change, and groundwater over-exploitation have put the available water resources in the basin under stress.

Water Accounting systems are being used together with remote sensing to overcome limited availability of hydrological and meteorological data. This provides a reporting mechanism for water flows, fluxes, and stocks to improve water planning and management. From an irrigation perspective the system measures irrigated cropped areas and water consumed by crops, thus providing a more realistic picture of water use rather than relying on water withdrawal data.

Full report available at http://www.fao.org/3/ca6679en/ca6679en.pdf

3 Improving efficiency of large irrigation schemes

Many large-scale irrigation schemes already exist in most Middle Eastern countries and new schemes are being planned and built. Improving their performance, particularly their water use efficiency, is a problem that needs urgent attention in view of increasing water scarcity in the region.

3.1 Some background

In 2014, Plusquellec [24] commented that large-scale irrigation had made a major contribution to increasing food production, reducing hunger and poverty, increasing employment, and securing rural livelihoods for many millions of smallholder farmers. But he was critical of large-scale canal irrigation as *'a technically stagnant sector for the past 50 years', unlike transport, medicine, and communications in which technology has brought many positive changes and developments*. Canal irrigation continues to suffer from the *hassles of manual operation with frequent gate re-settings to regulate water flows to farmers and it suffers from being a hybrid sub-sector, is it water resources or agriculture?*

Large discrepancies have long existed between design assumptions based mainly on physical criteria (hydraulics, agronomy, engineering) and operational reality that falls short in terms of water use efficiency, productivity, and socio-economic and institutional aspirations. Plusquellec [25] also pointed to the complexities of political patronage and corruption, which is endemic in many developing countries and which has often influenced irrigation design and management activities aimed primarily at maintaining the status quo.

Much of Plusquellec's criticism was based on World Bank experiences of investing in large-scale irrigation developments in Asia, though similar comments may equally apply in other parts of the world that have developed similar schemes.

The significant global expansion of irrigation in the 1960s and 1970s, mainly government managed schemes, failed to meet planned expectations and this led to a slow-down in new investment in the 1980s. There were many reasons for this. Irrigation, although a vital input, was just one of many inputs needed to produce crops and sustain farming livelihoods. Many schemes lacked effective agricultural extension services, mechanisation, quality seed and fertiliser inputs, and roads, transport systems, and market structures to effectively get produce to customers and to emerging agri-food industries. It is these many facets of growing and marketing crops that add to the complexities of achieving good performances from irrigated farming.

But canal irrigation had its own problems to deal with. Large canal systems have proved difficult to manage and water supplies were often unreliable, which tended to demotivate farmers who were unwilling to pay for poor irrigation services [25].

There was a dearth of trained irrigation professionals and technicians to manage water distribution. Water was often poorly distributed among farmers with excess water in places (usually near the head of canals where farmers could take advantage in times of water shortages) and deficits in others (usually at the tail end of canals). Overall, irrigation scheme efficiencies were reported as low as 30% and many of the better managed systems did not reach much beyond 50% (based on a ratio of crop water requirement to water withdrawn from the source).

In some countries, the lack of flexibility and unreliable water supplies from canal irrigation is blamed for the rapid expansion and over-exploitation of groundwater that now provides water for one third of the global irrigated area. Conjunctive use of groundwater is seen as a response from farmers who were unable to get their share of water from the canals and canal managers. Farmers benefited from more reliable, flexible, and adequate groundwater supply close to their farms and the freedom to choose their own cropping strategies. In some countries, the extensive water losses from poorly managed canal systems have recharged local groundwater that farmers now exploit. However, within this success were the seeds of failure as groundwater sources are already being over exploited and in some cases the damage is irreversible because of saline intrusion. This suggested that attention should again return to surface water resources and improving canal irrigation.

Engineering solutions...

How did all this come about? Initially governments invested only in major irrigation infrastructure such as barrages, dams, and primary and secondary canals: farmers, mostly smallholders, were left to sort out the tertiary and on-farm systems. Many were unable to organise finance and cope with modern irrigation water delivery and so farmers continued to use centuries old irrigation methods that fostered poor crop yields. In the 1970s, some agencies started to build tertiary systems with farmer participation and consolidated land holdings with the intention of making them easier to irrigate. About half the water wasted on schemes was from farms and so a common response was to improve on-farm irrigation practices, line farm channels, adopt precision land levelling, and encourage farmers to form Water User Associations (WUAs) to take responsibility for managing tertiary systems. However, little was done to improve management of primary and secondary systems.

Other engineering solutions were tried such as installing flow measuring devices, based on the assumption that *you cannot manage what do not measure*. This did not solve the problem as there was a shortage of dedicated trained canal operators to gather data and a lack of administrative structures and effective canal management to make good use of the information for canal operation. Clemmens [26] commented that water measurement is a key component of water control, but it was not enough on its own to make significant improvements in water productivity.

Management solutions...

In the 1980s, as conventional engineering failed to solve problems, the common wisdom was that deficiencies in management and related institutional problems, rather than technology, were the main constraints to improving performance. Engineers, who designed and built schemes, were mostly responsible for managing irrigation systems. And they often lacked knowledge of non-technical factors such as political and social structures among farmers, economic constraints, and environmental concerns that were beginning to influence irrigation development. It was also increasingly clear that *top-down* approaches to managing schemes were not working well. The time when managers could dictate to farmers what crops to grow and how they would be irrigated was passing, and farmers were asking for more flexible and reliable water supplies which often caused conflicts between farmers and irrigation agencies. This was not helped by a lack of funding to pay for recurrent costs of operation and maintenance, and poor coordination between engineers, that designed, built, and operated irrigation systems, and farmers and agricultural extension services that focused on growing crops. Thus, attention shifted from *hard* engineering infrastructure to *soft* engineering involving participatory irrigation management (PIM), strengthening institutions, and training to bridge the gap between engineering and agriculture. In 1984, the International Irrigation Management Institute (now renamed the International Water Management Institute) was established to conduct research to improve irrigation management.

Since the mid-1980s, many governments, and not just in developing countries, were finding it difficult to finance the recurring costs of operation and maintenance (O&M) and to collect water charges from farmers. Centrally managed irrigation bureaucracies also lacked the capacity to provide water services to large numbers of smallholder farmers [27]. To overcome the problems many government agencies began a programme of transferring irrigation management responsibilities, including the costs of O&M to farmer groups, such as Water User Associations (WUAs). Implicit in this was that farmers were more likely to operate systems more effectively and according to their requirements, and increase productivity enough to compensate for the increase in costs [28]. Thus, Irrigation Management Transfer (IMT), became the focus of attention. There was widespread adoption of IMT in many countries, promoted by irrigation agencies rather than farmers, including Turkey and Jordan. Early evidence was mixed whether IMT improved performance, and governments underestimated the complexities of this change in approach and the need for continued government support to farmers. Irrigation agency managers, with a culture of top-down management, were not always ready for IMT, which was the beginning of a service-oriented approach to irrigation management [29]. (see more on IMT in section 3.4.4)

Rethinking technology for management...

In the 1990s, Horst [30] questioned whether management was the crux of irrigation problems? *Do we need to apply cosmetic surgery by only trying to improve the management environment without considering the technology? Is it not time to examine the root of the problem: the design of irrigation schemes?*

In 1999, Burt [31] also argued that many steps taken over the previous 30 years have, for a variety of reasons produced mixed results and have largely failed to make the expected improvements in (irrigation) performance. Improving management alone could not boost the performance of poorly designed or built irrigation schemes. Technical improvements were essential to complement improvements in management.

Horst [30] looked back in history to the early 20th Century to understand today's irrigation problems, when the colonial powers, (particularly the British, Dutch, and French) and the United States began building large canal irrigation schemes. Each adopted their own approach based on the local circumstances.

French engineers developed automatic floating gate systems to cope with irrigation in water scarce regions of North Africa and have continued to use such systems across France today.

The British had to contend with heavily silt-laden water in India and used adjustable gated weirs to provide flexibility of supply, and proportional farm offtakes to equally distribute available water among farmers. They also promoted the *Warabandi* system: a time-share approach to equitably distributing whatever water was available irrespective of discharge or volume [32]. The overall aim was to share limited water resources in drought prone areas to combat extreme poverty and famine among smallholder farmers.

The Dutch favoured simple fixed weirs that required no adjustment to distribute flows and secure sugar cane production for export. The US favoured large irrigated farms and installed constant head orifice structures to distribute and measure water use.

Despite the different approaches, there were common features: strong, top-down, centralised management, open canal distribution systems, and either fixed or adjustable gated structures to regulate, divert, and measure flows. Systems were *supply-driven* providing water continuously, intermittently, or in rotation among farmer groups at tertiary level. Irrigation agencies operated the systems based on standard fixed cropping patterns across the scheme and rigid irrigation supply schedules that did not always match with crop water demands. Although the systems may have been fit for their intended purpose at the time, they tended to be inefficient, with large percolation losses causing water-logging and excess water running to waste. They also lacked flexibility and flows were generally unreliable, particularly at the downstream end of schemes. The different approaches to design persisted in the post-colonial period when engineers from the former colonies began to use their knowledge and experience to provide consultancy services and influence irrigation system design in other countries and situations.

Based on his research, Horst [30] concluded that most irrigation schemes used one of three basic methods to control canal flows: simple fixed structures (e.g. weirs and orifices) that cannot be adjusted, structures that could only be opened or closed, and structures that could be gradually adjusted. He linked them diagrammatically to the level of complexity of operating the canal system, the way farmers manage their irrigation, and the potential efficiency of the system (Figure 8).

Simple fixed distribution structures were the easiest to manage, produced potentially high levels of efficiency, and were well understood among farmers, but they lacked flexibility in terms of cropping. In contrast, gradually adjustable systems offered freedom for farmers to choose when and how to grow different crops. But in reality they were unreliable and difficult to manage, farmers did not understand the complexity of managing variable canal flows, and efficiencies, though high on paper, were poor in reality. Some researchers contended that the greater the operational flexibility of a system, the better was the possibility of matching supply with demand. However, Horst argued that in practice *this reasoning often led to overly sophisticated structures, cumbersome and time-consuming to operate, and complicated operational procedures resulting in sub-optimal operation. The necessity for measuring and monitoring only added to the operational complexity*.

In 2019, Plusquellec [28] again concluded that many of the problems of canal irrigation can be traced back to the initial scheme design. But he also pointed out that critics of engineering designs failed to understand the importance and complexities of irrigation engineering and the lack of engineers with specialist knowledge to plan and design canal systems that can respond to the flexible water requirements of modern irrigation farming.

Irrigation design was still in the hands of civil and agricultural engineers trained to deal with uniform, steady flow systems based on meeting maximum crop water demands with little thought given to the control needed for systems operating with changing flows. In other words, they were far too complicated to be managed well. It was important either to adapt technology to the level of management capability or increase management skills to cope with sophisticated irrigation technologies. This is the essence of modernising irrigation today.

> ...either adapt technology to the level of management capability or increase management skills to cope with sophisticated irrigation technologies

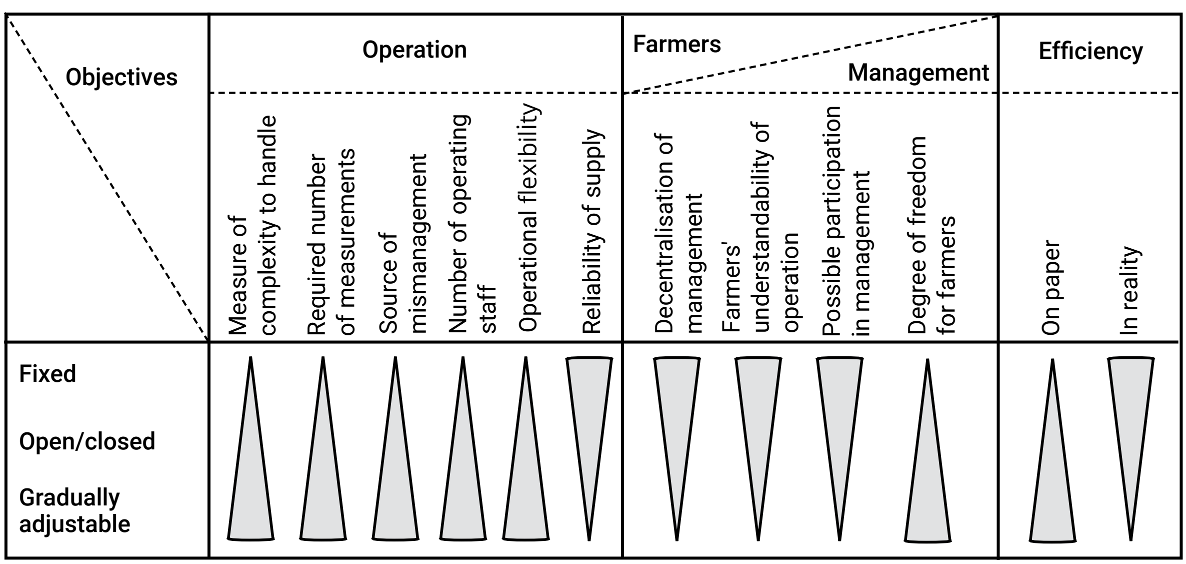


Figure 8 A diagrammatic representation linking methods of water control to the level of complexity of operating canal systems, how farmers manage their irrigation, and the potential irrigation water efficiency (point of triangle indicates low value; base indicates high value to above statement) [30].

3.2 Modernising irrigation

Modernising irrigation is seen as a means of rectifying past mistakes by taking a more holistic and coordinated approach to improving irrigation performance by upgrading/improving all aspects of an irrigation scheme to respond to the requirements of modern farming.

This is being driven partly by farmers who want more flexible and reliable water delivery to their farms and partly by growing concerns among governments about the costs of O&M, increasing water scarcity, and the desire to increase agricultural water use efficiency in a sector that is considered by many to be inefficient.

Modern irrigation is essentially concerned with responding to the needs of farmers by making the best use of available resources and technologies and bearing in mind likely future needs.

Together this is intended to significantly improve irrigation system performance, water productivity, and farm incomes (see section 3.4.1). However, the complexity of achieving improvements through modernisation should not be underestimated (Box 7).

The United Nations Food and Agriculture Organisation (FAO) described irrigation modernisation as: *a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, with the objective of improving resource utilisation (water, labour, economic, and environmental) and water delivery to farms. Implicit in modernisation is a shift from traditional supply-driven irrigation to demand-driven irrigation and introducing the concept of providing an irrigation service to farmers [51].*

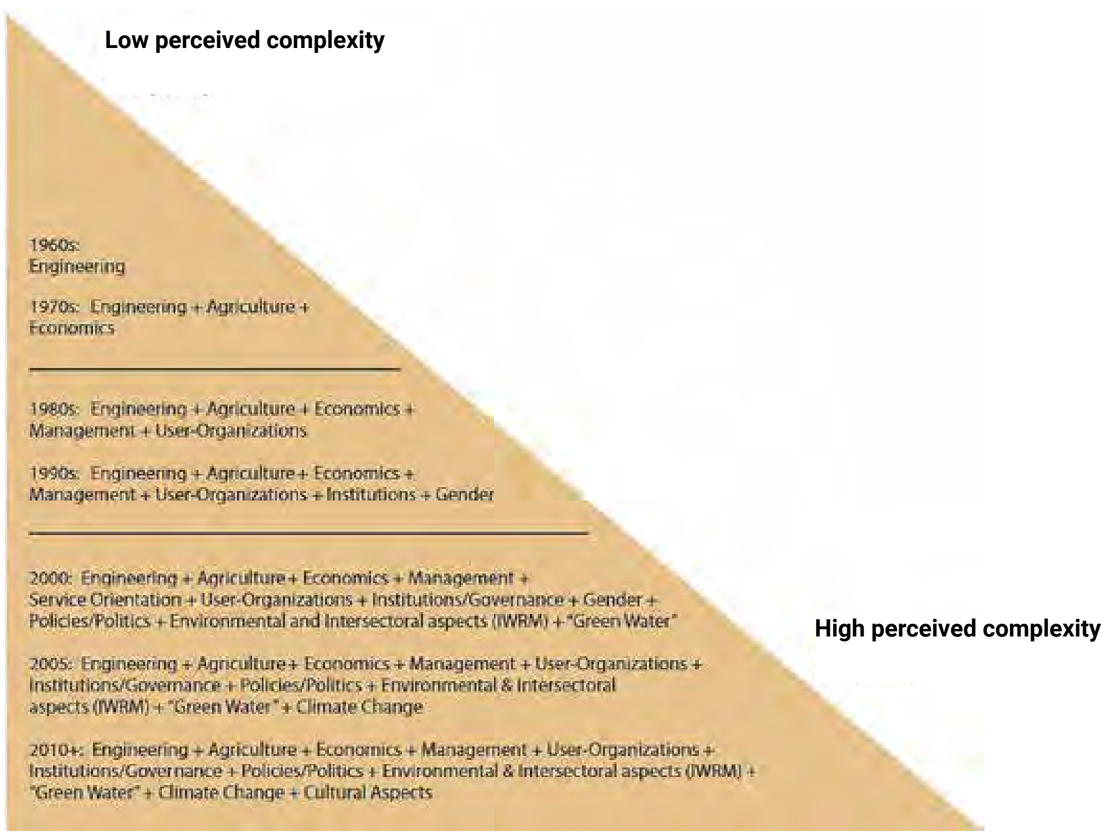
Photo: Rubiconwater, Australia

Modernising irrigation involves two essential and complementary components. The first is technical: this is the most visible aspect of irrigation, and involves modernising the physical infrastructure: canals, pumping stations, and control structures.

The second is less visible, though equally important, and involves upgrading irrigation management and the institutional structures that govern irrigation to ensure they have the capacity and capability to provide irrigation services appropriate to modern farming.

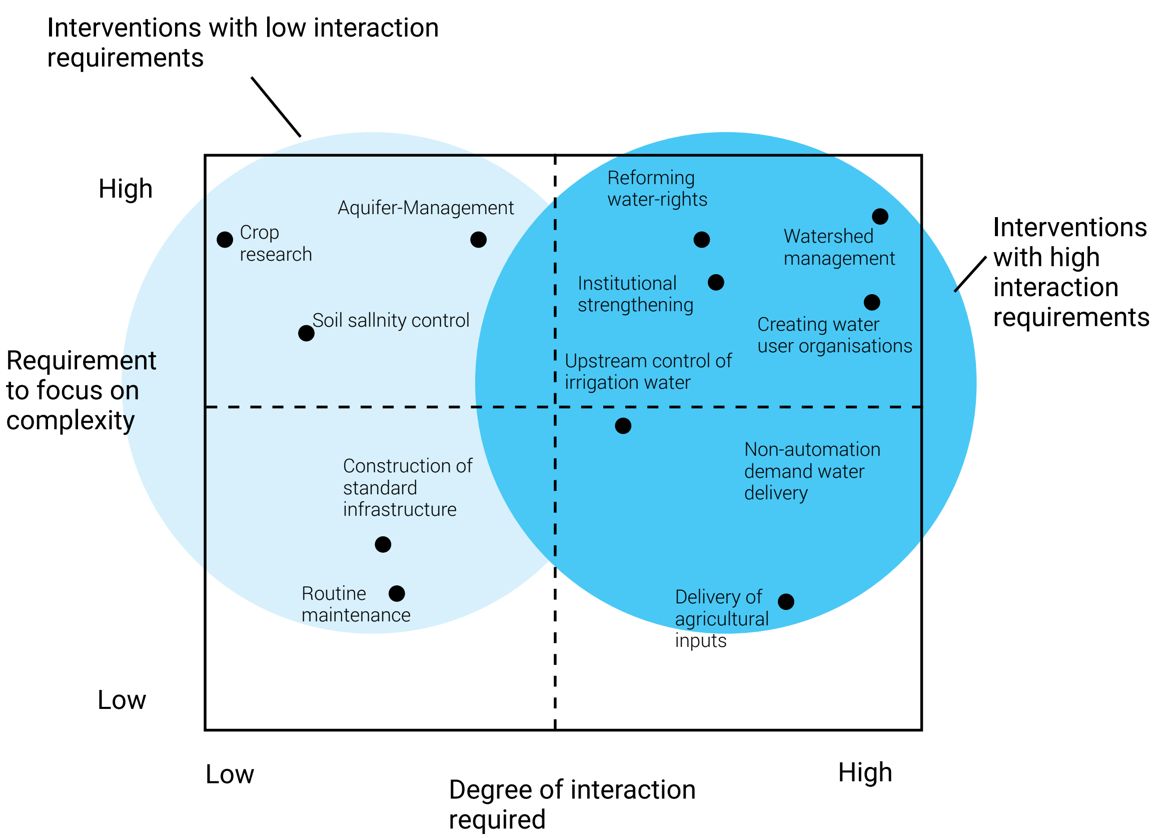
BOX 7 COPING WITH COMPLEXITY IN LARGE-SCALE IRRIGATION SCHEMES

In 2009, Huppert examined how perceptions of irrigation systems and services have evolved over the past 50 years from a relatively simple engineering and technology issue to one that now involves almost everything including the proverbial kitchen sink. Huppert suggested that for investments to perform substantially better, it is important to understand and influence how the sector works in practice, and how irrigation services and change processes are shaped not only by the bio-physical constraints but also by political, social, and cultural considerations. Focusing on the interests, perceptions and strategies of policy actors' (irrigation agency, farmers, WUAs, the rural elite, politicians) in relation to defined policies and how these shape and reshape negotiation processes, resource allocations, and formation of alliances in policy processes are crucial to unpacking how existing power relationships shape outcomes.



BOX 7 COPING WITH COMPLEXITY IN LARGE-SCALE IRRIGATION SCHEMES contd

Huppert also provided a framework as a guide to those aspects of irrigation development that are inherently complex and require extensive interaction with stakeholders (top right quadrant). Interventions that are less complex and require minimal interaction can be addressed through a typical project activity, (lower left quadrant). Thus, canal maintenance is relatively straight forward and does not require much discussion, whereas forming WUAs will require much time, effort, and patience to develop strong independent organisations with no clear pathway as to how this will be achieved.



Source: [33]

3.3 Modernising infrastructure

Modernising irrigation infrastructure is about improving the water control system. This is distinct from rehabilitation, which is about re-engineering deficient infrastructure to return it to its original design.

Modernisation is often misunderstood and associated only with high technology or costly automation. However, Horst [30] argued that modernisation depended on local circumstances, and improvements could be achieved by using simple technologies as well as the more sophisticated options. Both are worthy options to consider as both have the same objective in mind: to find technological solutions to replacing manually adjustable systems that have proved so difficult to manage.

However, there is one key difference: automation offers the option of *demand-oriented* water deliveries, whereas simplifying will remain essentially *supply-oriented* – with all the inherent disadvantages associated with this approach. Not everyone agrees with this premise (Box 8).

3.3.1 Automation

Automation is attractive because it is seen as modern and up to date. Although many existing schemes still use hydraulic control structures and methods developed in the first half of the 20th century, technology advances in automation based on automatic and remote control, computer modelling, and advanced communication systems are already in use mainly in Australia, France, and the United States. This has significantly reduced the numbers of staff needed to operate and maintain systems, but at the same time it has increased the skills that staff need. Although pilot projects on automation and computer models elsewhere appear to have been less successful than expected, it is unrealistic to assume that these modern techniques are not going to be used in future irrigation development.

Modernisation…can be achieved by using simple technologies as well as the more sophisticated options

BOX 8 NOT EVERYONE AGREES WITH THE NEED FOR FLEXIBILITY

It is worth noting that not everyone sees modernisation as the pathway to improving scheme performance. Some argue, that in developing countries, there is little need for flexible water delivery, as the agricultural benefits are relatively minor, and management skills are the most constraining factor. Thus, irrigation systems should be as simple as possible. Modern technologies are too costly, they are difficult to maintain, and vandalism in remote places is likely to be a problem. Some researchers argue that crops grew well when farmers adjusted their cropping patterns to suit rotational water supplies that were reliable. The additional benefits of flexible supply were not enough to balance the high investment costs and operational complications. However, such comments must be seen in context. In this case farmers adopted uniform cropping patterns and rainfall was well distributed throughout the season.

Figure 9 Automatic control of canal water levels a) Floating gate b) Duckbill weir

Learning from the past, it is vital that automatic technologies take full account of local circumstances including staff who are fully trained, and not forgetting that farmers must also be willing and able to accept such systems.

Laycock [35] describes canal automation as either passive or active.

Passive automation

Passive automation usually consists of float-operated gates, baffle distributors, and long-crested weirs that do not require human intervention or computer control beyond their initial settings. They are used to control upstream and downstream water levels, divide flows, and control farm offtakes. Float-operated gates (Figure 9a) are self-regulating with clear advantages: no cables, computers, controllers, or power supply. One disadvantage is there are few companies that manufacture these gates[5]. Long-crested weirs (duckbill weir see Figure 9b) are useful for controlling upstream water levels within close limits even though canal flows may vary considerably. They are also referred to as *simplified technology* as well.

Float-operated automatic upstream control can improve canal operating efficiency, but automatic downstream control gates can make significant improvements as they change the control system from *supply-oriented* to *demand-oriented* irrigation.

Passive automation - downstream control

Most canal systems are designed and operated using *upstream control* (Figure 10a). A cross-regulator controls water levels upstream of canal offtakes to ensure command water levels in canals are enough to maintain gravity flow throughout the system and onto the farmers' fields. Weirs are commonly used for cross-regulators (they a good for controlling water levels) and orifices/pipes for offtakes (as they are good for controlling discharge and are insensitive to varying upstream water levels).

In contrast, downstream control (Figure 10b) places the cross-regulator (usually a float-operated gate) upstream of the offtake and controls the downstream water level and discharge into the offtake regardless of upstream water level or demands downstream. The advantage of this approach is that the canal system can automatically respond to changes in demand as farmers open or close their offtakes.

[5] Manufacturers include GEC Alsthom (previously Neyrtec, Neyrpic) Perrier Sorem, France; Waterman Industries, US; and Rubiconwater, Australia

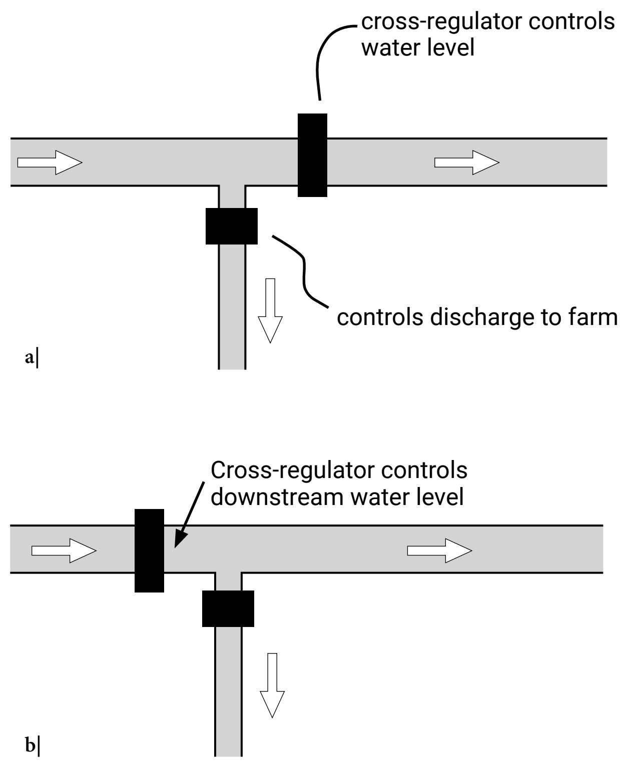


Figure 10 a) Upstream and b) downstream control

If an offtake is opened, the canal water level falls, and this automatically opens the cross-regulator gate and allows more water downstream to restore the water level. The water level upstream of the regulator now falls and this in turn affects the downstream water level at the next cross-regulator upstream. This opens and releases more water downstream, and so on until the 'hydraulic message' travels to the head of the canal to signal that more water is required downstream.

Thus, downstream control using automatic float-gates is essentially an on-demand system. It responds to the opening and closing of canal offtakes. Contrast this with upstream control, which cannot automatically respond to changing farmer demands. Only by sending a message to the operator at the head of the canal can a farmer change the flow in the canal system.

This constraint, which is common to all canal systems using upstream control, can waste water. For example, if there is a canal breach downstream an upstream controlled canal would continue to flow as there would be no indication of the problem until someone alerted the operator at the head of the canal. A breach on a downstream controlled canal would quickly be seen as rapidly falling water levels at the head of the canal, allowing operators to act and stop the flow. Water is also stored in canals using downstream control when not in use and this reduces canal filling times and shortens the response time when farmers start to irrigate. There are additional design and cost implications with downstream control but the potential for increasing efficiency can be significant.

A note of caution: downstream control only works when enough water is assured for the whole growing season, such as a reservoir supply. With increasing uncertainties of assured supply, this technology will become vulnerable and is not suitable for the unpredictable nature of abstraction from rivers.

Active automation

Active automation can be adapted to both upstream and downstream control systems to control adjustable gates and pumps using computer-based operating procedures that emulate the process usually undertaken manually by operators. Rules like: *Close the cross-regulator gate because the water levels are too high or a farmer downstream wants more water so start opening the cross-regulator gates to increase the flow* require turning into language that computers and control systems understand. This all requires a sophisticated knowledge of control theory and control systems, and fuzzy logic which enables imprecise human-like behaviour to be programmed into computers rather than just simple yes/no logic. An example in canal control language might be: *the water level is probably going to increase so we need to start closing the cross-regulator a bit* [35].

There are many options to consider such as *gate-stroking* that reduces the response time to changes in flow; *centralised controlled-volume* operation which targets water volumes in canal reaches according a pre-determined schedule; *centralised dynamic regulation* that uses feedback to continually adjust flows in response to changing demand; and *centralised real-time control* which aims to provide water on-demand in an upstream controlled canal system.

Most systems rely on mathematical algorithms base on non-steady flow simulation models of the canal system that require accurate knowledge of the system's geometry. Instrumentation required includes sensors to measure the control variables such as water levels, gate openings, and discharge; motors to change gate settings; and communication links to receive information from sensors and to transmit instructions to change gate settings, which include telephones, cabling, remote signalling using radio or satellites. Telemetry requires power at the sensing point and solar power is increasingly being used in remote locations. A challenge for remote control in developing countries is often maintaining systems and the risk of theft.

In 2014, the American Society of Civil Engineers (ASCE) published the results of a Task Committee on recent advances in canal automation [36]. This Manual of Practice (No 131) is the most comprehensive up to date publication on automation for canal systems.

Figure 11 Active automation on a main canal

BOX 9 USEFUL VIDEOS ON AUTOMATIC CONTROL IN CANAL SYSTEMS

Rubicon automatic control systems
https://www.rubiconwater.com/news/767/what-is-high-performance-surface-irrigation

https://www.youtube.com/watch?v=I3RUFh1-87k

https://www.youtube.com/watch?v=EjVy7rLUjpE

Waterman automatic control systems
https://www.youtube.com/watch?v=WFdu1wf1PDs

Like automation, technology solutions are sought that simplify water delivery and avoid the complexities of manually adjustable gates

3.3.2 Simplified technologies

Simplifying technologies are an alternative that rely on existing knowledge and perceptions of how irrigation should be planned, constructed, and managed. Like automation, technology solutions are sought that simplify water delivery and avoid the complexities of manually adjustable gates. This includes proportional farm offtakes that reduce flows into farms in proportion to reduced flows in the canal system, on-off gates, and stepwise distributors like baffle (modular) distributors that deliver constant discharge irrespective of upstream water level (Figure 12).

Intermediate reservoirs are another option, as is converting canals to low-pressure pipe systems that can respond rapidly to changes in demand.

Figure 12 Baffle distributor that delivers a fixed discharge regardless of upstream water level. Variations in flow are made by opening different baffles.

Reservoir storage

Reservoir storage is analogous to the use of storage tanks in the home that provide a balance between the supply from the water company and the demand for water in the home. They are particularly useful when supplies are unreliable, by removing uncertainty and providing water on-demand. Reservoirs provide similar benefits for irrigators.

Once water enters a canal system it continues to flow and cannot be stopped, unlike pipe systems where closing a valve can stop the flow. The challenge is to develop an operational plan to manage the flow. In many systems the plan does not match farmer requirements in terms of timing, duration, and volumes, and water is wasted. Providing water storage at the interface between the farmers' fields and the canal system can be a buffer that overcomes this mismatch (Figure 13). Storage, usually for only 1-2 days, can absorb surpluses and shortages and offers flexibility for system managers to supply water when it is available and for farmers to use it as and when they need it.

Water can flow continuously in the canal system, which simplifies canal operation, and farmers store water and use it as and when they wish to irrigate, often during daylight hours when they can have better control over applications.

The ideal place to store water is close to farms. In some schemes the tertiary canals are oversized and act as reservoirs. In the Sudan, this system has been in use since colonial times and is referred to as *night storage*. In others, reservoirs are built at the head of the tertiary canals (Box 10).

Management responsibilities are clearly split between the irrigation agency, which is responsible for the main canal system, and individual/groups of farmers who are responsible for the tertiary canals and reservoirs.

A comment from an irrigation manager in the US was: *Farmers like to see the water*. This is true the world over. With reservoirs you can see the water is there ready to use and this can build confidence and trust between farmers and operators. Reservoirs enable farmers to have more control over field applications, use higher flow rates that are more efficient for surface irrigation, and hold back excess water. Reservoirs can also bring additional benefits from multiple use such as community water supply and fish farming, a valuable source of protein among many communities.

Farmers like to see the water. This is true the world over

BOX 10 NIGHT STORAGE BALANCES SUPPLY WITH DEMAND IN THE SUDAN

The Gezira scheme in Sudan uses simple technologies by present-day standards. It was designed before the development of modem canal water-control technologies. The main and branch are designed to flow continuously, the tertiary canals are oversized for storing water arriving during the night. This solved the problem of low efficiency during night irrigation and provided a solution to matching supply and demand using upstream control. A negative feature is that the oversized minor canals trap silt and weeds grow. Also there are health risks with slow moving water, such a Schistosomiasis and Malaria.

The system is also used in Kano in Nigeria where buffer reservoirs for flexible water delivery and automatic flap gates provide upstream water level control and ensures constant flow at offtakes.

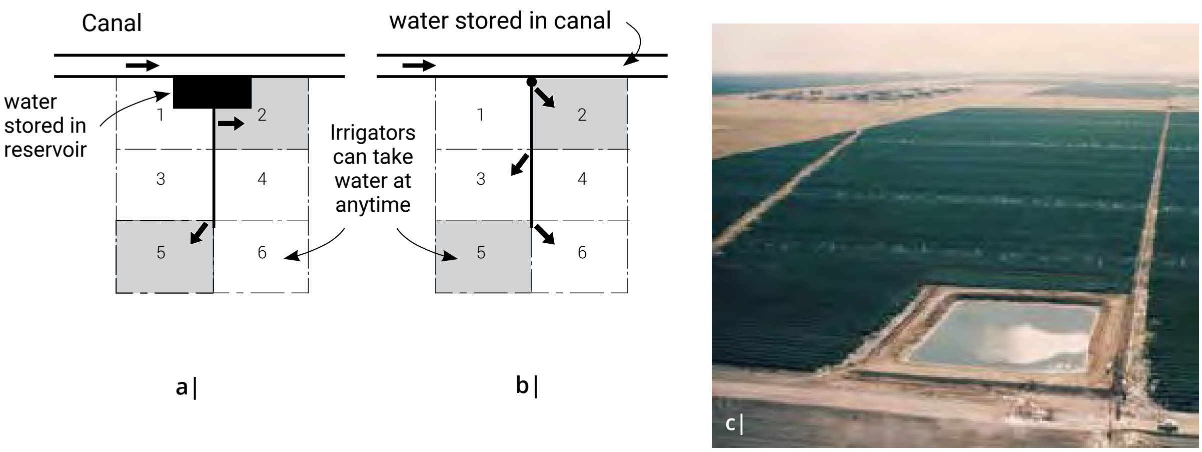


Figure 13 Reservoir storage a) on-farm b) in the tertiary canal c) on-farm reservoir

Low-pressure pipe systems

Low pressure (0.2-0.5 bar) pipe systems for all types of surface irrigation (basin, border, and furrows) are finding favour in some countries as a means of simplifying water management and reducing wastage (Figure 14).

Merriam [38] suggested they offer an intermediate solution between lower cost earthen canals and the more expensive sprinkler and drip irrigation systems. Interest in this system comes not just from farmers but also from industry as it offers a marketing opportunity to provide hardware to farmers. Pipe systems, usually large diameter concrete or PVC, have many advantages over canal systems. The main one is in managing water on-demand. In our homes we enjoy piped water supply that responds rapidly to our demands for water, and when we do not need it, we can close the taps. Similarly, in a low-pressure pipe network, when a farmer opens or closes an offtake it responds rapidly.

In contrast, canal systems respond much more slowly to changes in flow. Water waves in canals travel around 1-3 m/s and so there are long delays as changes in water level travel upstream to an operator and farmers must wait, often for hours before water arrives. In large canal systems it can take many days for water to travel from the headworks to the field. This is one good reason why we use piped systems to our homes. We would not tolerate the inconvenience of canal supply!

Van Bentum [37] lists the benefits as:

- Systems become demand rather than supply-oriented when pipes are used. Pipe systems respond rapidly to changes in water demand.
- There is reduced wastage, greater flexibility, and reliability of supply.
- Short water transit times enable water to be moved around a command more rapidly than with channels.
- Less land is taken up with the irrigation system.
- Pipe systems are generally thought to be expensive. But there are savings in terms of reduced land, water, and labour. Simplifying irrigation management practices and improved efficiency may well justify the additional cost.

Gated pipes fit well with low pressure pipe systems (Figure 14b). They provide good flow control into basins, borders, and furrows; a level of control that is lacking in most canal systems and is one of the main reasons why irrigation application efficiencies are low for surface irrigation. Gated pipes can enable farmers to reduce their infield water losses from deep percolation and runoff (see section 4.2.2). When flows are reliable farmers tend not to not use more water than is necessary, they turn off valves when they have finished irrigating. Farmer groups do not all need to irrigate at the same time and discharges are easily measured ensuring a fair apportionment of water charges.

Lining canals

Open canals are still the most common means of conveying irrigation water on schemes. They are usually constructed in the natural soil and require regular maintenance. Some canals are lined with clay, concrete or geotextiles to reduce seepage, to improve canal performance, and reduce maintenance. Installation costs are high and maintenance, when needed can also be costly (Figure 15).

Factors influencing conveyance efficiency include: canal size, shape, and slope; water losses from seepage and evaporation; how well they are maintained to avoid erosion, siltation, weed infestation; and the degree of control and automation used to control water flow. A practical method of detecting seepage losses is to walk along canals looking for wet areas, cracks in embankments, animal burrows, and poor maintenance.

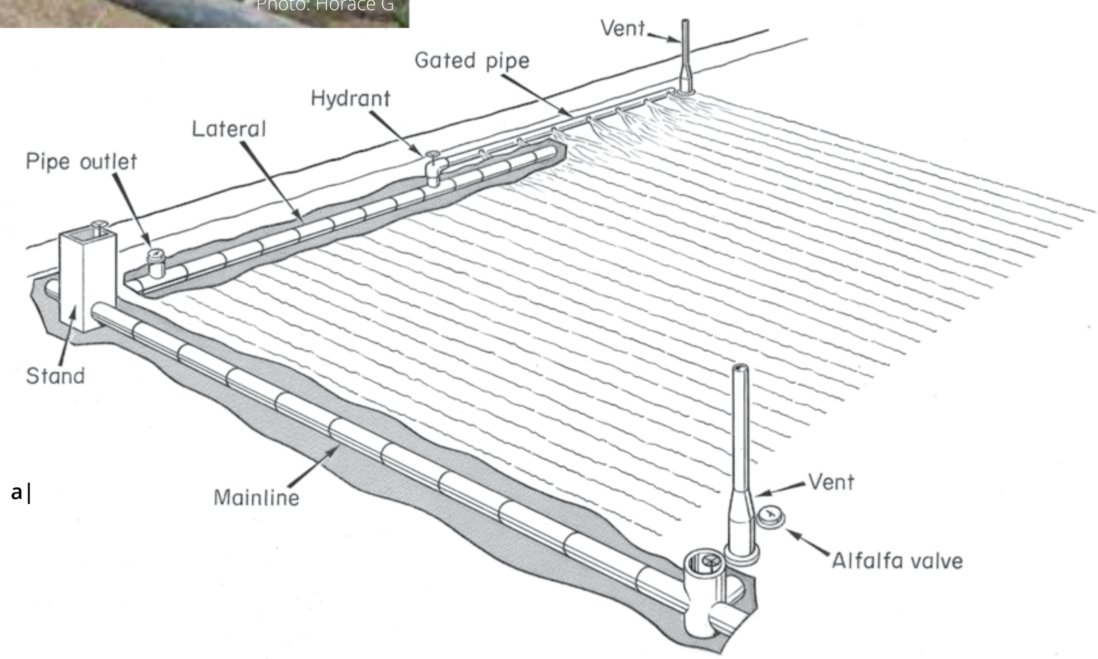


Figure 14 a) Low-pressure pipe system for surface irrigation b) gated pipe used to irrigate furrows.

Methods of measuring losses includes the inflow-outflow method and the ponding method [39], [40], and [41].

In the past there has been a preference among agencies to install concrete lining to control seepage losses. But concrete can deteriorate over time with cracks occurring and joints opening. It does not take large areas of damage to cause heavy seepage losses.

In 1993, Haigh [42] showed that a 99% perfect lining can have seepage losses equivalent to a comparable unlined canal. Increasingly, geo-synthetics are being widely adopted in all aspects of civil engineering and may be a preferred option for canal lining as well. Lining canals to reduce losses when water is scarce needs careful attention and must take account of return flows (see section 2.6).

Figure 15 Canal linings a) concrete b) geotextile material

3.4 Modernising management

Modernising irrigation management is essential to complement modernising irrigation infrastructure. This will involve significant change in management culture and supporting/changing institutional structures to ensure they have the capacity and capability to provide irrigation services appropriate to modern farming and to the needs of the farmers.

3.4.1 The concept of service

Fundamental to modernising irrigation management is the concept of s*ervice-oriented management* (SOM) – providing an irrigation service to farmers and delivering water. Irrigation agencies have often been deficient in defining and monitoring the service they provide to farmers. Modernisation is a major shift from the past when irrigation agencies traditionally adopted a *top-down* approach to irrigation management when operators told farmers how and when they would receive water. The concept of irrigation service was introduced in the 1980s together with methods to evaluate service quality [43]. In a modern irrigation scheme, farmers should expect a level of service that defines water quantity and quality, reliability, and flexibility of water deliveries. Flexibility is closely related to improvements in agricultural performance and is defined in terms of frequency, flow rate, and duration. There is a tacit assumption that providing farmers with a well-defined level of irrigation service will lead to increases in water use efficiency and improve the overall performance of large-scale irrigation schemes [29].

Levels of service must clarify who is responsible for what. This includes all those involved: farmers, WUAs, operators of primary, secondary, and tertiary canal networks, and the irrigation agency. Each layer of the irrigation system provides a service to the layer downstream.

Levels of service can range from highly flexible services to individual farmers, to relatively inflexible services provided to large farmer groups. Service agreements will also specify costs which form the foundation of an asset management strategy and influence management capacity upgrade programmes.

In summary, levels of service is a set of operational standards set by the irrigation agency in consultation with irrigators, the government, and other affected parties and with due regard to associated costs. It must come from an extensive consultation process and provide a set of targets against which operational performance can be measured and revised on an on-going basis to respond to change.

The notion of service is important when farmers are expected to pay for water, particularly when in the past it was delivered free. Farmers are unlikely to pay for water if there is a lack of confidence in scheme managers to provide a high-quality service. The quality of that service will depend on the efficiency of the irrigation system which in turn depends on the physical infrastructure and the ability of system managers and farmers to use it as the designers intended.

Modernising irrigation management is essential to complement modernising irrigation infrastructure

A note of caution: Improving irrigation services does not automatically mean increased water productivity. This depends on multiple factors like farmers who are risk averse to markets, and the availability of finance, seed, labour, and chemicals. Improved services, such as better timing and reliability of supply can also increase water demand for irrigation as farmers switch from basic grain crops to higher value fruit and vegetables. They may also use efficiency savings to expand their irrigated area rather than hand water back to the irrigation agency (see section 2.6). Paradoxically, when water is scarce, demand tends to increase as irrigation efficiency and water productivity improve [44].

3.4.2 Assessing management capacity

Modernisation includes transforming how irrigation systems are managed and operated and changing the rules and institutional structures, like water rights, water delivery services, accountability mechanisms, and incentives. Institutional and organisational changes at all levels from irrigation system management to on-farm irrigation management are often needed to improve irrigation services to farmers.

Many large-scale irrigation schemes were designed, built, and managed by government officials, and their capacity and ability to undertake their management roles and responsibilities varies among schemes and countries. Sagardoy [45] identified several different types of irrigation management organisations: state farms and cooperatives; specialised water management organisations: irrigation associations, government run irrigation schemes; and multi-purpose water management organisations. Thus, the extent of changes needed largely depends on the current management system and culture and what is expected in the future.

Prior to making changes, it makes sense to understand current management practices and capabilities, what will be expected during and after modernisation, and identify the performance gaps. There are four potential gaps [27]. The first is a *technological gap* and this is discussed in section 3.3. The second is the *implementation gap*. This is a gap between how management procedures are supposed to be implemented and how they are actually implemented, such as adjusting gates, maintaining canals, and reporting information. A third is the *achievement gap*, which is the gap between management targets and actual achievements. The fourth is the *performance gap*. This is the difference between what people think should be the ultimate impacts of irrigation farming and what happens in practice. This includes measuring impacts of irrigation on agricultural and economic profitability, water productivity, poverty alleviation, and the physical environment, such as waterlogging and salinity.

The gap analysis will vary from scheme to scheme depending on local circumstances but the questions to address will include:

What are the main performance gaps?

How big are the gaps?

How important are they to overcome them?

Where data exist, a quantitative analysis will be possible. Where data are not available, a qualitative assessment will be needed based on rural appraisals and meeting with farmers and irrigation department staff. The next step will be to decide what management reforms are needed to overcome the gaps.

In view of the increasing competition for scarce water resources it will be important to assess irrigation performance in the context of integrated water resources management (IWRM) at basin level.

3.4.3 Participatory irrigation management

Participatory irrigation management (PIM) has been a prevalent theme in irrigation for over 40 years. Indeed, an international network on participatory irrigation management (INPIM) was established in the 1980s to promote PIM (though now disbanded). The participatory movement has long advocated that the size of government should be reduced, and that people should participate more in governance, management, and finance to promote sustainable and equitable development. Participation promotes the subsidiarity principle of making decisions at the lowest level possible, and introduces the concept of self-reliance as a development strategy [46].

PIM is about farmers engaging with government in irrigation decision-making. Farmers can be involved in various management functions, including, planning, design, operations, maintenance, rehabilitation, resource mobilisation, and conflict resolution. The involvement can be at various system levels from the field channel to the entire system [47]. In 2007, South Africa's Water Research Centre established a guide for irrigation development practitioners on PIM principles and approaches for revitalising smallholder irrigation schemes [48].

Today, the idea of farmer participation is well accepted, and it is almost unthinkable for irrigation planning, design, and significant changes to take place without some form of involvement that goes beyond mere consultation. Participation is a central feature within integrated water resources management (IWRM) and is enshrined in SDG 6 of the UN 2030 Development Agenda [3]. PIM lies within IWRM where irrigation water demands can no longer be dealt with in isolation and must be considered alongside those of domestic and industrial demands, and water for the environment.

Collaborative modelling is gaining momentum as a water resources planning approach that formally brings together water-users and technical experts. Developing models is not just an analytical process but one that builds consensus, trust, and improvements in decision-making [49].

Figure 16 Working together: WUA farmer meetings

3.4.4 Irrigation management transfer

Irrigation management transfer (IMT) is a more specialised aspect of PIM that is distinct from farmers participating *with* irrigation agencies; it is a process of shifting irrigation management functions *away* from irrigation agencies to private sector entities, such as non-governmental organisations (NGOs), or more commonly farmer groups like WUAs [27]. WUAs decide what services they need and are willing to pay for and negotiate with the irrigation agency to provide the services. Key to IMT is defining irrigation services and how the irrigation agency will arrange to provide them (see section 3.4.1). IMT fits well with the concept of modernisation and is seen as an important part of the reform process to improve irrigation management capacity.

IMT is a significant shift in the way irrigation is managed. This is not a new idea, IMT has been part of a global trend since the 1980s. Experience in irrigation, as in other sectors of natural resources management have often shown that while government may be good at taking a national planning perspective, they are not so good at managing resources at a more localised level. Managing large canal systems requires major resources and expertise and governments are well placed to provide them. But just how far down the system should this control be exercised? There comes a point when, not only is it prohibitively expensive to maintain such external control but it may also be unnecessary. Indeed, many IMT initiatives were driven by policies that shifted the burden of O&M costs from government to farmers. Interestingly, most were initiated by governments rather than pressures from farmers.

Table 1 Potential impacts of IMT [47]

Positive impacts	Negative impacts
Farmer perspective	
Sense of ownership	Higher costs
Increased transparency	More time and effort required to manage
Greater accessibility to system personnel	Less disaster assistance
Improved maintenance	No assured rehabilitation assistance
Improved irrigation service	Less secure water right
Reduced conflicts among users	Decreased agricultural productivity
Increased agricultural productivity	
Government perspective	
Reduced government costs	Less direct control over cropping patterns
Greater farmer satisfaction	Need to reduce staff levels/union opposition
Reduced staffing levels	Reduced ability to implement new agricultural and irrigation policies
Reduced costs to the economy	
Irrigation agency perspective	
Fewer conflicts to deal with	Reduced bureaucratic and political influence
Reduced operational involvement	Uncertainty of agency role
New responsibilities	Reduced opportunity for rent-seeking
Reduced opportunity for rent seeking	Reduced control over water resources
Reduced political interference	
Reduced O&M staff levels	

BOX 11 IS PIM REALLY IMT?

IMT involves *replacing* the role of government in irrigation management, whereas PIM seeks to strengthen the *relationship* between water users and government. The concepts overlap when, prior to transfer, government and farmers participate in negotiations to establish the rules and responsibilities of the government agency and the recipient organisation. Despite the differences, the overlaps mean that PIM is often widely used to include IMT.

Source: FAO [46]

In 1997, Svendsen [47] reviewed PIM/IMT in five countries (Argentina, Colombia, Mexico, Turkey, and Philippines) and concluded that the overall benefits were positive, though there were also negative impacts depending on different points of view (Table 1). Paying for services may be seen as a problem by individual farmers but as a benefit for the WUA and the government. There was significant institutional change with much effort devoted to reform.

Many traditional government structures were dismantled with job losses while new associations of water users were formed by farmers to take over the responsibility of managing irrigation systems. Professional and technical staff as well as farmers have had to learn new skills and adjust their attitudes towards this new socio-economic environment that is so very different from the one in which many have worked for most of their lives.

Svendsen's review demonstrated the complexity of transferring management authority to WUAs. This is a process and not a project and may take a decade or more to make successful changes. It may involve changes in national policy, regulations, and organisational structures; creating new local organisations, transferring ownership of infrastructure and equipment, and changing personnel and management functions.
IMT can solve problems but it can also create new problems. A WUA may not have the technical or administrative skills for their new role, and low productivity prior to the changes may become a more acute problem when farmers are expected to pay a fee for services which were once free [47].

The most comprehensive review of IMT in 42 countries was undertaken by FAO in 2007 [46]. Their conclusions are many and detailed but overall, they found that:

- The closer involvement of WUAs has resulted in increased accountability, transparency, and responsibility.
- Governments were overly optimistic about WUAs providing their own basic support services, though some WUAs have started to provide a wider range of agricultural services to their members.
- IMT led to significant increases in fee collection but this was not always sustainable and has been erratic.
- IMT does not necessarily lead to increases in cropping intensities or yields, though there were no cases where agricultural productivity decreased.
- IMT has led to improvements in communication between farmers and irrigation managers. There has been an increase in both accountability and responsibility in providing irrigation services.
- Large job losses in the public irrigation sector did not happen. They either did not occur in most countries or WUAs absorbed technical staff into the private sector.
- Capacity development in WUAs has generally been poor and was detrimental to performance in the critical early years of transfer. This was due to a lack of funding and a lack of understanding of WUA training needs.

IMT is a process and not a project and may take a decade or more to make successful changes

BOX 12 IMT IN TURKEY – EXPERIENCES IN THE EARLY YEARS

Turkey is the only country in the Middle East with first-hand experience of IMT. The early years offer invaluable experiences for other countries facing a similar pathway.

Turkey is equipped to irrigate some 4.86 million hectares, mostly medium and large-scale surface irrigation schemes. In 1993 it implemented an IMT programme largely driven by budgetary problems; rising labour costs and a freeze on government recruitment with consequent impacts on the government's ability to continue operating, maintaining, and expanding the irrigated area; and World Bank pressures to improve cost recovery.

Turkey has a long-established tradition of both strong central government and a dependency on irrigated farming. But within three years the General Directorate of State Hydraulic Works (DSI), the government's main executive agency for water resources planning, execution, and operation, had succeeded in transferring almost 1 million hectares (60% of publicly managed irrigation) to local government units and Water User Associations (WUAs) created at a local level. By 2007 the area transferred was 1.6 million hectares. WUA managed units, averaged 6,500 hectares, much larger than units established in Asian countries in the 1980s. The organisational structure adopted was unified rather than federated, much like the irrigation districts in Australia and the US. Turkey's structure also has strong similarities with Mexico, which is not surprising given the close interactions and experience sharing between Turkey and Mexico early in the programme.

Under the programme WUAs entered contracts with DSI to take administrative responsibility for tasks such as indenting for water with DSI and managing water distribution in tertiary systems including maintenance. Initially, IMT doubled the fee collection rates, thus shifting O&M costs from public to the private sector. Although there was resistance within DSI to reducing O&M personnel initially, staffing levels gradually declined and significant savings were expected to come from this.

Second generation problems emerged in the wake of IMT. DSI faced difficulties in reducing staff, introducing a charging mechanism for bulk water transfer to WUAs, and developing a new role in the post-transfer era. WUAs faced many problems, among which were undefined water rights and water insecurity, restricted options for acquiring heavy maintenance equipment, and the need to increase direct farmer participation in WUA governance and reduce dependence on village and municipal leadership.

The flexible and pragmatic conduct of the IMT programme and enthusiasm apparent among WUA leaders was an encouraging sign for the future. However, complacency was considered a real danger. Like IMT in many other countries, there was a realisation that this was a long-term process and not a short-term project.

Sources: [50] [47] [18]

Vermillion [27] suggested that successful transfer depends on:

- Having the capacity to create or alter local organisations
- Openness of the political economy
- Legislation to support local water services
- Clear water rights
- Strong support from bureaucracies and local elites.
- Appropriate irrigation infrastructure manageable by farmer groups

Strong commitment at the highest political levels will be needed and pressures sustained through policy formulation and implementation.

If conditions are not met, then the scheme may not be ready to adopt an IMT policy.

A positive answer to three key questions will determine whether a scheme or country should adopt IMT:

Is IMT necessary in order to overcome current management performance gaps?

Is implementation of IMT feasible?

Is there strong enough political commitment to IMT?

BOX 13 IRRIGATION AGENCY AND FARMERS PARTICIPATE IN THE JORDAN VALLEY

The Jordan Valley Authority (JVA) ensures irrigation water delivery to farms by opening and closing valves at each farm which are installed in enclosed concrete boxes. This was perceived as a complex task as the valves must be operated by qualified staff to meet the diverse cropping patterns in the valley. Because of staff constraints this proved difficult to manage and the unpredictability of the water supply due to unforeseen water scarcity added to the problems of managing the supply. Since there was little or no interaction with farmers throughout the process, some farmers would break the boxes and open valves to access the water. JVA rebuilt the boxes and tried to prevent farmers from illegally opening valves but this was unsuccessful.

In recent years JVA has realised that water delivery under conditions of diverse cropping patterns and unpredictable water supplies is a complex service requiring much greater interaction with farmers. Water user groups were established to work with JVA staff and to take responsibility for operating valves and allocating water among themselves in periods of scarcity and uncertainty. As a result it has been possible to establish a continuous process of balancing farmers' needs and actual water availability and to have the farmers themselves organise water delivery to the farms. Damage to valves and boxes is no longer a problem.

Adapted from Huppert [33]

3.5 The MASSCOTE approach

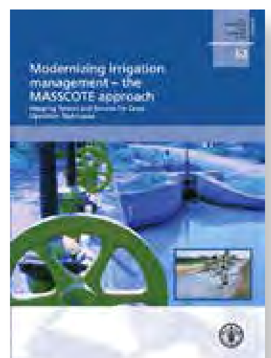
The MASSCOTE methodology developed by FAO [51] was specifically designed to assist technical experts, irrigation professionals and managers, engaged in the difficult task of modernising medium-to-large irrigation canal systems.

The entry point is canal operation, but the scope is modernisation with specific identified targets in terms of effectiveness in relation to money, water, and the environment. Although mainly based on FAO's work in Asia, it is generic in nature and is thus applicable to large irrigation schemes elsewhere.

MASSCOTE (Mapping System and Services for Canal Operation Techniques) seeks to stimulate a critical sense among engineers to diagnose and evaluate obstacles, constraints, and opportunities, and develop a consistent modernisation strategy. The methodology takes a step-by-step approach to convert complexity into simple and straightforward elements. These are explored in a recursive process leading progressively to a new management setup and improvements in canal operation and water delivery service (Box 14).

BOX 14 THE MASSCOTE APPROACH – STEP BY STEP

Steps 1 to 5 are about collecting baseline information



Step 1: Mapping performance using Rapid Appraisal Procedures (RAP)

This includes indicators of efficiency such as water use efficiency, crop yield, and budget. This sets the base line for monitoring the impacts of modernisation.

Step 2: Mapping capacity and sensitivity assesses the status of existing physical infrastructure

This includes conveyance, water level/discharge control, measurement, in relation to original design criteria and the current operational plan. Sensitivity refers to how the canal system actually behaves after the control structures have been set for a particular water distribution plan. Steady state discharges and water levels may be the established management target, but this rarely happens in practice. Significant and often unintended changes in canal flows and water levels occur, for example when farmers and operators open/close or adjust gates, that create perturbations[6] which in turn affect the distribution and allocation of water across the scheme. The question that needs an answer is: just how sensitive is the canal system to perturbations?

Step 3: Mapping perturbations

Both water level and discharge perturbations are the norm rather than the exception and are a permanent feature of canal systems. Understanding their origins, extent, and influence on water distribution is important if managers are to detect and manage them. Perturbations can be positive as well as negative, enabling managers to share surplus water, divert it to storage, or reduce delivery to some offtakes.

6 Perturbations are unintended changes that take place in discharges and water levels in canals which can create unintended variations in flow to farmers.

BOX 14 THE MASSCOTE APPROACH – STEP BY STEP Cont'd

Steps 1 to 5 are about collecting baseline information

Step 4: Mapping the water network

Managers must have an accurate knowledge of a system's water balance: where water is coming from, where it is going, and the volumes involved. This is essential for assessing irrigation scheme efficiency and for tackling environmental issues such as waterlogging and salinity build-up.

Step 5: Mapping the costs of Operation and Maintenance (O&M)

Assessing the costs of O&M are required to establish the real cost of providing a service to farmers and setting water charges. This includes the cost of water, staff, energy, offices, communication, and transport. Understanding the link between O&M costs and a level of service forms the basis for setting future levels of service, improving performance, and cost effectiveness.

Steps 6 to 11 are about mapping a vision for Service Oriented Management (SOM) and modernisation

Step 6: Mapping services

Mapping services involves assessing all the different services provided to different users and their related costs. This is needed to analyse modernisation options and to establish a preliminary vision for the irrigation scheme. Options include different service categories, the level of flexibility and the allocation and scheduling of water deliveries.

Step 7: Mapping management units

Large schemes are often divided into sub-units for O&M purposes including defined levels of service which may differ from one sub-unit to another. Within each subunit, a workable compromise is required among a mix of criteria including the physical/hydraulic system, the institutional/managerial resources in each sub-unit, and the costs involved.

Step 8: Mapping the demand for operation

This is about assessing the resources, opportunity, and demand for improved canal operation. This is largely determined by the anticipated level of service to farmers, but the analysis will need to include the constraints imposed by the operating characteristics of the canal system, including the extent of perturbations and the sensitivity of structures to changes in supply and demand.

Step 9: Integrating mapping options for operation improvements

This is about specifying how existing water resources and inputs will be allocated in a more cost-effective and responsive way, changing the operational strategy, and investing in improved techniques and infrastructure. Modernising a scheme should make full use of advanced concepts in irrigation and hydraulic engineering, agronomic science, economics, and social science to identify the simplest components and a workable solution. Some schemes may require very simple water-control devices, while others need more sophisticated controllers and communications equipment to achieve a desired level of performance.

Extensive farmer participation will form an important part of selecting the most appropriate option to pursue. There is a wide variety of designs, concepts, structures, methods of control, and schedules and it is essential that farmers at the downstream end of the system are fully satisfied with the proposed quality of service.

Steps 10 and 11: Integrating SOM options and developing a vision and plan for modernisation

Based on this mapping in steps 1-9, it should be possible to develop a vision for irrigation and a plan for implementation. Performance will only improve if designers and operators have a common and well-defined vision of operational procedures and maintenance requirements, if performance standards are precisely defined at each management level, and if there is an appropriate incentive structure.

Monitoring and evaluation will also be part of the process of modernisation to ensure that objectives are achieved and maintained.

3.6 Why modernisation uptake is slow

Although some countries are beginning to modernise their irrigation schemes, take up is slow for a variety of reasons [28] :

- Concept of client service is not widely understood or adopted for irrigation services
- Too costly and constraints imposed by donor agencies
- Adherence to old design standards and operational procedures
- Irrigation managers, engineers and others resist change
- Risk aversion and adherence to outdated standards
- Lack of operational experience and service motivation by planners and irrigation departments
- Lack of experience on how to modernise
- Outdated curricula in universities
- Lack of evidence of the superiority of modern systems
- Limited choice of suppliers of automated control equipment
- Policy reforms to establish water rights and volumetric charging for water
- Modern control difficult to implement on deteriorated canal systems
- Several levels in improving irrigation service

3.7 Impact of irrigation fees and tariffs

Economists see irrigation as an obvious case for introducing volumetric water pricing to reduce over consumption and increase efficiency but in reality, the issue is far from simple. A study commissioned by the FAO in 2004 [68] focused on the application of charging tools and the practical lessons that can be drawn from documented case study experience. The findings were designed to be of value to national policymakers, donor agencies, and researchers who formulate or advise on irrigation policy.

Firstly, there is confusion over terminology. A wide range of terms are used to describe payments made for irrigation services and the costs incurred in providing them. The cost of water must be distinguished from the price, though for a farmer they are in effect the same. Most common is to recover the costs of O&M –the direct expenses incurred in providing the irrigation service – though some argue that there should be an element or full cost recovery for the capital investment in irrigation schemes [68]. Much theoretical work has been done on the economics of irrigation water pricing, but there is still a considerable lack of understanding of what impacts can be realistically expected from water pricing policies in practice.

Water charges include all the payments that a beneficiary makes for irrigation services which may be fixed, volumetric, or crop based. A water charging system embraces all the practicalities required to set a level of cost recovery, and how the charge will be levied and collected.

Water price is often synonymous with charges but more commonly it means the payment per unit volume of water supplied to the farm.
In many countries that are unable to monitor or measure flows into farms, area-based charges are levied as a cost per hectare with the tacit assumption of a fixed amount of water delivered to the farm. This is essentially a land area tax rather than a water charge. But not everyone pays for water. In some cultures and political contexts, it is unacceptable to place a price on water. While in others the practicality of metering, invoicing, and collecting relatively small amount of money from tens of thousands of smallholder farmers can become prohibitively expensive and a nightmare to administer.

The FAO study concluded that the effect of volumetric water charging on water saving was minimal as current prices tended to be well below the levels that farmers considered water saving as a significant financial consideration. Indeed, studies indicated that the price would need to be at least 20% of net income to begin having a significant impact on water use. In many countries, the price paid may only be a few percentage points of net income.

Although the agricultural sector is seen as wasteful in its use of water, the available evidence suggests that pricing incentives do not always reduce losses. Firstly, individual farmers have no control over the losses in a large canal system which account for approximately half of the losses in a scheme. Secondly, where farmers take excess water, return flows to the river or aquifer will mean that the overall level of water availability in the basin is not affected, although the costs service delivery may increase. Some international agencies are now arguing that charges should be based on consumption rather than withdrawals. (see return flows section 2.6).

The available evidence suggests that pricing incentives do not always reduce water losses

If farmers are faced with increasing charges for water delivered, they may choose to improve on-farm efficiency which perversely, may increase consumption despite reducing demand for water deliveries. A case in point is Australia where several farmers increased water consumption following modernisation which reduced return flows [16].

FAO suggested that the introduction of a water charging policy is likely to be part of a larger package of measures designed to provide good irrigation services for which farmers are willing to pay. But FAO's study of water charges reviewed over 25 studies and found that physical sustainability was never achieved through water pricing alone. Broadly, two types of intervention can restrict and reduce water consumption – pricing and some form constraint on demand through rationing. No country relies on pricing alone to balance supply and demand [70].

Some international agencies are now arguing that charges should be based on consumption rather than withdrawals

3.8 More research needed

Numerous reports have already been published over the past 40 years or so, of case studies and the use of technologies, PIM, and IMT, but there is little up to date research on the benefits of either automated or simplified approaches to improving irrigation within the current broad understanding of modernising irrigation, particularly in developing countries.
As modernisation is introduced it will be important to rigorously monitor and assess the impacts to inform future planning and design.

Much more work is needed to establish the most appropriate ways forward, including experiences in applying the MASSCOTE approach.

The International Commission on Irrigation and Drainage (ICID) also recognises the need to bring together the experiences of modernisation from which others can benefit. In 2015, it established an international working group to focus on modernisation and revitalisation of irrigation schemes (WG-M&R) (see Box 15).

BOX 15 TERMS OF REFERENCE FOR ICID WORKING GROUP ON MODERNISING IRRIGATION

In 2015 a Working Group was established on modernisation and revitalisation of irrigation schemes (WG-M&R). The scope of work includes: investigating, analysing, and disseminating information on new developments and formulating recommendations with respect to: planning and preparation for modernisation and revitalisation of irrigation schemes; cost sharing, institutional and organisational frameworks; methods and techniques of lining conveyance and distribution canals; canal control systems with respect to automation, using internet, mobile communication and remote monitoring; improving communication, operational capacities, and flexibility for system operation and maintenance; and standardising codes of practice for irrigation systems.

Membership of the WG includes Iran, Iraq, and Turkey.

NOTE: The International Commission on Irrigation and Drainage (ICID) was established in 1950 as a scientific, technical and voluntary not-for-profit non-governmental international organization (NGO)
(www.icid.org)

4 Improving efficiency On-farms

Although saving water is a priority for governments and irrigation scheme managers, it is not usually a priority for irrigating farmers who are more concerned about saving money and maximising profits. Farmers are often more concerned about the costs of irrigation, the financial benefits of crop yield and quality, and resilience to water scarcity. An indirect benefit of addressing these concerns is often water savings and increased on-farm irrigation efficiency.

4.1 A pathway to irrigation efficiency

Although the classical methods of measuring irrigation efficiency on-farms are described in sections 2.2 and 2.3, the results in themselves are not so helpful in guiding farmers to improve their systems and performance. Knox et al [52], suggested that farmers should think about efficiency as a goal to be achieved by taking a holistic approach to improving all aspects of on-farm irrigation rather than relying on calculating a single number, which has limited practical value. This approach is known as the p*athway to farm irrigation efficiency* (Figure 17). Assessing efficiency in this way also makes the point that the pathway is not a one-off procedure or measurement, rather it is an on-going process of iteration over the life of the farm irrigation system.

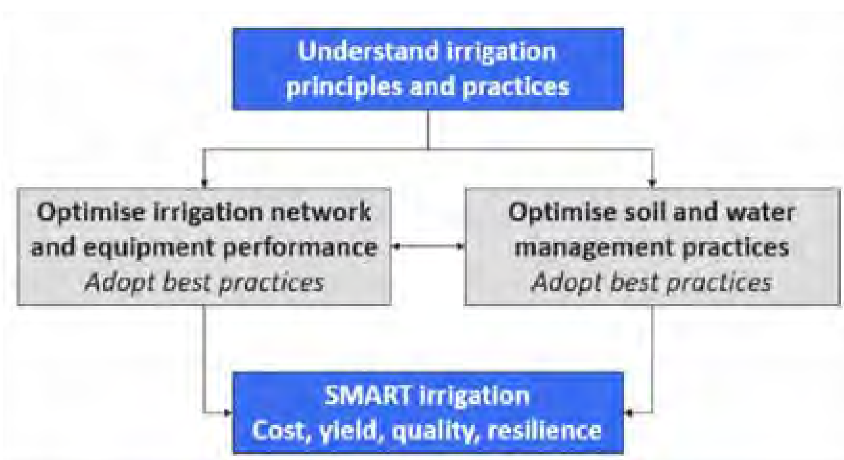


Figure 17 A pathway to farm irrigation efficiency

The pathway emerged from discussions with farmers who repeatedly highlighted the difficulties they experienced in evaluating their farm irrigation systems and establishing priorities for improvement. Knox et al [52] divided the pathway in three elements. The starting point was for farmers to fully understand the principles and practices of irrigation and how these applied to their systems. A questionnaire helped farmers to evaluate their knowledge and understanding of irrigation – their local water resource issues, pumping and application equipment, and irrigation management practices. The questionnaire also helped to highlight areas where knowledge gaps exist and where training should be focused (Figure 18).

Other steps along the pathway include systematically optimising the irrigation network and equipment performance, and the soil and water management practices. At each step farmers should be encouraged to adopt best irrigation practices.

Understanding irrigation principles and practices is an essential first step to improving irrigation performance. This includes understanding crop water requirements – how much water crops need; effective rainfall – how much water is already available and what is needed from irrigation; soil water retention – how much water can soils hold; how crops respond to irrigation – sensitive stages of crop growth; and the basic hydraulics of their irrigation system – canals, pipes, pumps, hydraulic control structures, and application methods – surface, sprinkler, and drip irrigation.

Optimising the performance of farm irrigation network and equipment, includes selecting the right pumps and power units (for pumped systems), reducing losses in canals/pipes and maintaining farm hydraulic structures for controlling and distributing water, and making sure that water is applied uniformly and adequately using appropriate methods of irrigation.

Optimising soil and water management practices ensures that water applications are managed (scheduled) according to crop water requirements without unnecessary waste, avoiding over-irrigation and/or surface run-off. This requires a thorough knowledge of water requirements of crops and hydraulic properties of soils plus knowledge of soil texture and structure, water-holding capacity of different soils, water readily available to the crop to avoid stressing the plants, and infiltration rate.

Together this should lead to an achievable level of efficiency that is practical and appropriate to local circumstances, not just in terms of water use but also cost, crop yield, quality, and resilience. This is often referred to as **SMART irrigation** – Sustainable, Managed, Accountable, Responsible, and Trusted irrigation (SMART) offers a broader understanding of irrigation efficiency. It implies that water is used effectively, and farmers can justify their water use and be held responsible for their actions.

Important aspects of efficiency for most farmers will include:

Cost: Do they buy their own irrigation equipment? How much are they charged for water? And is there a cost in applying water, such as energy for pumping water and hiring labour? Reducing costs, particularly for pumping will also reduce water use, as energy use is related directly to pressure and volume of water pumped.

Crop yield and quality: Farmers will want to maximise or optimise crop yield and produce quality rather than save water, as this will achieve the maximum farm income.

Resilience: farmers will want to reduce their exposure to environmental shocks such as drought and water scarcity. This too will indirectly drive increases in on-farm water irrigation efficiency.

For each question, circle the answer that best fits your situation. Then add up your score and refer to the box below to rate how well you are performing.

Q1. Do you have enough water in a season to meet your total crop irrigation demand?

1. Don't know
2. Inadequate volume
3. Adequate in an avergae year
4. Adequate in all years

Q2. Can you abstract enough water to meet your crop water requirement in a peak month?

1. Don't know
2. Inadequate volume
3. Adequate in an avergae year
4. Adequate in all years

Q3. Do you have a strategy for managing periods of limited water availability/restriction?

1. No plan
2. Limited consideration
3. Some consideration
4. Detailed strategy

Q4. How efficient is your on-farm storage and distribution system?

1. Don't know
2. OK
3. Good
4. Excellent

Q5. Does your irrigation system (e.g. gun boom) operate at its design pressure in each field?

1. Don't know
2. No
3. Yes, in most fields
4. Yes, in all fields

Q6. How uniformly does your system apply irrigation water within the field?

1. Don't know
2. Large variations
3. Some variation
4. Only minor variations

Q7. Do you know the rate of water applied (e.g m^3/hr) by your system?

1. Don't know
2. Based on manufacturer's information only
3. Measured some time ago
4. Measured routinely

Q7. What is the current physical condition of your pumping, distribution and application system?

1. Don't know
2. Major repairs required
3. Minor repairs required
4. No repairs required

Q9. Do you compare your crop returns yield against the volume of water applied?

1. Not measured
2. At farm level only
3. Sometimes at farm level
4. Routinely at farm level

Q10. Do you use a scientific tool (e.g. neutron probe, computer model etc) to scedule your irrigation applications?

1. No, visual inspection only
2. Scientific tool on some crops
3. Scientific tool on all crops

Q11. Do you modify your irrigation application in response to forecast weather conditions?

1. No
2. Sometimes
3. Usually
4. Always

Q12. What is the quality of the water you use for irrigation?

1. Don't know
2. Marginal
3. Satifactory
4. Good

Q13. Do you think you would save water by becoming more efficient?

1. Yes, definitely
2. Maybe
3. Don't know
4. No

Now add up your score to access your opportunity to improve irrigation efficiency:

Score:
0-17 Major
18-34 Moderate
35-51 Minor

If your score is low then revisit the questions to see where you can best make improvements to your irrigation system and management practices.

Figure 18 How well do you think you are irrigating? A 5-minute irrigation performance assessment

4.2 Optimising performance of network and equipment

4.2.1 Farm conveyance systems

Both canals and pipes are used to distribute water around the farm. Pressurised pipe distribution systems usually supply water to sprinkler and drip irrigation systems. Open canal distribution systems usually supply water for surface irrigation – for basin, borders, and furrows, though some farmers use low-pressure pipes.

Conveyance efficiency is measured in the same way as for larger irrigation schemes:

$$\textit{Conveyance efficiency} = \frac{\textit{Volume delivered to the fields } (m^3)}{\textit{Volume delivered to the farm } (m^3)}$$

Typical conveyance efficiencies range from 65% to 90% for canals and over 90% for pipes.

Canals are the most common means of conveying water on schemes. They are usually constructed in the natural soil and require regular maintenance. Some canals are lined with clay, concrete or geotextiles to reduce seepage, improve canal performance, and reduce maintenance, though installation costs and maintenance costs can be high.

Factors influencing conveyance efficiency include canal size, shape, and slope; water losses from seepage and evaporation; how well they are maintained to avoid erosion, siltation, weed infestation; and the degree of control and automation used to control water flow.

A practical method of detecting seepage losses is to walk along canals looking for wet areas, crack in embankments, animal burrows and poor maintenance.

Methods of measuring losses includes inflow-outflow method and the ponding method [39], [40], and [41].

The efficiency of farm canals benefits from regular maintenance, cleaning and repairs, dealing with canal breaches, and maintaining hydraulic control structures. They may also benefit from improved control and automation using automatic control equipment like those supplied by Rubicon and Waterman (Figure 19).

Pipes For pipe systems, factors that influence efficiency include: direct water losses from leaky pipes, joints, bursts, and drain down. Maintaining system pressure is vital for uniform and efficient irrigation when using sprinkler and drip irrigation. Pressure loss is the most common problem in piped irrigation systems and is as important as water losses to farmers. Low pressure results in poor application uniformity with consequent adverse impacts on crop yield and quality.

Maintaining pressure requires an understanding of pipe and pump hydraulics, as the most common causes of pressure loss include excessive pipe friction, wear and tear on pipes and pumps, inappropriate use of pumps, leakage,

Figure 19 a) automatic gate b) underground pipe outlet c) gated pipe used to control flows in farms

and using pipes that are too small in diameter for the flow resulting in high pressure losses. Effective control and automation can reduce both pressure and water losses.

4.2.2 Water application methods

The three main water application methods used on farms are surface, sprinkler, and drip irrigation. Globally, surface irrigation (basin, border, and furrow irrigation) is the most widely used method and accounts for over 90% of all irrigation methods. Sprinkler irrigation accounts for about 8% of global irrigation and drip irrigation for 2%.

Key performance indicators

There are three indicators commonly used to assess the performance of surface, sprinkler, and drip irrigation.

Adequacy – has enough water been applied to fill the soil in the crop root zone?

This is the ratio of the average depth of water added to the root zone (in mm) to the average depth required (mm):

$$\text{Adequacy} = \frac{\text{Average depth stored in root zone (mm)}}{\text{Required depth to be stored (mm)}}$$

Uniformity – has the water been evenly spread across the field?

Uniformity is usually measured using catch cans set out on a grid over the test area during a typical irrigation (Figure 26). The variability can be shown visually as contours or as three-dimensional plots using standard software programmes.

The Christiansen Coefficient of Uniformity, was developed in 1942 [53] primarily for sprinkler irrigation, and is a numerical assessment of the *average error*:

Christiansen's Coefficient of Uniformity (CU) is defined by:

Where: $CU = 100\left(1 - \frac{\sum x}{mn}\right)$

$\sum x$ is the sum of the absolute deviations from the mean (in mm or ml) of all the observations

m is the mean application depth (in mm or ml)

n is the number of observations (catch cans)

Although there are inadequacies in using this simple statistical formula (e.g. it does not differentiate between over and under irrigation), it is universally accepted and is enshrined in the International Standards Organisation (ISO) [54].

An alternative formula used for surface and drip irrigation uniformity is Distribution Uniformity (DU). This looks at how badly the worst quarter of the field is irrigated:

$$\text{Distribution uniformity (DU)} = \frac{\text{Average lower quarter depth of water applied (mm)}}{\text{Required depth of water applied (mm)}}$$

The average low quarter depth of water applied is the average of the lowest 25% of all the depth readings made.

Improving uniformity can increase crop yield without necessarily increasing the amount of water. Some farmers make irrigation uniformity a priority, though it is not a measure of efficiency. In contrast, some farmers tend to over-irrigate to compensate for the lack of uniformity. This may increase crop growth in previously under-irrigated areas but may cause water logging and poor growth in other parts of the field. This will impact on the water use efficiency.

Efficiency – has any water been wasted during an irrigation?

Efficiency should not be confused with uniformity as is often the case. It is quite different and is defined as the ratio of the volume of water usefully added to the root zone to the volume delivered to the edge of the field being irrigated:

$$\text{Efficiency} = \frac{\text{Volume stored in the root zone } (m^3)}{\text{Volume delivered to the edge of the field } (m^3)}$$

Surface irrigation

Basin irrigation is the most common method, followed by furrow irrigation and then border irrigation. There are obvious physical differences between basin, border and furrow irrigation. But less obvious is the differences in water management techniques used to apply water which is fundamental to ensuring adequate, uniform, and efficient irrigation [55].

Principles

Although the objective of surface irrigation is to apply water uniformly and adequately across a field, initially the irrigation is far from being uniform (Figure 20). As water flows across the field, the opportunity for infiltration is always greater nearer to the farm canal than at the far end of the field. To ensure a more uniform and adequate irrigation, the flow must continue until the water reaches the end of the field and has enough time to infiltrate and fill the root zone. Figure 21 demonstrates the classic problem of surface irrigation: How does a farmer ensure an adequate irrigation at the far end of the field, without losing excess water through deep percolation beyond the root zone across the rest of the field and at the same time avoiding water loses from runoff?

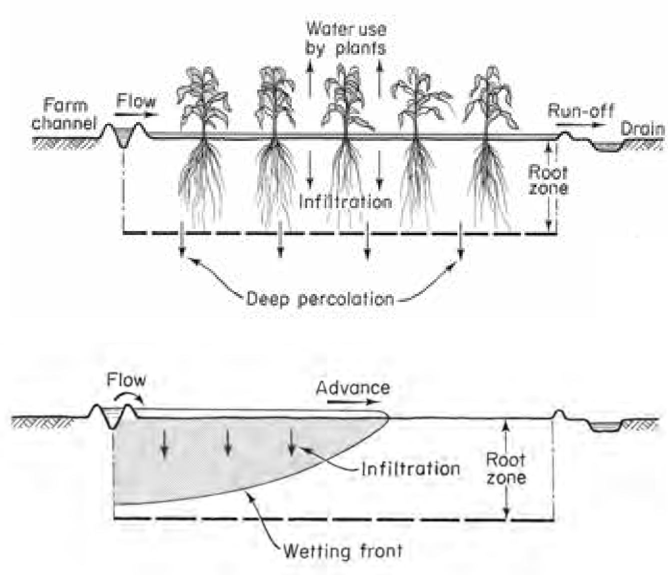


Figure 20 Water movement across the soils surface and in the soil profile during surface irrigation

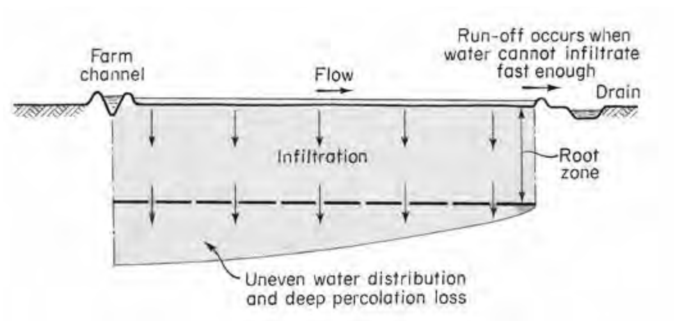


Figure 21 The surface irrigation problem

This is a relatively simple concept, but it is extraordinarily difficult to put into practice on the farm without wasting too much water, on different soils, land slopes, crops and rooting depths, and canal flow rates.

Understanding what is happening in the field is the first step to improving the water application efficiency. The techniques of basin, border, and furrow irrigation are three distinct ways in which farmers overcome the problems of deep percolation and excess runoff (Figure 22) [55].

Basin irrigation is the simplest and most widely used technique and is adaptable to most crops. The land is divided into level areas surrounded by earth bunds in which water can be ponded until it infiltrates into the soil. The basin size and shape depend on the land topography (slope and field size), soil type, flow rate in the farm canal, irrigation depth, and farming practice. The basin technique overcomes the deep percolation problem by using large flow rates that cover the basin quickly. Runoff cannot occur because the basin holds the water like a tank until it infiltrates. Water application efficiency ranges from 50% to 90%. Inefficiencies come from poor land preparation, different soil types in a basin, and fixed irrigation schedules [55].

Border irrigation looks physically like basin irrigation, but the irrigation technique is quite different. Borders tend to be long and are gently

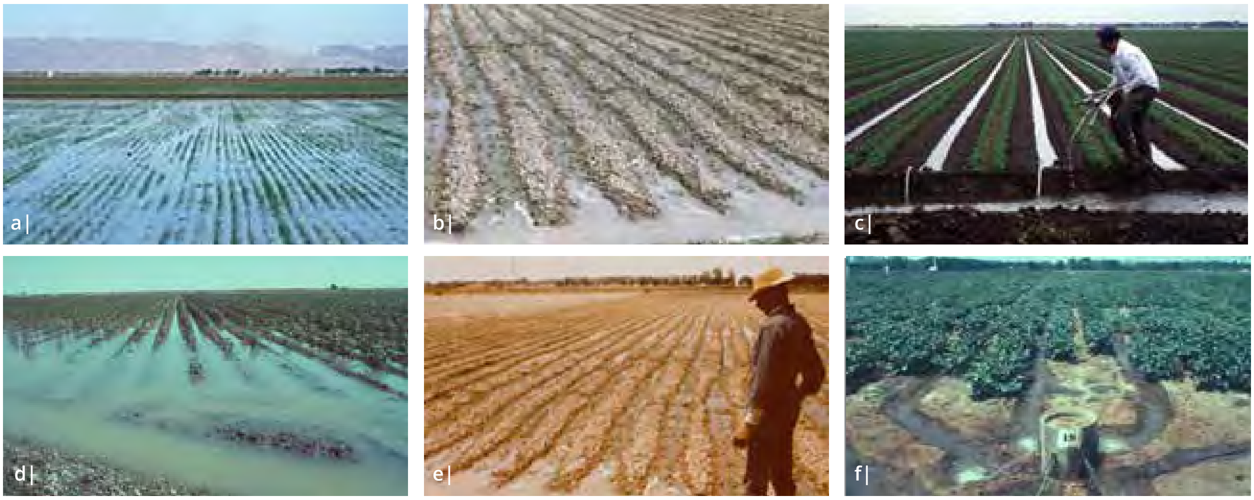


Figure 22 Typical a) basin, b) border, c) furrow irrigation. d) a lack of furrow tail drainage, e) good tail drainage/reuse, f) piped furrow irrigation

sloping rather than level. Small flow rates are used, and farmers control a sheet of water as it flows down the slope infiltration as it advances. At some point the farmer cuts the inflow and water recedes from the top of the field, gradually completing the irrigation. Borders are suitable for most field crops, and they have a greater potential efficiency than basin irrigation. However, they are more difficult to manage. Inefficiencies come from poor land preparation, different soil types along the border, fixed irrigation schedules, and using the wrong low rate [55].

Furrow irrigation is used to irrigate row crops that do not like to stand in ponded water, like cotton, sugar cane, and potatoes. Water flows down furrows between ridges in which the crops grow and infiltrates both vertically and laterally into the ridges. Large flows are used to ensure water advances rapidly down the field to avoid deep percolation, but once the flow reaches the end of the furrow, runoff is inevitable.

Common faults	Subtract from 90%
No return flow system	20-40%
Poor land grading	10-20%
Different soil types along a furrow	5-10%
Water advance time to long	10-20%
Stopping inflow too soon to avoid runoff	10-20%

To avoid this, farmers either cut-back on the inflow until the irrigation is complete or allow water to runoff the end of the field into drainage channels and then re-use it on fields further down the system (Figure 22d,e). Water application efficiency ranges from 50% to 90%. Inefficiencies come from poor land preparation, different soil types along the furrow, a lack of a return flow system, fixed irrigation schedules, and using the wrong flow rate [55]. Well managed furrows can have application efficiencies as high as 90%. The following is a guide to the impacts of poor practice on efficiency. On many schemes, farmers have little or no means of correcting these common problems. It is thus little wonder that surface irrigation is considered to be inefficient [55].

General comment: Surface irrigation is widely practised by farmers and is inherently an efficient method of applying water, but it is not well understood, and this is one of the reasons why it has a reputation for inefficiency. But the main constraint on many irrigation schemes is the lack of control that farmers have over the flow rate into their farms and without this control it is very difficult to apply water efficiently. Indeed, many farmers have little idea of what the term *flow rate* or *discharge* means. This is the language of engineers rather than farmers.

Evaluating and improving performance

Although mathematical models and design methods have been developed for sizing basins, borders, and furrows, mostly in the US, they are not very practical for use on small farms and schemes where farmers have little control over their water supply. Most basins and borders are sized based on local experience and perceived good practice and are influenced by other factors, such as topography and soil types, cultivation and mechanisation requirements, and field access. In view of this, methods of evaluating surface irrigation performance were developed in the US in the 1950s and 1960s, which were of more practical value on the farm.

These involve observing and measuring what happens during a typical irrigation, including measuring canal flow rates, soil water, infiltration, water advance and recession across the field and runoff, as a means of assessing the water application efficiency [55].

The evaluation is a diagnostic tool to enable farmers who have an understanding of the principles of surface irrigation, to take practical steps to solve irrigation problems. These may include changes in flow rate and the size or shape of the basin or furrow to improve performance [56], [57].

BOX 16 USEFUL VIDEOS ON SURFACE IRRIGATION

Intro to surface irrigation
https://www.youtube.com/watch?v=Ya5ikTKZgIo

Basin irrigation
https://www.youtube.com/watch?v=DcFl8GuKF84

Border irrigation
https://youtu.be/d1kcYb44VsU

Furrow irrigation
https://www.youtube.com/watch?v=CEQjuc0gpmM
https://www.youtube.com/watch?v=MpxGnrN1Mv4

Priming siphons
https://www.youtube.com/watch?v=cMVFCeoysXc

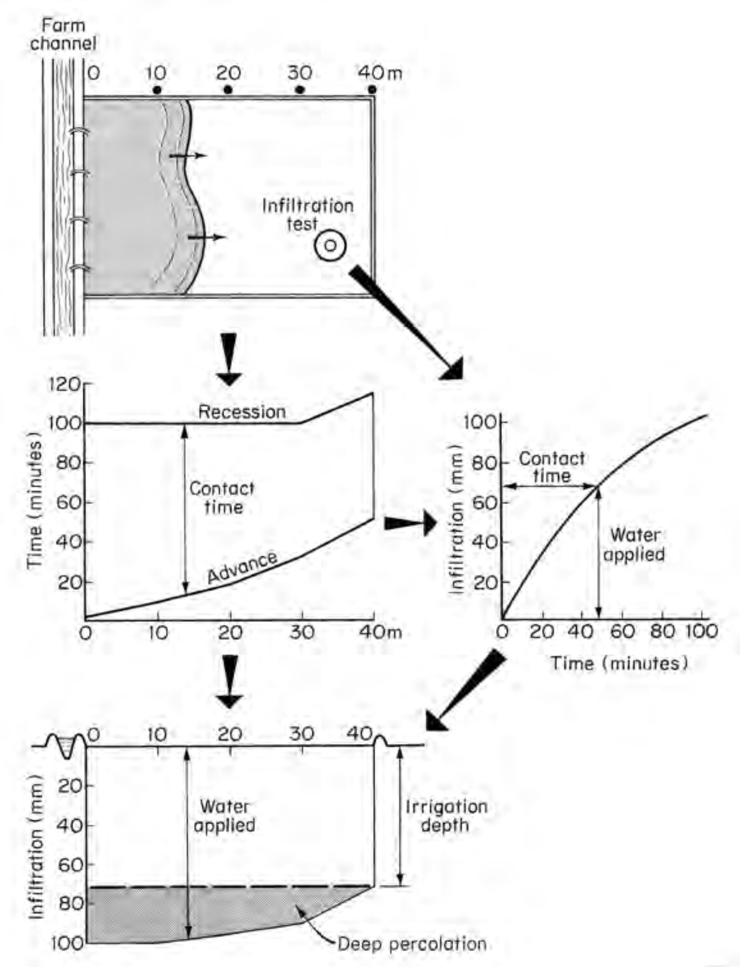


Figure 23 Typical results from a basin irrigation evaluation [55]

Sprinkler irrigation

There are many different sprinkler systems to match different crops, soils, climate, site conditions, and different water, labour, and capital constraints. Basic components include a pump to pressurise the system, pipes to distribute water and sprinklers to spay water over the land under pressure. The most basic system (Figure 24a) was developed in the 1930s along the US east coast where surface irrigation was too permanent and costly to install for supplementary irrigation. At the same time, aluminium was being used for light-weight pipework, centrifugal pumps were being developed, and farmers needed a system they could move from field to field and irrigate as and when it was needed.

The basic sprinkler system was born and is still the most used sprinkler system in the world. Its main drawback was a high labour requirement and designers have since developed equipment to replace labour with automation, such as rainguns and centre pivot machines (Figure 24c,e). The introduction of low-pressure machines (Figure 24e) was a response to the energy crisis in the 1970s. This reduced water application costs but increased water application rates and focused attention on putting water where the crop needed it rather than just spraying it into the air and hoping it came down in the right place (Figure 24f).

Figure 24 Typical sprinkler irrigation systems **a)** small rotary sprinkler **b)** close up of sprinkler head **c)** mobile raingun **d)** wetting pattern from a rotary sprinkler **e)** low pressure centre pivot machine **f)** putting water where it is needed

Sprinkler operating pressure (2-4 bar). Farmers say that *pressure is king*. Sprinklers perform best when operating at the recommended design pressure, the water jet should be straight with water droplets falling along its length (like a curtain). When pressure is too low the jet appears bowed, droplets are large and can damage the crop, and uniformity is poor producing a doughnut ring effect in both the wetting patterns and the crop (Figure 26e).

Maintaining pressure is essential but there is always a tendency for pressure to fall. The most common reasons include excess friction in pipes; wear and tear on pumps, pipes, and sprinkler nozzles; inappropriate pumps and motors; over-stretching the system by trying to run too many sprinklers at the same time (Figure 25); using pipes that are too small in diameter; and leakage.

Spacing: Spacing sprinklers too far apart will result in poor uniformity.

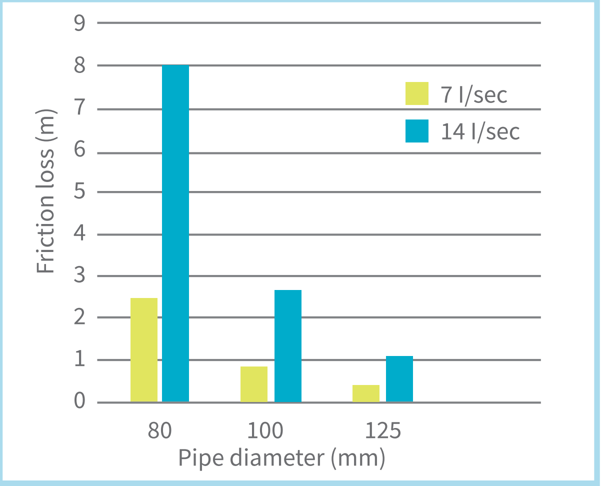


Figure 25 Over stretching the pipe network: doubling the discharge increases the friction (pressure) loss in the system

Wind: Wind speeds above 1.3 km/hr can seriously distort sprinkler wetting patterns and lead to uneven water application. The impact can be reduced by closer sprinkler spacing and arranging laterals across the direction of the prevailing wind.

Evaluating and improving performance

Sprinkler performance can be evaluated based on field measurements of adequacy, uniformity, and efficiency. Uniformity is measured using catch cans set out on a grid over the test area during a typical irrigation (Figure 26a). The variability can be shown by drawing contours or as three-dimensional plots using standard software programmes. Christiansen's coefficient is the universally accepted method of calculating uniformity from the data collected from the catch cans.

Control and automation can reduce water losses and increase efficiency, including automatic system shutdown when there is a pipe burst, pressure regulation across the system, the use of variable speed pumps, and matching pumps and drivers (electric and diesel) with irrigation requirements.

The factors that affect sprinkler performance include operating pressure, sprinkler spacing, and wind speed and direction.

Figure 26 Sprinkler evaluation **a)** measuring uniformity **b)** pressure **c)** discharge from a sprinkler **d)** flow meter on mainline **e)** doughnut ring effect in crop when pressure is too low

Drip irrigation

Drip irrigation (also called trickle irrigation) is increasingly being adopted for use on many crops though globally it only accounts for around 1% of the irrigated area. In the Middle East it accounts for 5%. Applying small amounts of water slowly and frequently through drippers (emitters) spaced along polyethylene tape or tubing offers potential for improved yields, more accurate, and more efficient irrigation. It is adaptable to a wide range of agroclimates, soils, and crops. It is ideal in situations where water is scarce, where soil conditions and water quality are poor, and labour is scarce or expensive.

There is a lot of interest in this method because of claims made about potential water savings and increases in crop yields. But how do these claims for drip irrigation stand up in practice?

Figure 27 Drip irrigation **a**) on field scale crops **b)** drip on protected fruit crop **c)** pressure control equipment

Does drip save water? This only comes from reducing water losses normally associated with surface and sprinkler irrigation. However, the agronomic demand for water remains the same irrespective of the irrigation method. The water required to grow a crop is largely determined by the crop and the evaporating conditions, not by the irrigation method.

Does drip increase Water Productivity?
Be clear about why there may be an increase. Is drip being compared to surface or sprinkler irrigation? Are you accounting for water losses in the calculation? Are you allowing for improved fertiliser use as most drip systems include fertigation? There is potential for a high degree of control over both water and nutrient applications, which can lead to high quality and timely production. Bear in mind that additional management skills go *hand-in-hand* with this system.

Does drip use less energy? Energy used is a function of pressure and discharge, so reducing either will reduce energy consumption. Drip systems operate at much lower pressures than sprinklers and so energy demand will be less.

Does drip cost more? In-field capital costs are much higher than for sprinklers and surface irrigation, but recurrent costs are often much lower, particularly when energy prices increase. So, it is important to assess both capital and recurrent costs to get a true picture of irrigation costs.

Most farmers who have switched to drip, grow high quality premium grade produce to meet urban market requirements rather than to save water. Farmers say that some water saving is possible, but it is not significant. Drip wetting patterns can be difficult to establish in newly formed ridges and beds because the soil may not be compact enough. Some farmers use overhead irrigation initially to wet up the soil profile. Drip irrigation is perceived as an environmentally friendly irrigation method. But disposing of large quantities of plastic tubing can create different environmental problems.

Evaluating and improving performance

Drip irrigation performance can be evaluated based on field measurements of *adequacy, efficiency,* and *uniformity.*

Uniformity for drip is usually determined by collecting and measuring the flow rate from a sample of individual emitters using a line of catch cans laid out along the drip lateral. Uniformity is measured as Distribution Uniformity (DU). This assesses how badly the worst quarter of the field is irrigated:

$$\text{Distribution uniformity (DU)} = \frac{\text{Average lower quarter flow rate from drippers (l/h)}}{\text{Average flow rate from drippers (l/h)}}$$

The average lower quarter flow rate is the average of the lowest 25% of all drippers measured.

The highest possible value for DU is 100% although even new systems will have a DU less than this due to the variability in manufacturing drippers. A well designed and maintained drip system would have a DU of 85-90%.

Figure 28 Measuring flow rate from emitters along a drip line a) surface line on grape vines b) buried line on potatoes

Like sprinkler irrigation, maintaining the design operating pressure is essential to obtain the best performance and many of the pressure issues affecting sprinkler irrigation also affect drip irrigation. Poor pressure control is the most common cause of poor uniformity. Figure 29 shows the results of a uniformity evaluation on a 2-year old drip line installed on sugar cane. An inspection of the drippers showed that several were partially blocked with debris and chemical precipitates and required cleaning or replacing. Dripper blockage is a common problem and filtration is an essential part of any drip irrigation system.

Control and automation can reduce water losses and increase efficiency, including automatic system shutdown when there is a pipe burst, pressure regulation across the system, the use of variable speed pumps, and matching pumps and drivers (electric and diesel) with irrigation requirements.

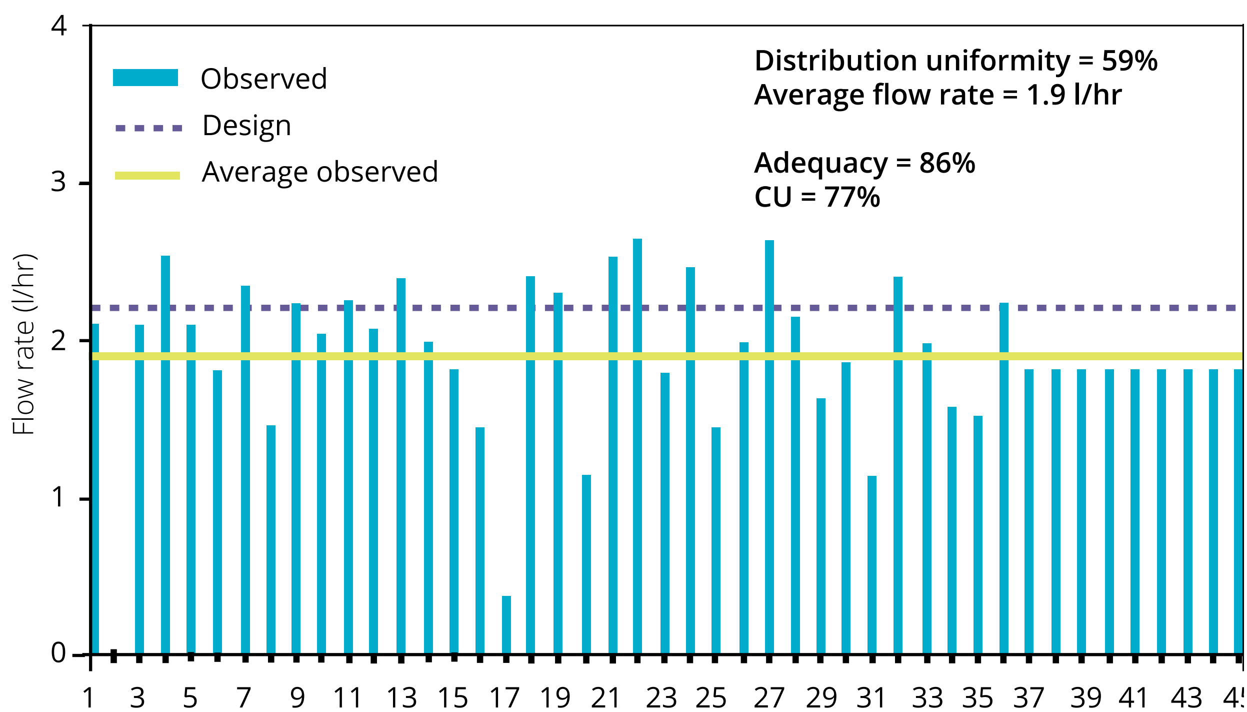


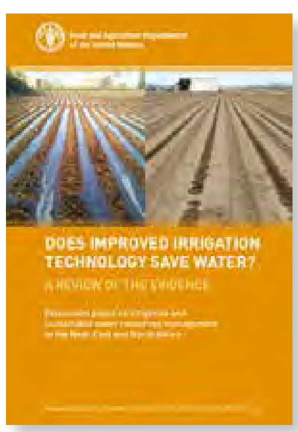
Figure 29 Emitter flow rates measured along a drip line which was two years old.

4.2.3 Switching to more 'efficient' technologies

Attributing efficiencies to irrigation technologies is a common practice and drip irrigation particularly is often cited as having high efficiency. It is one of the reasons why decision-makers often encourage the use of such technologies to save water, as concerns about water scarcity increase. There is evidence to suggest that both sprinkler and drip irrigation systems have the potential to use less water, but this does not always happen in practice. The savings can only come from reducing the losses observed using other methods; by reducing deep percolation and run-off. It is not possible to reduce the amount of water needed to grow a crop, which is often the assumption implicit in a comment such as: *drip irrigation is much more efficient*. Crop agronomy studies tell us that there is a direct correlation between water and yield. Up to a point, the more water applied the greater the yield [58].

Thus, a crop needs to have the same amount of water applied irrespective of whether it is surface, sprinkler, or drip irrigated. The saving comes in the potential to reduce the losses, not in the water the crop needs to grow (see Box 17). Switching to high efficiency irrigation methods may not always result in significant overall savings of water if the previous losses were recaptured by others (see return flows section 2.6).

Recent investigations by FAO [16] have also shown that switching to high efficiency solutions, such as sprinkler and drip irrigation, and sophisticated scheduling, can increase irrigation efficiency but not always as intended (Box 18). They can save water, but research has shown that most farmers were interested in increasing their farm income and so they used the saved water to increase their irrigated area or intensified cropping, rather than release it for others to use downstream.



BOX 17 DRIP IRRIGATION CAN EASILY BE MISUNDERSTOOD

At a recent FAO (2019) webinar on water accounting, 12 out of 29 irrigation professionals agreed (incorrectly) that using drip irrigation would reduce crop water use over other irrigation methods. This misunderstanding can lead to inappropriate investment in what appears to be a water-saving system. The reality is that crops consume the same amount of water to produce yield irrespective of how the water is applied to the crop. Drip systems do have the potential to reduce water losses from seepage and runoff that can occur with other methods. But drip irrigation cannot reduce the water used by the crop without impacting yield. Indeed, some drip systems use more water because soil water is maintained close to field capacity and farmers tend to over-irrigate to make sure they are applying enough water [4]. The efficiency is more about how the system is managed rather than the technology *per se.*

Source: author attending FAO webinar in 2019

Switching to high efficiency irrigation methods may not always result in significant overall savings of water

However, in most circumstances, surface irrigation is the most difficult to manage, particularly in the hands of farmers who may not have the knowledge and skills, nor the control over the key parameters like flow rate and scheduling. One of the big advantages of both sprinkler and drip irrigation is that many of the management skills needed are built into the design of the system, like pressure, flow rate, and application rate. The farmer is then left with the decision: when to irrigate and how much to apply [59].

The right technologies are not just determined by function. They can greatly reduce the drudgery of lifting water and applying it to crops in an adequate and timely manner. However, they must be simple to use, reliable, easy to maintain, and be sensitive to gender specific needs, not least because two-thirds of people living in water-stressed areas are women. Context plays a crucial role: where it is being used, by whom, and how it is introduced. The latter is poorly understood and is one of the main reasons for so many past technology failures.

BOX 18 EFFICIENCY IMPROVEMENTS DID NOT ALWAYS SAVE WATER IN NEBRASKA

A survey of irrigating farms in Nebraska, USA, published in 2019, found that most farmers who converted to more efficient irrigation systems did not change the amount of water they applied. One exception was in orchards and vineyards, where switching to drip irrigation was associated with less water applied per acre. The survey found that in some cases, the use of efficient technologies increased water use, as it provided farmers with additional flexibility to expand irrigated land or to switch to more water-intensive crops and reduced return flows to aquifers.

Source: [17]

4.3 Optimising soil and water management practices

Optimising soil and water management practices ensures that water applications are managed (scheduled) according to crop water requirements without unnecessary waste, avoiding over-irrigation and/or surface run-off.

This requires a thorough knowledge of water requirements of crops and hydraulic properties of soils [60]. For soils, this includes information on soil texture, water holding capacity of different soils, water readily available to the crop to avoid stressing the plants, and infiltration rate.

Infiltration rate is the rate that water can enter the soil. For sandy soils, pores are large, and water can move downwards easily. Clay soils have much smaller pores and so water moves downwards very slowly. For surface irrigation, the infiltration rate determines how much water gets into the soil for a given application time. For sprinkler irrigation, if application rates exceed infiltration rate, water may run off and be wasted.

4.3.1 Irrigation scheduling

Scheduling irrigation is about putting the right amount of water into soil at the right place at the right time [61], [62]. Day-to-day irrigation management requires farmers to make scheduling decisions: *when to apply water and how much to apply?* The objective is to maintain an optimum soil water environment for crop growth. This may not necessarily mean for maximum yield, the objective may be the most economic yield, best crop quality, or the most efficient use of water. Water applied in the wrong place at the wrong time has no benefits (Table 2). Under-watering can cause water stress, reduce yield and quality; while over-watering can cause water-logging which reduces yield, quality, and trafficability, and can increase energy costs, labour and water use. Thus, decisions made about water scheduling will impact farm irrigation efficiency and water saving.

Figure 30 Tools for irrigation scheduling a) automatic weather station b) rain guage

Application efficiency will affect the amount of water to be applied. Normally, a farmer should apply the gross application, which includes the crop water requirement plus a percentage to allow for inefficiencies. If a farmer decides to apply water to meet only crop water requirements, then inevitably some areas will be inadequately irrigated whilst others will be over-irrigated and drainage losses will occur. The farmer could choose to apply less and reduce drainage, which results in high efficiency but poor adequacy. He could choose to apply more, which results in good adequacy but low efficiency. Or a compromise between the two. The optimum ratio of gross application to the required application will ultimately depend on the cost of applying water and the yield response from the water application.

Scheduling tools are available including the use of crop indicators, measurement of soil water, estimating soil water deficit, and calculating a water balance. However, many irrigators still rely on subjective methods to determine when is the right time to irrigate, usually by walking and observing the crop and handling the soil to see how dry it feels. This is not an accurate way of assessing soil water and pressures to save water

Table 2 The impacts of poor scheduling

Irrigate too much or too early, then soil becomes too wet	Irrigate too late or too little, then soil becomes too dry
waste of energy (pumping)	yields may be reduced due to water stress
waste of money	inefficient use of fertiliser
risk of waterlogging (yield / trafficability problems)	
leaching of fertilisers and nutrients	
waste of water (a larger area could be irrigated)	

are now forcing some farmers to move towards more scientific objective scheduling techniques. Tools for determining irrigation schedules should be complemented by walking the system and observing what is happening. Crops are a good indicator of irrigation performance and poor irrigation practice will soon be apparent as poor crop growth.

However, Burt points out [63] : *There is absolutely no point in discussing modern irrigation scheduling, soil moisture measurement devices, and water measurement with farmers who receive water on a rotation basis or if the farmer does not have the ability to modify the duration of the water delivery. The reason is simple; the farmer has no control over the topics (scheduling tools) being discussed. In other words, unless irrigation water is available 'on-demand' or true arranged schedules, these principles do not apply.*

Merriam [38] added that: *sustainability of irrigation and drainage enterprises depends on the farmers' ability to control their own destiny. In arid environments, farmers can only do this if they have reasonable control over their water supply. Without a reliable water supply, farmers are at the whim of the chaos that is inherent in large-scale water-delivery systems. This explains why farmers are willing to invest in tube wells that are under their control.*

4.3.2 Adopting best practices

Adopting *best practices* has proved over time to lead to more efficient irrigation. Farmers need to consistently rank irrigation highly within farm management activities; ensure they have a detailed knowledge of their farm soils from an irrigation perspective; monitor each irrigation event, use objective monitoring tools to schedule irrigation, and remain open to new irrigation ideas.

Benchmarking is another aspect of best practice. There are farmers who innovate and strive for improvement to gain competitive advantage in the market for produce, while others lack enough technical knowledge and skills and time to adapt. Here the role of benchmarking [64, together with WUAs [65], provide opportunities for farmers to work collectively in sharing ideas and transferring knowledge and to demonstrate efficient use by comparing their performance with others.

4.3.3 Improving water productivity

Globally, water productivity (WP) (see section 2.3) in terms of yield has increased by at least 100% between 1961 and 2001 without increasing water consumption. Such increases have enabled the world to accommodate a doubling of the population with increasing food intake. World wheat harvested areas and average yields is just one example of the progress made (Figure 31). FAO argues that a 1% increase in WP in food production generates a potential water use of 24 litres/day/capita. To produce the equivalent gain in domestic water supply would require a gain of 10% in agricultural WP, which would take many years to realise. Thus, investing in reducing agricultural water use is the best means of freeing up water for other purposes [66].

Unlike efficiency measures, WP for the same crops can vary when grown in different climatic environments and crop management conditions. The practicality of measuring WP over large areas is a problem and so too is assessing crop value expressed in monetary terms, particularly for vegetable and fruit crops for which the price can vary from day to day.

Although WP is usually expressed in terms of water consumed by the crop through transpiration, should water losses also be included as consumption, at least in terms of water use on the farm? If so, then water efficiency improvements will be reflected in an increase in WP. If a farmer was paying for water on a volumetric basis as it comes into the farm, then it would be of value to include losses as they represent a cost of production.

Expressing water productivity in terms of farm income per cubic metre can also help farmers to make decisions about which crops to grow. In Jordan for example, WP on farms varied from US$0.3/m^3 for potatoes to US$0.03/m^3 for wheat [66].

The key principles for improving WP are (i) increase the marketable yield or value of the crop for each unit of water transpired; (ii) reduce all water losses (drainage, seepage, and percolation), including non-essential evaporative demand; and (iii) increase the effective use of rainfall, stored soil water, and water of marginal quality.

The second and third principles have impacts beyond the farm and are components of a much wider IWRM basin approach for water productivity improvement.

Most WP gains come from reducing water losses on farms and in some cases switching to more appropriate technologies. But irrigation practices, such as deficit irrigation, can also increase WP.

There are times during crop growth that farmers can reduce the amount of water they apply and extend the interval between applications without unduly affecting the crop yield and quality. The effect is to increase WP. This technique relies on a good understanding of the relationship between water and crop yield and the more sensitive stages of crop growth when a lack of water can seriously affect yield. The relationship that links evapotranspiration to yield has served farmers well for the past 40 years or so. But agronomists have now developed a deeper understanding of how crops grow and respond to water, and the lack of it, and so more sophisticated techniques, such as FAO's AquaCrop, are now available that enable farmers to provide the right amount of water at the right time for optimum yield and WP (see Box 19).

As with most farm irrigation practices, it is essential for farmers to have reliable access to water and full control of flow rates to take advantage of such techniques. WP can be improved by adopting agronomic practices that reduce water losses on the farm. These include improving soil water holding capacity, using mulches to reduce evaporation from moist soils, and puddles between crop rows. Although not directly an irrigation matter, improved nutrient management and integrated weed and pest management can also increase WP.

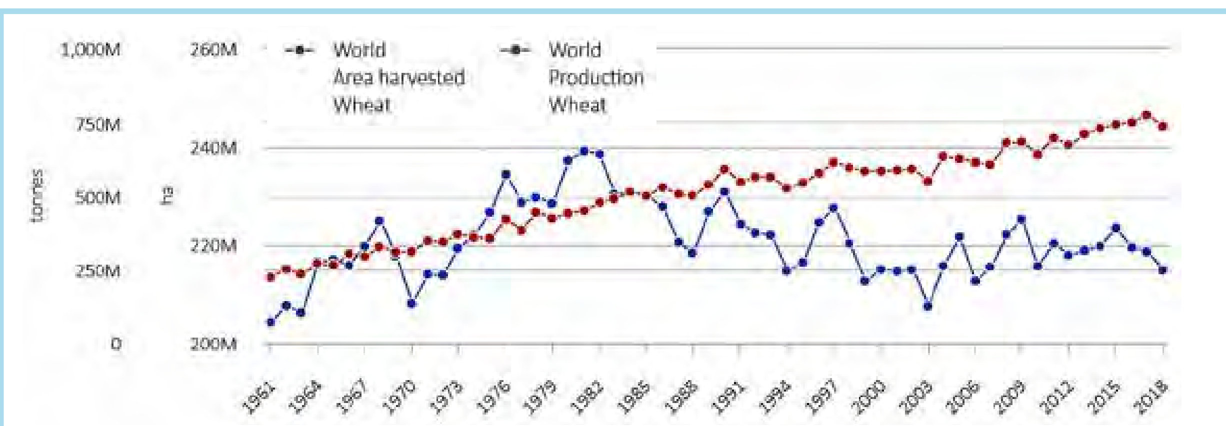
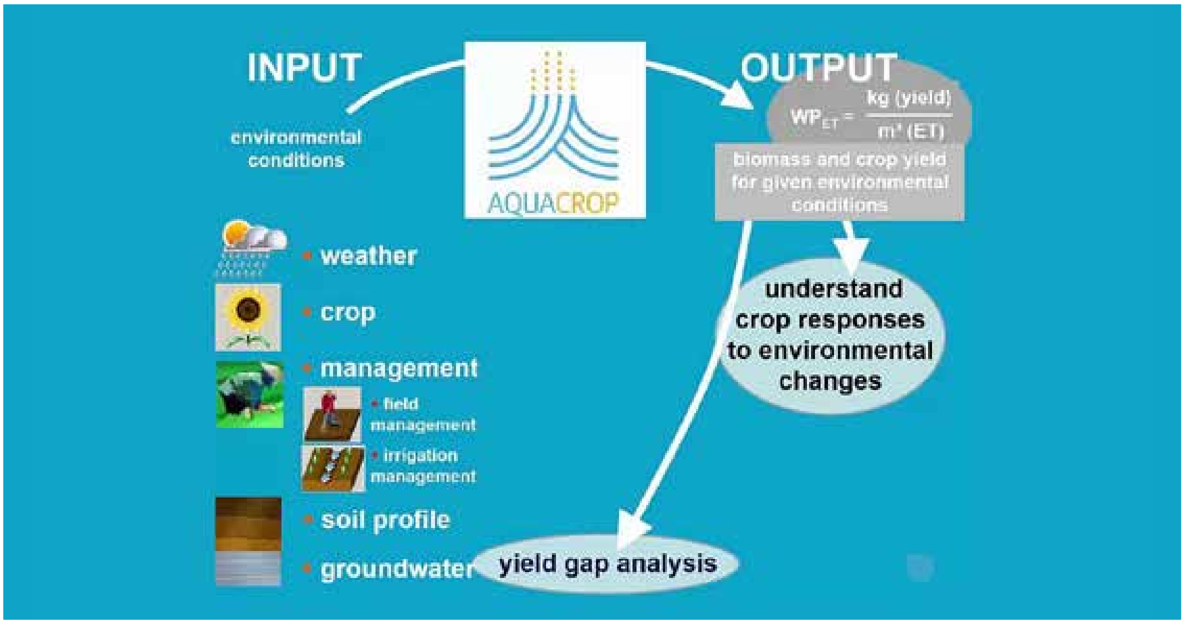


Figure 31 World wheat harvested area and average yield from 1961-2018[9]

BOX 19 AQUACROP – LINKING SOILS, CROPS, AND WATER TO IMPROVE WATER PRODUCTIVITY

The relationship between biomass production and water consumed through transpiration is well known and was adopted by FAO in 1979 when the organisation first published information on the yield response of a wide range of irrigated crops [67]. Water stress and reduced transpiration results in reduced biomass production that in turn normally reduces yields. The approach that linked a reduction in evapotranspiration to a proportional reduction in yield, has served irrigators well for some 40 years but it suffers from drawbacks as a result of aggregating variables, i.e. it took a black box approach and referred only to the final yield evapotranspiration rather than transpiration. As a result, the yield response factor has proved, in several cases, to be significantly variable.

In 2012, FAO published AquaCrop. This supersedes the 1979 version and explored in more detail what was in the black box; the components and their impact on growth and yield. The product was a crop growth model that simulates yield response to water of herbaceous crops and is particularly suited to address conditions where water is a key limiting factor in crop production. The model deals with complex biophysical processes linking water and crop growth but is designed to be simple to use, yet accurate, and robust. It relies on a relatively small number of explicit parameters and mostly intuitive input-variables requiring simple methods for their determination. The calculation procedures are grounded in basic and often complex biophysical processes to guarantee an accurate simulation of how a crop responds within the plant-soil system. As a planning tool, AquaCrop can provide a baseline for productivity analysis, taking account of major crops, irrigation regimes, and agricultural practices in the cropping season.
Source: [58]



[9] FAO. 2011. FAOSTAT online database, available at link http://faostat.fao.org/

5 Developing Capacity

Countries in the Middle East have a long tradition of irrigation with experienced professionals and organisations that have a legacy of knowledge and experience of irrigated agriculture. Despite the conflicts in parts of the region over the past two decades, it is anticipated that much of this corporate memory is still strong.

However, the rapidly changing nature of water scarcity in recent decades and the need to modernise irrigation farming inevitably lead to question whether established capacity is fit for purpose. For some countries, the focus may be concerned with how to modernise existing systems, institutional structures, and to train people at all levels from farmers to decision-makers on the best ways to deliver services to farmers, while for others, there may be urgent need to re-build capacity curtailed by years of turmoil.

Countries across the region will have different priorities and capacity needs and for this reason the following section is generic in nature and reviews the process of capacity development both immediate and the long-term.

Chapters 1 to 4 have described the process of modernisation and the options available for improving irrigation water use efficiency that can form the basis of future education and training programmes. But changing technologies alone cannot bring about the changes needed. This section is about developing the capacity to put technologies into practice – the people and their technical and managerial skills, the organisations, and the institutional structures that enable people to work effectively.

5.1 Some background

In 2004, FAO [71] highlighted a consensus among policy-makers in the developing world that a lack of capacity was constraining development in irrigated agriculture. This was not a new issue; but training people was usually considered more as a *bolt-on* to the more important mainstream activity of infrastructure development. In 2018, the UN review of SDG 6: the Water Goal [3] [5], suggested that little had changed and reported a worrying lack of capacity across the water sector in developing countries and agriculture in particular. The review suggested that this was now becoming a serious constraint to water-related development. Governments and donor agencies have not helped as they have often seemed more willing to invest in *hard* infrastructure rather than *soft* education and capacity development, which is much less visible and also more difficult to measure success.

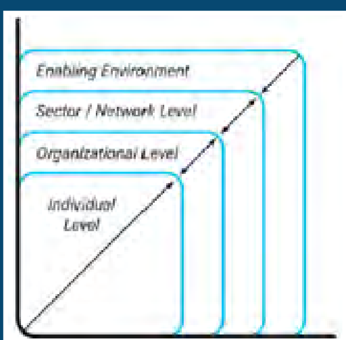
It was common to hear stories about young professionals being sent abroad to gain expertise, only to find they decided not to return home, or if they did, they found more lucrative work in sectors other than irrigation. This tended to discourage agencies from funding overseas irrigation training though it was not usually replaced with local provision.

Thus, a lack of capacity development has been a worrying trend for decades, yet paradoxically we all know that people with knowledge and skills and effective organisations are essential to make technologies work for us.

FAO [71] reported some confusion over the meaning of capacity development. It seemed to be wrapped up in a host of concepts such as participation, empowerment, technical assistance, and organisational development. But in 2002, UNDP [72] defined capacity development as: including both attainment of skills and the capabilities to use them but the key questions posed were: which skills and whose capabilities?

UNDP concluded that there were no easy answers because each development context was unique and continually changing. Solutions were specific to the circumstances of countries and communities, and this made capacity development such an inexact science. Developing capacity is people centred but goes well beyond education and training individuals to include good organisations and strong institutional structures within which individuals can work effectively, and an enabling environment that encourages successful irrigation development (see Box 20).

BOX 20 THE FOUR LEVELS OF CAPACITY DEVELOPMENT



I Individual level:

This is the most concrete and familiar part of capacity development and includes educating and training various stakeholders, farmers, and local professionals.

II Organisational level:

This refers to the wide range of organisations involved in irrigation such as water user organisations, research groups, government extension agencies, private companies that share common objectives such as improved livelihoods at a farming level or improved water management or increased agricultural productivity at a national level. The capacity of an organisation is embedded in the ability of its individuals to work together within established rules and values and to interact with other organisations.

III Sector level:

Highlights that irrigation is part of the larger picture of IWRM and reflects the increasing awareness of the need for policies that integrate all aspects of water development and not just irrigation.

IV Enabling environment:

This represents the broad national and international context within which irrigated agriculture can develop. It has immense influence over what happens at the lower levels. It is concerned with policy at the highest levels in government, the socio-economic conditions that enable or discourage irrigation development and the legal framework that provides farmers with security of tenure for land and water and the power to seek legal redress when contracts are broken.

All levels are linked. Organisations of water users are shaped as much by society (laws, regulations) as by individuals (skills, leadership, relationships). However, the levels provide a structure that allows capacity development to be examined and analysed and they provide possible entry points for support and technical cooperation. Source [71]

Addressing these different levels of capacity development calls for coordinated inputs from multiple disciplines and often requires collaborations that cross boundaries between agencies and ministries. The increasing involvement of private sector entities in irrigation and agriculture is creating new demands for more responsive agencies. Two approaches are needed:

- The first is to develop a long-term strategy for building capacity to meet future requirements of irrigation development
- The second is to meet more immediate needs, usually training to meet current needs and to prepare for the potential changes planned for in the long-term strategy.

5.2 Developing a long-term strategy

According the UN report on water and jobs in 2016 [2], data were scarce on national capacity-development strategies for the water sector, though some countries were planning to produce them. More strategic planning was needed to support water-related development.

Earlier, in the 1980s, attempts to plan strategically were based mainly on developing people (known then as manpower planning) and attempted to improve the science of assessing the supply and demand for people to support the development of new large-scale irrigation schemes being built in sub-Saharan Africa [74]. This provided a methodology for assessing requirements at all levels from vocational to professional, based on projected rates of irrigation development (Figure 32).

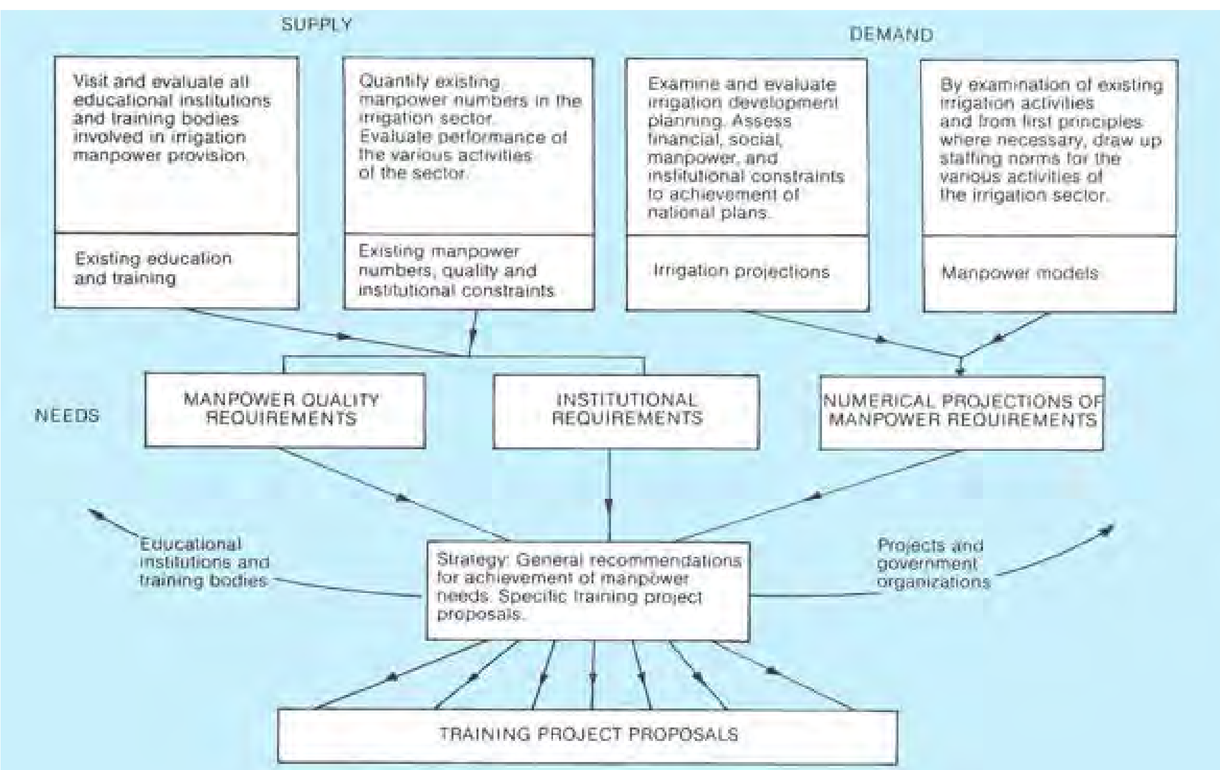


Figure 32 Manpower planning methodology

This accounted for both quantity and quality of human resources, the institutional requirements, and provided numerical projections of human resource needs and for training. Although this approach is dated, the principles are still sound, and could provide a foundation to plan for today's water sector.

FAO [71] built on this early work to recommend a strategic approach to capacity development for the irrigation sector. FAO suggested that capacity should be at the forefront of planning processes rather than infrastructure. The central question becomes – *What infrastructure is needed to support the desired capacity development? – rather than What capacity development is needed to support new infrastructure?*

A strategic approach should respond to local circumstances and initiatives, with local ownership and leadership, and incorporate the concepts of participation and subsidiarity (decision-making at the lowest possible administrative level). Capacity development is not just a *one-off* project, rather it is a continuous process that requires regular updates to respond to changing circumstances such as the current drive for irrigation modernisation. Planners like to call this a *rolling plan or adaptive planning:* a plan that changes and adapts to changing circumstances.

To support the development of a strategy, FAO [71] suggested linking the four levels of capacity development (Box 19) with the activities that make up a well-functioning irrigation sector to map out the territory where capacity is needed (Table 3). This includes the operational activities of planning, design, construction and O&M and the more strategic activities of research, education and training, and networking.

The capacity to undertake research, to educate the next generation of practitioners, and to set up and operate networks are all seen as important areas of capacity. Guiding principles of subsidiarity and participation are added to demonstrate the move away from the traditional top-down approach towards a service-oriented approach to irrigation management.

The 'grid' serves as a good starting point for questions and discussions among stakeholders on capacity development needs.
Where are the capacity gaps?
Are more individuals needed and if so, which?
Are the constraints mainly in operation and maintenance on farms or in support organisations provided by government or the private sector?
Does the environment enable or discourage irrigation?
Is the education and training provision able to provide the basic human resources for the sector?

Table 3 A 'grid' map of the irrigation territory for capacity development – a useful start-point for discussions

Capacity levels	Irrigated agriculture activities						
	Research	Ed & Tr	Planning	Design	Construct	O&M	Networks
IV Enabling env.							
III Sector							
II Organisation							
I Individual							
	Guiding principles: subsidiarity and participation						

Priorities identified from the grid lead to an assessment of the *supply* and *demand* for human resources (level I – individuals and their education and training needs) but with organisational implications in mind (level II). Levels III and IV can also be assessed in a similar manner but are outside the scope of this report.

Demand

The demand side of capacity requires an assessment of the shortfall in both quantity and quality of professionals, technicians, and farmers needed to support current and future irrigation development.

This includes the capacity of training and research institutions that support irrigation development and an assessment of farmers' ability to practice on-farm irrigation in line with good agricultural practices.

Future irrigation policy, such as modernisation, will affect both the future quantity and quality of people needed. Although this may not yet be part of government policy, such issues should be discussed with senior ministerial staff to obtain their views.

Many individuals will require additional skills to those of irrigation, to be effective within an organisation. FAO suggested several dimensions of individual capacity should be assessed (Table 4). Shortfalls in any of these areas, and not just in irrigation knowledge and skills, should be recognised as a capacity gap that needs to be filled.

Existing and future job descriptions with minimum qualifications and experience will help to identify gaps in knowledge and skills and training needs. Job descriptions for farmers will also help to identify the knowledge and skills they need to practice efficient irrigation and to work together in WUAs.

Priorities identified from the grid map lead to an assessment of the supply and demand for human resources but with organisational implications in mind

Table 4 Dimensions of capacity for individuals

Dimensions of capacity Individual level I	Existing capacity	Possible future capacity	Estimated capacity gap	Possible strategies
Job skills and needs				
Professional development				
Access to information				
Performance/incentives				
Values/attitudes/motivation				
Relationships/interdependence				
Professional integrity				
Communication skills				

Organisational capacity

Sufficient numbers of appropriately trained and individually motivated people are important, but it is essential that people work within well ordered and motivated organisations to ensure that irrigation development takes place as planned. Poor organisations and a constraining institutional environment are likely to constrain the performance of individuals. Examples of this may be a lack of clear organisational and individual objectives, poor supervision, and staff evaluation procedures, lack of financial and career incentives, a hierarchical culture that inhibits staff from getting on with their work, and external influences such as lack of funds and inadequate coordination between departments and ministries. These and other capacity dimensions of organisational capacity need to be assessed (Table 5).

Assessing the capacity of organisations to meet their objectives, particularly large ones, can be a long-term, on-going, and complex process. However, if changes are needed, every effort should be made to begin the process of assessment and to examine, at the most senior levels, the issues listed in Table 5, as they may have important bearings on the performance of individuals (level I) both now and in the future. Resources issues are involved in this but comments on these dimensions will be of value to those establishing the overall strategy.

In most cases, existing capacity can provide a useful starting point for discussion about the future. Although it is recognised that a clear picture of the future of irrigation may not be immediately available, ideas and insights that staff have are likely to be of benefit. It is important to make appropriate use of existing capacities and be realistic when assessing the future, from a financial and human resource point of view. Remember the strategy is not set in concrete, it can be adapted and improved with time. Clearly capacity assessment should follow policy goals and effective policy reform will be an essential prerequisite. In some countries there may be a lack of capacity to identify a clear policy framework and to generate commitment to the policy. This will need addressing first to avoid constraints that can create a log-jam downstream.

One dimension that will require attention is the inter-relationship among organisations as irrigation development will be part of the much larger picture of IWRM. Within the irrigation sector, it will specifically involve the principal ministries dealing with water and agriculture. How effective are these in terms of supporting irrigation farmers?

Table 5 Dimensions of organisational capacity

Dimensions of capacity Organisation – level II	Existing capacity	Possible future capacity	Estimated capacity gap	Possible strategies
Strategic management				
Culture/structure				
Processes				
Human resources				
Resources – financial				
Resources – information				
Infrastructure				
Inter-relationships				

Supply

The supply side of capacity is about assessing the education and training provision for irrigation in-country, including farmer training as well as professionals and technicians.

A list of all available irrigation training is required including training undertaken outside the country that is regularly relied upon to augment in-country training. This includes both long-term education courses and regular short courses organised at universities, colleges, and technical schools. It should also include any plans for new training establishments and courses.

Where possible, each programme should be evaluated to assess quality and appropriateness for current and future needs. Some of the indicators of performance include staff/student ratios, pass rates, curriculum content, physical resources, qualifications for successful completion of course and staff qualifications. Deficiencies in staffing and resources should be noted on the demand side.

There is a tendency to focus the teaching curriculum on the technical issues of irrigation and avoid the other equally important dimensions that enable individuals to function effectively. For this reason, it is important to go beyond the technical aspects to consider short falls in such areas as management, participation, motivation, and working with farmers.

Matching supply and demand

Matching the demand for human resources with supply can take place within the various organisations. Here are some examples of what may be needed:

Within government and irrigation agencies

- Assess the numbers of professionals and technicians already in post and their training needs.
- Assess the immediate need for additional numbers of professionals and technicians. This should include job titles, job descriptions, qualifications and any additional training needed.
- Assess the future need for professionals and technicians to meet future irrigation development plans over the next 10 years. This should include some indication of when these staff will need to be in post and an assessment of their training needs.
- Assess the immediate and future institutional capacity needs of both ministries.
- Indicate the phasing of future capacity needs over the 10-year period.

Within the farmer community

- Assess the immediate and future capacity needs of farmers to practise on-farm irrigation in line with good agricultural practices using sample surveys in farming communities.
- Assess their ability and willingness to take on water management responsibilities and identify training needs to support this e.g. formation of WUAs.

Irrigation training facilities

- Assess the training facilities (universities, colleges, training schools) available in-country for irrigation and related training in institutional development issues for professionals, technicians, and farmers. This includes an assessment of the physical facilities to undertake training and the staff numbers and their ability to deliver training.
- Where possible, identify projects that would enable training for professionals, technicians, and farmers to be undertaken in-country.

5.3 Meeting immediate needs

Developing and implementing a strategy is a long-term and continuing process, but once there is a vision for the future, more immediate training plans can be developed and implemented that meet both current needs and prepare people for the changes to come.

Some principles are common to all training. Continuing to provide training which is *more of the same,* is unlikely to serve countries well. There is often a tendency for training to follow established curriculum. Adults tend to teach the young the skills they were taught as young people, even though they may not be so useful in today's society. In education circles this is often called the *Sabre-Tooth curriculum* [75] a story about a tribe still teaching about, now extinct, sabre-tooth tigers when the young should be learning about modern methods of hunting and fishing. The debate of old and new can be endless but it will be essential to begin immediately to build new elements of modernisation into all training at all levels.

There will be a need for specialist skills, but most professionals will also require a broad understanding of irrigation. Many strategies have been developed to guide trainers to meet today's curriculum, such as the T-shaped education competency profile [76]. This recommends water professionals should have in-depth knowledge of one discipline (vertical leg of the T) plus broader professional and personal competencies, and a basic understanding of other disciplines (horizontal bar of the T). Bridging the long-standing gap between engineers who manage irrigation systems and agronomists who help farmers with irrigation cropping is just one example. Engineers would do well to have a basic understanding of what it takes to grow a crop under irrigation; while agronomists need a basic understanding of hydraulics and flow control to understand the constraints that engineers face when managing canal systems.

There are many other gaps to be bridged with management, economics, and environmental issues.

Agricultural engineers specialising in soil and water engineering are a cadre that sit well within the disciplines of engineering and agronomy and are often ideally placed to manage irrigation canal systems while understanding the need for services to farmers.

A programme for training – where to begin?

The nature and extent of training needs will depend on local circumstances and identified priorities within countries, whilst bearing in mind that future capacity needs may be very different from those at present.

The training needs are likely to be substantial at all levels and so the immediate training provision should focus on *training the trainers* in order to reach as many people as possible. Trainers should be selected from professionals, field staff, and farmers who have demonstrated their ability to communicate their knowledge and skills to others in the workplace. Other trainers should be drawn from training departments within government ministries, universities and colleges that support irrigation training. Selecting the best communicators may not always mean selecting the best engineers and agronomists.

The immediate training provision should focus on *training the trainers* to reach as many people as possible

Training methods should not just be *talk and chalk*, rather delivery should demonstrate the skills their trainees will need. Thus, training should be interactive, participative, based on learning-by-doing, and avoid being too theoretical and academic. It should be practical and to-the-point, addressing the needs, questions, problems and practices that trainees will encounter in their daily working environment. Case studies should be used to put participants in practical situations and allow them to understand and deal with real problems. Field trips should be programmed to show how theory is applied in practice.

Initially, training is likely to be at a senior professional level and should:

- Reinforce basic irrigation engineering and agronomic knowledge and skills and the role of irrigation in integrated water resources planning.
- Update professionals on the latest developments in irrigation technology and management to create a modern vision of irrigation.
- Create stronger links among irrigation organisations for the benefit of irrigation farmers.
- Improve community development skills to enable professionals and technicians to communicate with farmers, work in a participative manner, and help to set up WUAs.
- Look ahead and consider what capacities and training will be needed to support future irrigation development.

The following is a typical example of a programme set up by the FAO to promote irrigation modernisation:

Study Tours to other countries are important to acquaint senior ministerial staff and professionals with new developments in irrigation technology and management and examine policy, legal, and institutional issues surrounding irrigation development and foster relationships and exchanges between irrigation ministries, training centres both within a country and other countries.

Capacity Development Workshops to establish both immediate training needs and to examine future long-term capacity. The aim is to produce a first draft of a capacity development plan and so the workshop would address several key questions:

What capacity is available in the irrigation sector?
What capacity is needed now and in the future?
What are the capacity gaps that already exist and
What gaps are likely to occur in the future?
How can the gaps be filled?

Irrigation training courses to provide key trainers with basic knowledge and skills of irrigation planning, design and management, and modernisation both from an engineering and agricultural perspective; and expose trainers to new ways of thinking by developing communication and participative skills so that they can pass on their knowledge and skills to other professionals, technicians, and farmers. Training both abroad and in-country.

Apprenticeships to provide irrigation professionals with short-term opportunities to work directly with irrigation agencies in other countries to gain experience in managing large modernised canal irrigation systems.

Extension staff and farmer training a pilot training initiative to test and develop a curriculum for training extension staff and farmers in on-farm irrigation skills and the role and organizations of WUAs. Also explore the Farmer Field School approach promoted by FAO [77].

This is just one example of many possible training projects that can be explored once training priorities are established during the capacity development workshops.

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