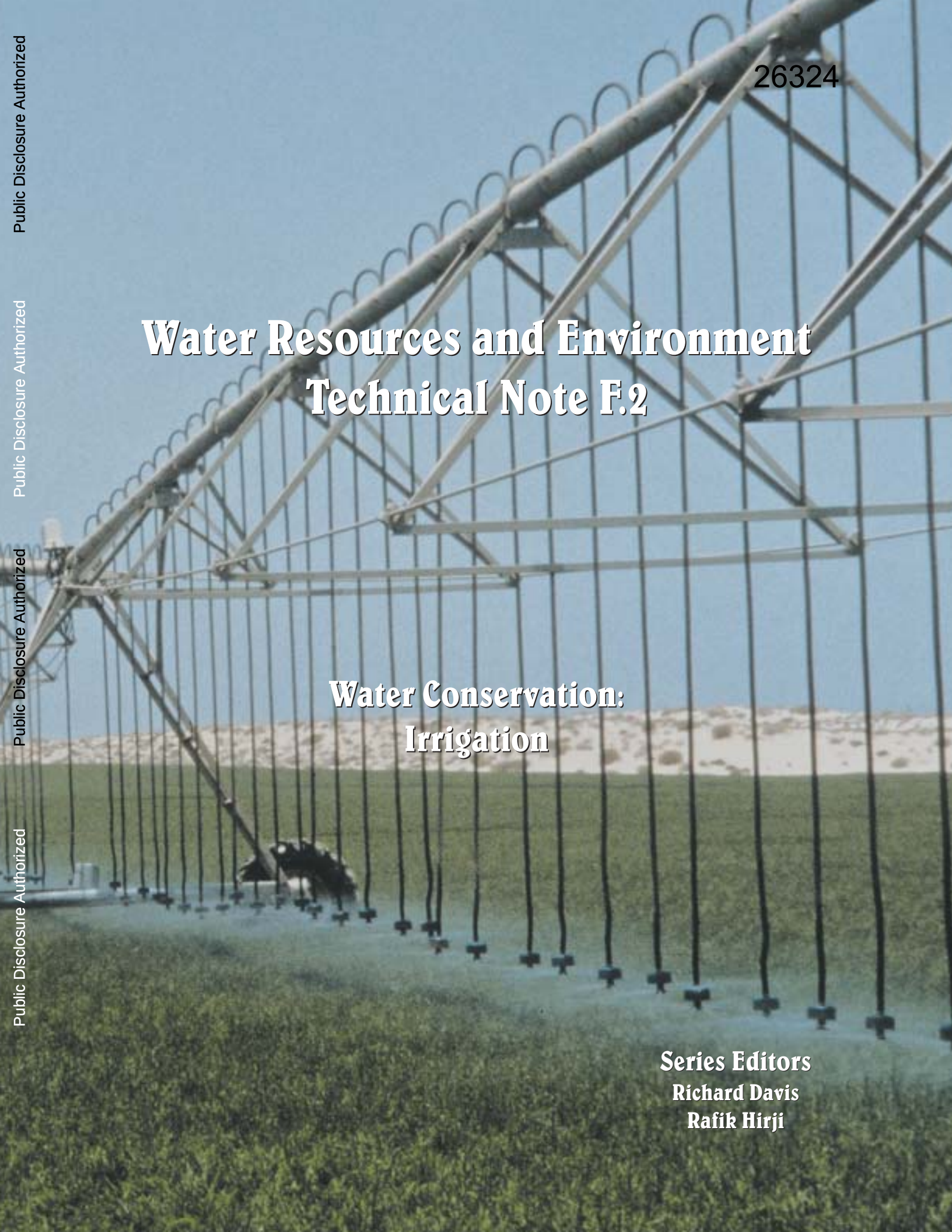

Water Resources and Environment Technical Note F.2

Water Conservation: Irrigation

Series Editors
Richard Davis
Rafik Hirji

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Contents

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Unless otherwise stated,
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center pivot irrigator

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(www.worldbank.org).

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FOREWORD

The environmentally sustainable development and management of water resources is a critical and complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-offs among social, economic, and political considerations. Typically, the environment is treated as a marginal issue when it is actually key to sustainable water management.

According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector' in that most environmental concerns are a central part of overall water resources management, and not just a part of a distinct water-using sector" (World Bank 2003: 28). Being integral to overall water resources management, the environment is "voiceless" when other water using sectors have distinct voices. As a consequence, representatives of these other water using sectors need to be fully aware of the importance of environmental aspects of water resources management for the development of their sectoral interests.

For us in the World Bank, water resources management–including the development of surface and groundwater resources for urban, rural, agriculture, energy, mining, and industrial uses, as well as the protection of surface and groundwater sources, pollution control, watershed management, control of water weeds, and restoration of degraded ecosystems such as lakes and wetlands–is an important element of our lending, supporting one of the essential building blocks for sustaining livelihoods and for social and economic development in general. Prior to 1993, environmental considerations of such investments were addressed reactively and primarily through the Bank's safeguard policies. The 1993 Water Resources Management Policy Paper broadened the development focus to include the protection and management of water resources in an environmentally sustainable, socially acceptable, and economically efficient manner as an emerging priority in Bank lending. Many lessons have been learned, and these have contributed to changing attitudes and practices in World Bank operations.

Water resources management is also a critical development issue because of its many links to poverty reduction, including health, agricultural productivity, industrial and energy development, and sustainable growth in downstream communities. But strategies to reduce poverty should not lead to further degradation of water resources or ecological services. Finding a balance between these objectives is an important aspect of the Bank's interest in sustainable development. The 2001 Environment Strategy underscores the linkages among water resources management, environmental sustainability, and poverty, and shows how the 2003 Water Resources Sector Strategy's call for using water as a vehicle for increasing growth and reducing poverty can be carried out in a socially and environmentally responsible manner.

Over the past few decades, many nations have been subjected to the ravages of either droughts or floods. Unsustainable land and water use practices have contributed to the degradation of the water resources base and are undermining the primary investments in water supply, energy and irrigation infrastructure, often also contributing to loss of biodiversity. In response, new policy and institutional reforms are being developed to ensure responsible and sustainable practices are put in place, and new predictive and forecasting techniques are being developed that can help to reduce the impacts and manage the consequences of such events. The Environment and Water Resources Sector Strategies make it clear that water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands.

With the support of the Government of the Netherlands, the Environment Department has prepared an initial series of Water Resources and Environment Technical Notes to improve the knowledge base about applying environmental management principles to water resources management. The Technical Note series supports the implementation of the World Bank 1993 Water Resources Management Policy, 2001 Environment Strategy, and 2003 Water Resources Sector Strategy, as well as the implementation of the Bank's safeguard policies. The Notes are also consistent with the Millennium Development Goal objectives related to environmental sustainability of water resources.

The Notes are intended for use by those without specific training in water resources management such as technical specialists, policymakers and managers working on water sector related investments within the Bank; practitioners from bilateral, multilateral, and nongovernmental organizations; and public and private sector specialists interested in environmentally sustainable water resources management. These people may have been trained as environmental, municipal, water resources, irrigation, power, or mining engineers; or as economists, lawyers, sociologists, natural resources specialists, urban planners, environmental planners, or ecologists.

The Notes are in eight categories: environmental issues and lessons; institutional and regulatory issues; environmental flow assessment; water quality management; irrigation and drainage; water conservation (demand management); waterbody management; and selected topics. The series may be expanded in the future to include other relevant categories or topics. Not all topics will be of interest to all specialists. Some will find the review of past environmental practices in the water sector useful for learning and improving their performance; others may find their suggestions for further, more detailed information to be valuable; while still others will find them useful as a reference on emerging topics such as environmental flow assessment, environmental regulations for private water utilities, inter-basin water transfers, and climate variability and climate change. The latter topics are likely to be of increasing importance as the World Bank implements its environment and water resources sector strategies and supports the next generation of water resources and environmental policy and institutional reforms.

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Technical Note F.2 was drafted by Hervé Plusquellec and Walter Ochs, building on the earlier work done by Jan Hoevenaars and Roel Slootweg of Geoplan of the Netherlands. It was reviewed by Doug Olson and Safwat Abdel-Dayem of the World Bank.

INTRODUCTION

As demand for water continues to rise rapidly and new sources of supply become scarcer, the conservation of water is increasingly important. Competition among water users affects irrigated agriculture in many arid and semiarid areas. These pressures will become more severe as water supplies are more fully utilized. Globally, agriculture accounts for 70 percent of water consumption, while industry accounts for 23 percent and households for 8 percent.[1] In developing countries, agriculture accounts for an even higher share of 80 percent. Consequently, even small improvements in irrigation water-use efficiency can make significant quantities of water available to further irrigation or to other users.

The World Bank's recently published Rural Strategy states that future investment priorities for agricultural water use will focus on improving the productivity of existing systems. This will not only defer the need for investment in new sources of water, but will also potentially protect natural resources and the environment by making water available for natural stream flows. The Strategy also points out that irrigation and drainage development and improvements will need to be planned and executed as part of integrated watershed/catchment systems.

This Technical Note is one of three dealing with irrigation and drainage (I&D) issues. Technical Notes E.1 and E.2 focus on environmental aspects of irrigation and drainage development and rehabilitation. This Note focuses on water conservation in irrigation. It starts with considerations of efficiency and the importance of taking an integrated approach to water conservation in irrigation. The second section of this note presents techniques to reduce losses from the conveyance and distribution systems, the different methods for on-farm water savings, and finally methods for improving operational flexibility and reliability–a prerequisite to improved water use at farm level. The last section discusses the policy tools that can be used to encourage irrigators to use water more efficiently.

A major conclusion of this Note is that neither technology nor policy reforms alone are sufficient to bring about more efficient use of irrigation water. More efficient application techniques will not be adopted by the water users if they are not accompanied by changes in pricing and improved operation of the water supply system.

[1] "Water Resources 2000-2001. People and Ecosystem: The Fraying Web of Life". UNDP, UNEP, World Bank, Water Resources Institute, Washington D.C.

Photo by Walter Ochs, World Bank

Irrigation canal, Inner Mongolia, China

CONCEPTS OF WATER CONSERVATION IN IRRIGATION

WATER CONSERVATION AND EFFICIENCY

Water conservation in irrigation is an important component of efforts to use water efficiently. Increasing competition for water resources in many river basins of the world dictates the need for careful planning and priority setting. The multiple uses of water make stakeholder participation in planning and management of water use systems, such as irrigation, a critical component of water conservation programs.

Movement of water through an irrigation system, from the water source (river, lake, reservoir) to the crop, can be considered as three stages:

- *Conveyance.* The movement of water from its source through the main and secondary canals or conduits to the tertiary off-takes.
- *Distribution.* The movement of water through the tertiary and on-farm canals or conduits to the field inlet.
- *Field application.* The movement of water from the field system and the application system to the crop.

Water conservation should be addressed in all three stages.

It is normal practice in irrigation engineering to assess the efficiency of irrigation systems at different levels: main canal, secondary and branch canals, tertiary system, and farm level. The efficiencies of these different levels are the percentages of the volumes of water supplied to the next level down compared to the volumes diverted from the higher levels. These efficiencies measure seepage and spillage losses and reflect an engineering perspective. While efficiency within an irrigation system need only consider irrigation water use, basin-wide efficiency must take account of all beneficial water uses. Box 1 defines water use efficiencies at different stages of an irrigation system and its source.

However, efficiency alone is not enough to define the performance of an irrigation project. Quality of service and indicators of productivity also need to be considered. For example, a canal system could have very high conveyance efficiency with a minimum of seepage and spillage losses, but if delivery of water is rigid or unreliable, there will be considerable waste further down at the farm level. Flexible and reliable service is the best user incentive for water conservation, because it gives security to the user. The productivity of water is often defined as the value of marketable produce per unit of water. Indicators of the quality of irrigation service, and indicators of productivity along with efficien-

BOX 1.
DEFINITIONS OF IRRIGATION EFFICIENCY

Basin water use efficiency (E_b). The percent of the catchment yield applied to beneficial uses in the catchment and its near-shore areas. These uses include both production and environmental uses but exclude water lost to evaporation, unrecoverable groundwater, polluted water, and offshore flows to the ocean.

Conveyance efficiency (E_c). The volume of water delivered to the distribution system divided by the volume of water diverted from the water sources.

Distribution efficiency (E_d). The volume of water delivered to the fields divided by the volume of water delivered to the distribution system.

Field efficiency or water application efficiency (E_f). The net irrigation water requirements minus effective rainfall (IWR) (sometimes defined as the volume of water required that will not create undesirable stresses in crops) divided by the volume of water delivered to the fields.

Overall irrigation efficiency (E_o). The net irrigation water requirements minus effective rainfall (IWR) divided by the volume of water diverted from water sources.

cies are needed to evaluate performance of irrigation projects.

These definitions of efficiency in irrigation systems differ from efficiency in urban water systems. In urban water systems, efficiency measures the volume of water treated to the volume billed (or delivered) to the consumers. Unlike overall irrigation efficiency, which includes end (field) uses of the water, urban water efficiency does not consider household use of water, which typically includes many wasteful practices. For comparative purposes, it would be more relevant to compare irrigation conveyance and distribution efficiencies with urban water efficiencies. However, conveyance and distribution efficiency is not able to be calculated accurately in most irrigation projects because of the difficulties in measuring water volumes in canal irrigation systems.

When planning water conservation measures, realistic values should be used for conveyance, distribution, and water application efficiencies rather than the optimistic values often found in textbooks. Where possible, these values should be measured within the project area under current and realistic irrigation practices. Table 1 shows typical, measured irrigation efficiencies achieved in Bank-financed projects.

INTEGRATED WATER RESOURCES DEVELOPMENT

An important but little appreciated fact about irrigation water use is that a substantial volume of water is recycled, thus providing a significant benefit to both other consumptive users and to the environment (Figure 1). Thus, part of the water diverted for irrigation flows back into a stream or ground-

Figure 1.
Typical water balance of irrigation projects

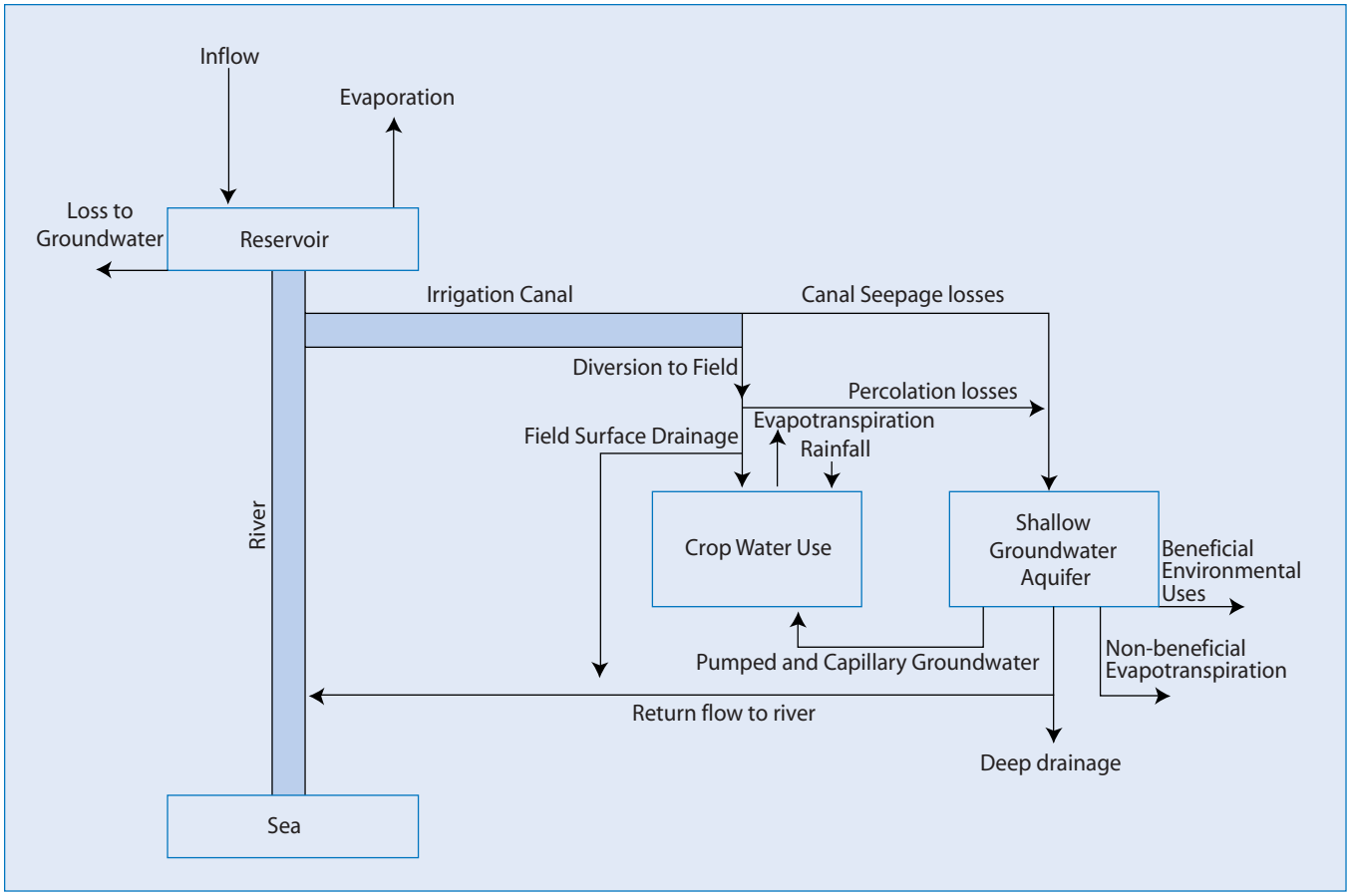


Table 1.
Typical irrigation efficiencies

System Type	Efficiencies (%)		
	$E_c \times E_d$	E_f	E_o
Open canal systems under manual control and surface application	60	50	30
Open canal systems under automatic control and surface application	70	60	42
Open canal system with advanced automatic control & field water-saving techniques	75	70	53
Pipe conveyance systems and drip techniques	95	75	71

water system, where it can be reused if the water quality has not deteriorated beyond acceptable limits. The remainder –evaporation and transpiration, drainage to the sea or a similar area, water that is too contaminated with salt, nutrients, pesticides to be useable - cannot be captured and reused and so is lost to uses within the river basin.

Some of this reuse occurs within the irrigation system. The Indus River basin provides an example of recharge of the alluvial aquifers and reuse, providing water with much higher value to most Pakistani irrigators. Tubewells were installed in large areas of the basin because surface water supplies were not adequate for the desired extent of irrigation. The overall basin efficiency is estimated at about 64 percent, about 60 percent higher than the combined efficiency of the surface system at about 40 percent (Table 2). The field efficiency is very high because of under-irrigation and the amount of water recycled through the tubewells.

Much of the water lost to transpiration comes from crops; a further amount comes from desirable aquatic plants (wetlands, etc). However, not all transpiration losses are beneficial. Some come from undesirable weed species and so are non-beneficial. Other losses come from fallow, waterlogged and salinized lands through capillary action, and evaporation. These evaporation losses are also non-beneficial. The problem of non-beneficial evaporation losses is exacerbated if shallow groundwater tables are created by irrigation inefficiencies.

Because water in a river basin can be used multiple times, the application of water conservation measures in irrigation can have both negative and positive impacts on third parties. A very effective water conservation program in an irrigation scheme could impair downstream users relying on groundwater recharge or on drainage water. Similarly, if the water allocated to an irrigation scheme remains unchanged after conservation measures are imple-

Table 2.
a) Water balance and
b) efficiencies of the Indus Basin Irrigation System

A) Phase of water cycle	Quantity (Million acre-feet)
Total river inflow	160
Canal diversion	107
Recharge of groundwater	56.4
Saline	19.7
Fresh	36.7
Crop use	68.2
Flow to Arabian Sea	39
B) Efficiency	**%**
Basin water use efficiency	64
Conveyance efficiency	82
Watercourse efficiency	65
Field efficiency	75

mented in an area where there is inadequate allocation for ecosystems, there is likely to be an expansion or intensification of irrigation with no resulting environmental benefits. For example, the imposition of a cap on water extractions in the Murray-Darling Basin in Australia (see Note C.2) is likely to lead to improved water use efficiency, reduced groundwater rrecharge, and reduced return flows to the rivers, making it difficult to meet instream flows for environmental purposes. Thus, water conservation needs to be accompanied by controls on beneficial water consumption if these perverse effects are to be avoided. This is discussed below.

However, these points do not constitute a case against improving irrigation systems. Improving water application can substantially reduce the environmental and production costs of salinization. The control of soil salinization requires that excess salt be moved from the crop root zone, but this requires only a minimal amount of water beyond the crop needs. The conservation of water is environmentally sound, and is the least expensive way to minimize drainage problems in irrigation project areas. Inefficiencies at irrigation scheme level impose costs on production, such as increased pumping cost in projects that depend on lift from a river, and depressed crop yields, particularly in the tailends of irrigation projects.

Efficiency improvements also produce other benefits, including improvements in human health, reductions in the cost of treating drinking water, less environmental contamination by agricultural chemicals, and reductions in the economic cost of multiple water withdrawals.[1]

Because of these interdependencies, water conservation in irrigation needs to be planned as part of a river basin plan involving other basin users and stakeholders. Water needs to be allocated to each of the uses in the basin based on the socioeconomic goals of the region and the country. Given that the major pathway by which water leaves the basin is through evapotranspiration (ET) from cropland, rangelands, forests, natural areas (wetlands, etc) and non-beneficial land uses, it is sensible to allocate water to these land uses in terms of ET. The allocations should include the flow requirements to maintain the aquatic environment and the services that it provides to communities of the river basin (Notes C.1-C.3).

Given the complexity of pathways and opportunities for reuse (Fig 1), it is very difficult to deliberately manage the internal flow pathways, including the various leakages. In simple terms, water for irrigation is extracted from either surface or groundwater sources; part is consumed through ET, and the remainder is returned to surface or groundwater bodies and is available for other users. The only water that leaves the local hydrologic system is the ET (the ET can return as precipitation, but this will almost always occur in areas geographically different from the irrigation area and local basin) or riverflows to the ocean.

Photo by Hervé Plusquellec, World Bank

Canal lining with geomembranes, Tarim Basin, China

[1] Gleick, P. 2000.

Since the major loss to the hydrologic system is via ET, irrigation water conservation needs to be in terms of reductions in ET. For planning and management purposes, it is convenient to divide ET into three categories: crop consumptive use (CU), environmentally beneficial ET, and non-beneficial ET. Water conservation planning in irrigation districts should be directed toward coming up with ways to reduce non-beneficial ET and to maximizing crop yields and the value of crop production per unit of CU, while preserving environmentally beneficial ET. This approach to managing by the end use of water and not the internal flow pathways assumes that leakages and other internal losses will eventually be used for one of these beneficial or non-beneficial uses, and so shifts the focus away from managing leakages and internal losses and toward managing only those leakages and losses that contribute to non-beneficial uses of the water.

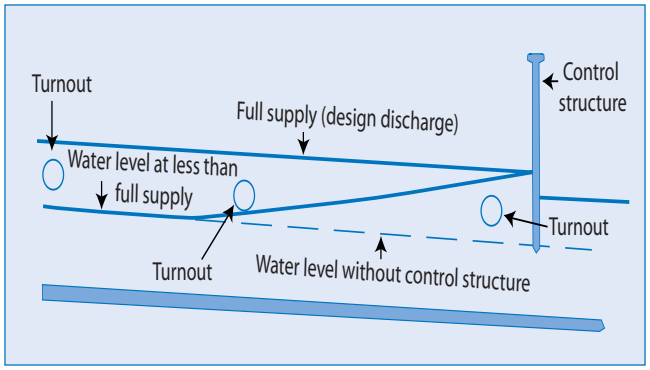
In practice, CU, beneficial ET, and non-beneficial ET need to be measured and monitored to put this new approach into practice. Until recently, this has been difficult and expensive. However, the continuing development of remote sensing technologies has made ET measurements both accurate enough and economically acceptable for practical application at a regional scale. Remote sensing has also been used to monitor ET usage at farm scale, although the accuracy is lower and the cost is greater than at a regional scale. Remote sensing of ET has the additional advantages that it can be used to show the time sequence of ET over months, seasons and years, and it allows for performance comparisons across different irrigation areas that are independent of local measurement techniques and standards. Box 2 describes the growing experience in the application of remote sensing to irrigation management.

HOW DESIGN AFFECTS PERFORMANCE OF IRRIGATION SYSTEMS

Many failures and problems in irrigation and drainage are caused by designs that are outmoded or that paid insufficient attention to operational aspects.

The design standards adopted in many developed and developing countries since the 1950s to deliver water according to crop demand were conceptually advanced. However, most of them failed to meet their objectives because of deficiencies in the water control technology and the complexity of the operational procedures. Managing an irrigation system equipped with manually operated gates at each branching point is a very complex task. The use of water control technology with structures requiring frequent adjustments, which has often been the norm during the intensive development of irrigation in developing countries from the 1960s to 1990s, has influenced the performance of irrigated agriculture. Additionally, many systems were designed to operate at full capacity without consideration for operation at less than full supply (see Figure 2). The frequent fluctuations in water level and flows due to changes in demand and supply accentuate the difficulty of delivering water to tail-end users.

FIGURE 2.
CROSS SECTION OF SUPPLY CHANNEL DESIGNED TO PROVIDE WATER TO TURNOUTS ONLY AT FULL SUPPLY LEVEL



BOX 2.
THE USE OF REMOTE SENSING FOR PLANNING AND MANAGING WATER ALLOCATIONS

Direct *in situ* measurement of evapotranspiration (ET) from crops is difficult because field measurement devices are expensive and require considerable knowledge to operate, and each type of plant exhibits a different response to atmospheric conditions. The heterogeneity of plants across an irrigation area makes the estimation of regional ET from point measurements subject to considerable error. These difficulties can be avoided if ET is calculated from remotely sensed satellite data.

Although satellite-based remotely sensed data have been available since the 1970s, reliable algorithms to estimate ET from these data have only been developed since the mid-1990s. These algorithms have been usually applied at regional scale because the data from weather satellites (typically NOAA-AVHRR with 1 or 2 km^2 pixels) are available daily and can be acquired free of charge on the Internet. Higher resolution data from LANDSAT and other such satellites with around 30x30 m pixels are needed for field-scale ET. They need to be purchased, are available less frequently, and only after a delay of some days. The accuracy of ET estimates from remote sensing is about 85 to 90 percent at field scale, comparable to estimates from traditional techniques. However, the accuracy at regional scale is better than 90 percent, and so remote sensing of ET is more accurate at this scale than with traditional methods.

The SEBAL algorithm for estimating regional ET, developed by IWMI and ITC, Netherlands, has now been successfully trialed in a number of countries, including the United States, Turkey, Brazil, and China. For example, the technique was tested in a 79,000 ha pilot area within Awati county in the Tarim Basin, China using both NOAA-AVHRR and Landsat data. Both cereals and cotton are grown in the area. Estimates of water use were made for beneficial and non-beneficial uses at the scale of Water User Associations (typically 2000 ha each). The crops were consuming only 40 percent of the water delivered. The actual water distribution was calculated to be 47 percent for crops, 24 percent beneficial eco-system use and 2 percent non-beneficial evaporation. Some of the excess was also believed to be contributing to a rising water table. The maps of ET showed that the water productivity (kg of crop/m^3 of water) of the 19 Water User Association areas was relatively low and, with one exception, did not vary significantly between WUAs. The maps also showed where the non-productive ET losses were occurring, thus helping direct managers to areas needing attention.

Sources: W. Bastiaanssen and M.G. Bos (1999). Irrigation performance indicators based on remotely sensed data: A review of literature. *Irrigation and Drainage Systems* 13: 291-311; W. Bastiaanssen, (no date). *Remote Sensing Monitoring in the Awati pilot area.* WaterWatch, Wageningen, The Netherlands.

Even donor-financed irrigation rehabilitation projects have not always incorporated design principles that reflect an operational understanding of the whole system. Many have focused on improving irrigation efficiency at the farm level (field efficiency) where the over-use of water is the most apparent. However, the inefficiency at farm level often reflects the inability of the main and distribution system to deliver water in a reliable and flexible way. It is only when the main distribution system is well operated that farmers will invest in on-farm water saving techniques. Only then can high returns be obtained from an increased application of other complementary inputs and a better choice of crops.

PHYSICAL WATER CONSERVATION TECHNIQUES

To provide efficient use of water sources, conservation techniques should be applied at all stages of the irrigation system from the storage reservoir to field application. To be fully effective, these physical interventions need to be coupled with institutional and policy reforms. Experience shows that agronomic changes and improvements in the operation of irrigation water delivery are more effective at conserving water than are improvements in irrigation technology such as canal lining and sprinkler systems. Changes in technology are often not sustainable without considerable support activities

and, even when they are introduced successfully, they can result in a reduction in leakage that was being used for other beneficial uses without a noticeable reduction in ET per unit crop produced.

RESERVOIRS

Evaporation losses from reservoirs are several times smaller than downstream losses from seepage or runoff, unless the reservoirs are very shallow, as occurs with the numerous tanks in India. Attempts to reduce evaporation from large reservoirs by spreading chemicals or physical barriers to evaporation have not been successful.

For safety reasons, seepage losses through dam foundations are minimized during construction. Seepage control is seldom considered in other parts of irrigation supply reservoirs. Modern lining techniques, using geomembranes, are frequently used in small- to medium-sized urban supply reservoirs because of the higher return on investment and the better topographic configuration of urban supply reservoirs compared to shallow, medium, and small irrigation dams. Increasingly, geomembranes are being used to line small regulating reservoirs and private ponds in irrigation projects in arid and semi-arid regions.

CANAL LINING

Water losses in unlined canals are usually high. One of the most important ways to increase the efficiency of water diverted for irrigation is to reduce the amount of water lost by seepage during conveyance to farmers' fields. Total seepage losses from main and secondary canals range from 20 to 45 percent. For example, the total losses in the Bari Doab canal in Pakistan were estimated at 47 cent of the inflow. The average loss of the 400-km Karakum canal in Turkmenistan, which runs in mostly sandy soils, was estimated at 43 percent during the first year of operation, although it decreased in subsequent years as the water table rose.

Lining of canals is the most common component of packages proposed by irrigation agencies for the rehabilitation and modernization of irrigation projects. There are many technical reasons for lining irrigation canals:

- Reduction of water lost by seepage
- Increase in canal discharge capacity
- Limitation of weed growth
- Reduction of waterlogging
- Prevention of bank erosion
- More equitable water distribution and reduction in transmission time
- Prevention of damages to adjacent land
- Reduction of drainage cost
- Reduction of canal dimensions
- Reduction in right-of-way and land acquisition cost.[2]

Box 3 describes the factors affecting seepage from unlined canals.

Rigid lining (cast-in-situ concrete, pre-cast concrete panels and bricks) is still the most common technique of canal lining in developing countries. However, rigid linings are often ineffective because of poor construction, particularly the compaction of the sub-base and the placing of concrete, and inadequate operation of canals with drawdowns that are too rapid and frequent dewatering. Even lining that has a good appearance may not be an effective seepage barrier because of small cracks or deficient joints that considerably reduce the effectiveness of the lining. Also, saturation of the soils after commissioning of a canal can cause some settlement of the soil mass, resulting in wide gaps underneath the rigid slabs resulting in further cracks. Preventive maintenance, including sealing of cracks and repairs of joints, is vital for the long-term effectiveness of rigid canal linings.

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[2] An additional advantage of canal lining–reduction of canal maintenance costs–is subject to debate. One of the largest recurring maintenance costs in many canal systems is the removal of weeds and plants from unlined canal sections. High quality, hard surface linings, which are relatively impenetrable by weeds and plants, greatly reduce the cost of weed control and removal from the canals. However, high maintenance and repair costs of some linings a few years after completion could offset the savings on weed control

BOX 3.
FACTORS AFFECTING SEEPAGE FROM UNLINED CANALS

The main factors affecting seepage are:

- Characteristics of the soil profiles: seepage rates from unlined channels can range from about 0.05 m/day for clay soils to 0.5 m/day for sandy soils
- Geometry of canals: greater depth of water and greater wetted perimeter increase seepage rates
- Depth to groundwater
- Amount of sediment in the water

Suspended material in the canal water is carried out by seepage into the pores in the soil. This is known as the self-sealing effect. For example, seepage losses immediately after construction of Donzere-Montdragon canal in France amounted to 16 m^3/s; but were reduced to 3 m^3/s within five years by the natural sealing effect of the silt-laden Rhone water.

Canal lining is very expensive, adding 30 to 40 percent to the total cost of an unlined system. Invariably the high investment cost is justified by the value of water saved by reduction of seepage losses. This justification is usually based on research studies that show that roughly 60 to 80 percent of the water lost in unlined canals can be saved by hard-surface lining. For example, research in Nebraska in 1986 showed that the seepage rates were reduced from about 300 to 140 mm/day and research in India showed that seepage reductions after lining ranged from 30 percent for main canals to 45 percent for distributary canals. Reduction of seepage losses is often assumed to be constant for the expected life of the lining. However, field experience and recent research studies do not always validate that assumption (Box 4). Consequently, decisions to line irrigation canals must be taken after a systematic study of the contributions of the seepage to beneficial and non-beneficial uses and a realistic estimate of the water that can reasonably be saved by lining if the contribution to non-beneficial uses needs to be reduced. The contributions of seepage to beneficial uses can often outweigh any advantages from canal lining.

Another option is to use flexible geomembraness protected with a rigid lining or with loose materials. This technique was used first by the U.S. Bureau of Reclamation and in some Middle East Countries with very difficult soils, including gypsum soils (Esfahan project in Iran; Balikh project in Syria) in the 1970s. The Forwah-Sadiaqia project in Pakistan's Indus Basin and the Tarim II Project in Western China (Box 5) are two Bank-supported, large-scale projects where canals were lined with geomembranes and seepage rates were dramatically reduced. Despite the experience that conventional

BOX 4.
FIELD RESEARCH STUDY ON BRICK CANAL LINING PERFORMANCE IN PUNJAB, INDIA

The design life for a brick-lined channel is usually assumed to be 20 to 30 years. Lining is expected to reduce seepage from between 200-500 mm/day for earth channels in sandy or clayey loams down to about 50 mm/day for a lined section. Short-term tests on perfect linings in laboratory conditions confirm that seepage rates from lined canals are negligible. However, field studies carried out in Punjab, India in the late 1980s showed that a lined distributary canal was losing 300mm/day within five years of construction, and lined watercourses varying in age from 6 months to 8 years were losing 320 mm/day on average. That is, the observed seepage losses from channels with linings older than four years were comparable to the seepage from unlined channels.

The wide gap between laboratory studies and practice arises from the poor quality of construction (quality of bricks, quantity of cement, and compaction of earth behind side walls) combined with wear from people and animals and stresses from repeated drying and wetting caused by rotational water distribution.

Source: Goldsmith, H., and Makin, I. (1989).

BOX 5.
CANAL LINING PROGRAMS IN THE TARIM BASIN, XINJIANG PROVINCE, CHINA

Seepage losses from the irrigation canals and on-farm percolation losses are largely responsible for excessive water use and consequent loss of water to the lower reaches of the Tarim River.

The Tarim I project dealt with water resources management issues within two oases only; the Tarim II project, still under implementation, is intended to improve the basin's environment and to partially restore the "green corridor" in the lower reaches of the river which provides a vegetation barrier to encroachment of the Taklimakan Desert. It was projected that the project activities, including canal lining, drainage improvements, and well-field construction (as well as water management improvements) would result in a reduction of 1,000 million m^3 in nonbeneficial evapotranspiration. Part of the saved water would be used for increased crop production and part would be used for the green corridor.

The Tarim irrigation canals first run on coarse-material lands—with slopes so steep that a high-quality lining is required—before reaching the irrigable lands with gentle slope and silty soils. The Tarim I project involved lining 980 km of canals, of which 860 km consisted in overlapping thin plastic films (0.2mm) protected with concrete or local materials such as cobble or gravel. This method was considerably improved for the Tarim II project through the use of geomembrane panels (0.5 mm), which are welded in factory and on-site. The Tarim II project includes the lining of 700 km of canals, of which about 400 km were lined with 5 million m^2 of geomembranes protected with local materials.

Seepage losses of 140 mm/day were measured from a canal lined with plastic film protected with concrete, and 300 mm/day from a canal lined with concrete slabs without plastic film in the Tarim I project. Seepage losses from a canal lined with welded geomembranes in the Tarim II project were reduced to a remarkably low value of 4 to 6 mm/day. Estimated seepage losses from the 57 canals lined during the Tarim I Project were reduced from 1,375 to 405 million m^3 and the water savings in the Tarim II project may be in the order of 600 to 800 million m^3. The additional cost compared to Tarim I—less than $3 million—makes this improvement the most cost-effective solution to improve the conveyance efficiency of irrigation canals. These results confirm previous observations on the mediocre performance of canal lining techniques that use only rigid materials.

The growth of irrigation and decline in environmental quality in the Tarim Basin in the Xinjiang Western Province of China is described in Case Study 1 in Note E.1.

lining techniques are not successful over the long term, the adoption of new technologies such as geomembranes to line irrigation canals has been very slow because of the high cost of importing material in most developing countries and the resistance to changes in design standards by many irrigation agencies.

FIELD-LEVEL WATER CONSERVATION TECHNIQUES

Water losses at farm level vary considerably with the method of on-farm water distribution and application. On-farm water losses with open canal distribution networks are estimated to be up to 40 percent in unlined ditches. In piped irrigation systems, the water losses range from 10 percent with localized micro-irrigation and drip to 30 percent with overhead conventional sprinklers (Table 3). For example, water use declined from 12,000 to 6,000 m^3 per hectare within seven years of converting a small project on the West Bank of the Jordan Valley from a surface system with fixed rotation to drip irrigation.

Selecting the on-farm distribution and application method that is most suitable for a particular irrigation application is important, since the wrong choice can cause soil erosion, waterlogging, and soil salinization. Soil characteristics, topography, and type of crops are the main factors to be considered, with the infiltration rate and the water-holding capacity (the amount of water that can be retained in the soil for use by the crop) being the two soil characteristics of most concern.

Water application methods in developing countries can be broadly divided into surface irrigation and pressurized irrigation techniques. Sub-surface ir-

TABLE 3.
APPROXIMATE APPLICATION EFFICIENCY OF VARIOUS ON-FARM IRRIGATION SYSTEMS AND METHODS

System/ method	Application efficiency (%)[a]
Earth canal network; surface methods	40–50
Lined canal network; surface methods	50–60
Pressure piped network; surface methods	65–75
Hose irrigation systems	70–80
Low-medium pressure sprinkler systems	75
Microsprinklers, microjet, minisprinklers	75–85
Drip irrigation	80–90

[a] These efficiency values are indicative. Actual values can range considerably depending on the level of management, the soil characteristics, and the method of application.

rigation is used in a small number of irrigation projects in the developed world but has little potential in the developing world and will not be discussed further here.

Surface irrigation. Field efficiency will be improved if surface water can be controlled so that the proper amount enters the soil to supply the water needs of the crop (plus a leaching fraction if necessary) uniformly across all parts of the field. Box 6 describes common surface irrigation methods. Uniformity of water distribution is very difficult to achieve if the land surface is uneven, resulting in low field efficiency, poor crop yields, and soil erosion with concomitant clogging of surface drainage systems. Excess water resulting from rainfall or over-irrigation–if allowed to collect in undrained areas of a field for extended periods–causes deterioration of the soil structure and provides breeding areas for mosquitoes.

Even if the land surface is even, more water will inevitably enter the soil at the upper end of the irrigated area than at the lower end. Some advanced surface irrigation techniques have been developed to minimize the lack of uniformity of irrigation, but are not widely used even in developed countries. Surge irrigation, releasing water in furrows for short times separated by closure periods, takes less time for the water to reach the lower end of the furrow, resulting in a better uniformity of water distribution and higher efficiency. Other techniques, such as gated pipe and cablegation, were developed to improve furrow irrigation, but experience shows they are generally too sophisticated to be used by smallholders in developing countries.

Adaptive research in the Middle East and North Africa has shown the difficulties in introducing surface water-saving techniques. In Egypt, irrigation trials were conducted with long-level basins and long-level furrows to improve water management, and included precision land leveling. At two sites, the trials were unsuccessful and farmers fared as well or better with conventional systems; at the other two sites, the reported net water savings were doubtful because drainage and groundwater recycling were not taken into consideration. New irrigation development areas in Morocco are subject to land consolidation with the adoption of a geometric layout of field irrigation and drainage ditches, and precise land leveling for the adoption of furrow or border irrigation in order to improve field efficiencies. Attempts to introduce gated pipes (uniformly spaced outlets for furrows) have failed, likely due to the added expense. Over time, farmers are shifting back to the traditional method of irrigation by small basins.

Pressurized irrigation techniques. About 20 million hectares worldwide are now irrigated by sprinklers and 3.2 million hectares are being irrigated by micro-irrigation techniques. Sprinkler irrigation delivers water in the form of rain drops precipitated over a large area. The equipment for sprinklers ranges from hand-moved irrigators and microsprinklers for small farms to center pivots, linear moves, and the recently developed LEPA systems (Low Energy Precise Application) for large farms. LEPA involves drop lines from either center pivot or linear move systems whereby water is applied

BOX 6.
SURFACE IRRIGATION METHODS

Furrow irrigation is suitable for crops that would be damaged if their stems were submerged. Row crops such as cotton, vegetables, sugar beet, and maize are irrigated by furrow. Considerable experience is needed to divide the water supply into a number of furrow streams and maintain correct rates of flow. Various devices are used for controlling the flow of water into each furrow. The most popular one is the irrigation siphon type. When water is delivered under low pressure, gated pipes with uniformly spaced outlets are used for releasing irrigation water into furrows.

Border irrigation makes use of parallel earth ridges, which guide a sheet of flowing water as it moves down the slope. This method is the most efficient for irrigation of close-growing crops such as alfalfa and pasture. The land must have a uniformly moderate slope. Careful land preparation is necessary.

Basin irrigation is the simplest method and most widely used for irrigating crops in developing countries. Many different crops are irrigated by this method. All systems of irrigated rice cultivation make use of basin irrigation. It is possible to modify the soil to decrease the infiltration rate. Compaction and puddling by animals (water buffaloes) has been a traditional method of land preparation in Asian countries. Infiltration rates of 1 or 1.5 mm per day have been consistently adopted for the calculation of irrigation water requirements in planning irrigation projects without any field measurement. Basin irrigation can be very efficient for crops other than rice if the basins are supplied with very large flows, as practiced in the United States.

at low water pressure directly to the crop to minimize losses from evaporation or wind drift. Micro-irrigation is characterized by the delivery of water at low rates to a limited soil surface area around the plants. The equipment includes drippers, sprayers, bubblers, and micro jets. Micro-irrigation systems and micro-sprinklers have the potential to create significant water savings for smallholder agriculture involved in high-value crops. Micro-irrigation has grown by more than six times over the last 20 years and, during the 1980s, started penetrating developing countries, mainly India and China.

Both sprinklers and micro-irrigation depend on water delivery through pressurized pipes. The capital cost of pressurized irrigation systems varies according to the method of irrigation and the type of installation. The cost of the solid installations for localized methods is higher than that of the hand move sprinkler systems. The cost for the installation of various piped irrigation systems in Europe is presented in Table 4.

Farmers generally adopt pressurized systems much faster than advanced surface application techniques. For example, about 65 percent of the farmers in the Jordan Valley have shifted from surface to drip irrigation over a 10-year period, primarily because of its advantages for water conservation. Farmers built small on-farm storage reservoirs lined with plastic sheets to prevent seepage losses and to provide the flexibility required for drip irrigation.

Agronomic improvements. The field efficiency of irrigation systems can be improved through both ag-

TABLE 4.
COMPARATIVE COSTS OF PIPED IRRIGATION SYSTEMS (1997 PRICES)

	Piped surface methods	Sprinkler hand move	Micro-irrigation solid installation
Installation cost ($/ha)	$1,400-1,700	$2,100-2,800	$3,000-3,950
Annual maintenance cost ($/ha)	$70-85	$105-140	$150-200

Photo by Walter Ochs, World Bank

Spaghetti tube drip irrigation, New Lands Irrigation Area, Egypt

ronomic developments and better control of water application. Overall, the aim is to increase the amount of crop produced per unit of water applied. Some of the agronomic improvements that conserve water include:

- *Use of short-duration crop varieties.* Some crop varieties have shorter growing periods, so less water is required to produce similar yields. For example, 120-day rice varieties have now been replaced by 90-day varieties in most parts of East Asia.
- *Improved crop genetics.* Improved crop types adapted to an area can be selected to minimize water use.
- *Deficit irrigation.* Agronomic research has demonstrated that a reduction of up to 25 percent in irrigation water supply may not substantially affect crop yields, especially cereals, as long as water is delivered at critical growth times. As a result, the number of irrigations of wheat in the North China plain has been reduced from five to three.
- *Improved cultivation practices (conservation tillage).* Managing the amount, orientation, and distribution of crop and other plant residue on the soil surface year-round conserves soil moisture, reduces erosion, and maintains or improves soil organic matter.
- *Plastic mulching.* Plastic materials can be used to conserve moisture, control weeds, and reduce erosion.

IMPROVING THE QUALITY OF IRRIGATION SERVICE

The operational performance of the system at all levels of water demand is one of the most important issues and one that often receives insufficient attention when development or rehabilitation projects are being designed. The design must reflect not only current requirements but also the expected requirements for future operations.

The choice of the system for water delivery–rotation, arranged schedule, limited-rate demand, and centralized scheduling–will influence the efficiency of water distribution. Most traditional delivery systems have no or little flexibility built into them. Thus, sharing water on a rigid rotational basis often leads to wasteful use, since users will generally take their full share at each turn irrespective of the water needs of their crops. On the other hand, delivery of water on request, also referred to as pre-arranged demand, is more likely to improve field efficiency since farmers are ordering water only when it is needed. However, this method requires the farmers to have confidence that their orders will be fulfilled.

The designer of a new or rehabilitated I&D scheme must also choose the control strategies and control equipment for the operation of canal irrigation systems. The selection of a control strategy and equipment has a major impact on the ability to provide a high quality of service to users, overall efficiency, and ease of operation of the system. Potential control strategies include local control versus centralized or supervisory control; upstream versus downstream control; or proportional versus adjustable control. Most projects combine two or more

control strategies at different levels of canals. The advantages and disadvantages of the different control strategies are discussed in technical publications.[4]

The last step in design is the selection of control equipment that fits with the selected control strategy. Although widely used, manually operated gated systems are the most complex to operate if the objective is to provide both quality of service and efficiency of water use. Automatic control equipment makes it possible to improve service and efficiency but requires more design skills and higher quality of construction and installation as well as access to skilled operations and maintenance staff for successful long-term operation. Goussard (1993) presents the salient features of the various types of control equipment used in irrigation projects.

Equity considerations should be included with water conservation when new or rehabilitated I&D schemes are being planned, including a water supply that allows tail-enders access to water that is consistent with the access of other irrigators.

INSTITUTIONAL AND POLICY REFORMS

INSTITUTIONAL REFORMS

In the 1980s, there was a widespread belief that deficiencies in management and related institutional problems, rather than technology of irrigation, were the chief constraints in the performance of irrigation systems, including poor recovery of investment and recurrent costs, poor morale and training among staff, and conflicts between farmers and irrigation agencies. It is now accepted that both deficiencies in management and institutions as well as technical issues are the causes of poor performance of irrigation projects. Box 7 provides the desirable elements for a national water conservation program based on experience in the Middle East.

Technical changes need to be combined with institutional and policy reforms to achieve improved water use efficiency in irrigation projects This is illustrated by the successful comprehensive modernization programs in the Office du Niger in Mali (Box 8).

Some of the policy and institutional changes that have proven to be successful for promoting water conservation include:

- Price incentives through volumetric pricing
- Water rationing
- User participation in the management of irrigation systems.
- Communications strategy.

Introduction of water trading within the irrigation sector will tend to improve the economic efficiency of the sector but is unlikely to affect overall irrigation efficiency. The same volume of water will be used, although the value of the products should increase with intra-sectoral trading because there is now an incentive to maximize the economic returns on the water within the sector. If inter-sector trading is permitted, then overall irrigation efficiency can improve because of the incentive to trade water previously used for low value crops to other sectors where it will achieve a higher return. However, basin water use efficiency may not change if inter-basin transfers are not permitted. The example from the Imperial Valley in California (Box 4, Note E.2) provides an example of inter-sectoral water trading.

VOLUMETRIC WATER PRICING

Prices, which accurately reflect water scarcity values, will improve water allocation and encourage conservation by giving information to users when they decide to use water. Volumetric charges are frequently used for irrigation water pricing in devel-

[4]See World Bank Technical Paper No. 246.

BOX 7.
DESIRABLE ELEMENTS IN A NATIONAL IRRIGATION WATER CONSERVATION PROGRAM

- A strong central organization, supported by a comprehensive code of water laws, empowered to plan and design efficient irrigation systems, allocate water, control water use and impose sanctions.
- Planning, where feasible, of regional or national grids for water distribution and joint operation of both surface water supplies and groundwater resources.
- For individual irrigation projects, well-founded decisions on the design of conveyance and distribution systems (whether to select pipe or open canal systems or use both systems), taking into account the on-farm irrigation technologies to be promoted.
- Decisions should be based on long-term water supply and demand projections in the project area, as well as marketing prospects for crops.
- Implementing, with the irrigation infrastructure, a comprehensive social and economic development plan for rural areas that promotes the general well-being of the population.
- Appropriate land reform and land consolidation programs to overcome land tenure problems and improve the efficiency of irrigation layouts and operation (in the main system and on-farm).
- Implementing a strong research program to develop or adapt on-farm technologies and practices for local conditions.
- A program for testing, demonstrating, and disseminating recommended technologies.
- A strong irrigation extension service (irrigation advisory service) to advise farmers on irrigation technologies, practices, and scheduling.
- A strong irrigation agronomy program to assist the irrigation extension service in determining optimal crop water requirements and developing recommendations for new cash crops.
- A program to train irrigation engineers, technicians, government workers, and water user association workers.
- An appropriate system of demand management consisting of water metering, water pricing, and possibly water allocations based on carefully researched crop water norms. A system of graduated water prices may be adopted so that the excess use of water is heavily penalized.
- Strong private sector involvement in manufacturing irrigation equipment and possibly provision of irrigation water.
- Extension services to the farmers (to be initially supported by the government if necessary).
- Quality control of irrigation equipment through standardization and issuance of quality marks for locally manufactured products by a national institute of standards.
- Access to agricultural credit so that farmers can purchase modern irrigation equipment. This may have to be subsidized initially, or may contain a grant element to provide sufficient incentive.
- The promotion of water user associations, especially where the supply of water in bulk would be possible.

Source: Van Tuijl (1993).

oped countries. Some irrigation districts in California have instituted incentive pricing rate structures to reduce the application of irrigation water, such as tiered pricing. Under tiered pricing, volumetric water rates are increased considerably for volumes exceeding a certain ceiling.

Measuring water volumes is expensive and prone to interference by landowners. Consequently, in most developing countries, water is charged per unit of irrigated land. In some countries, the unit rate varies with the type of crops, reflecting the higher average consumption of some crops such as sugar cane and rice. A few countries, such as Morocco and Brazil, use a two-part tariff for irrigation. For example, Brazil imposes a fixed charge to recover investment costs, and a variable part calculated to cover the operation and maintenance cost of the project. This approach has the advantage that there is a guaranteed income for the irrigation organization from the fixed part even when the variable part is negligible because of either a wet year (and hence no need to irrigate) or a dry year (when little irrigation water is available). This avoids the budgetary problems that arise when pure volumetric charging is used.

BOX 8.
OFFICE DU NIGER, MALI: FROM FAILURE TO SUCCESS

The Office du Niger, created for cotton cultivation in the 1930s, was managed by a government-owned company. For many years, the Office du Niger was an example of a centralized irrigation system with a heavy financial burden. In the 1950s, cultivation of cotton was abandoned and replaced by rice paddies because of the rapid increase in waterlogged conditions. The Office had a monopoly on buying crops, resulting in low farm gate prices. Under these conditions, there was little incentive for farmers to pay their water fees. O&M was neglected and the system was steadily breaking down. It was only maintained by direct government support.

A consensus was reached during the 1980s by all parties that the system had to be reformed. The monopoly was removed and farmers were given a role in the decisionmaking. Office expenditures were made transparent. The Office now concentrates on the essential functions of water services, planning, and maintenance. The paddy management and commercialization functions of the Office du Niger were progressively privatized. Water fee collection rates are now close to 100 percent in the well-rehabilitated zones. Modern water control systems were installed for the main conveyance of the distribution network and the paddy land was precisely leveled. These technical improvements made it possible to adopt high-yielding rice varieties, resulting in an increase of paddy yields from 1.5 to 6 ton/ha. Water use dropped from 1,500 m^3/ton to 250 m^3/ton, a 6-fold improvement in water use efficiency, leading to a decrease in the volume of water diverted for irrigation. This restructuring of the Office made it possible for the agronomic and economic performance of the project to improve dramatically.

Source: Couture, J.L. and P. Lavigne, 2000. Institutional Innovations and Irrigation Water Management in Office du Niger, Mali (1910-1990). World Bank Workshop on Institutional Reforms in Irrigation and Drainage; G. Diemer, 2002. Reform of Governance of the Office du Niger in Mali, International Network on Participatory Irrigation Management No 12, October 2002.

Some countries do not apply water charges because of cultural traditions–in some Islamic countries, water is regarded as a gift of God–or because water charges are assumed to be included in other taxation mechanisms such as land taxes (Indonesia and Thailand).

Methods of water charging that are not based on the volume of water delivered will have little or no impact on water conservation. Raising irrigation water fees does not provide an incentive to conserve water. To the contrary, an increase in water charges may give the impression that irrigators are entitled to use more water because they are paying more.

Charging for the volume of water consumed requires both physical and institutional infrastructure to be feasible and effective. Volumetric water charging requires a) the measurement of volumes of water used in order to assess charges; and b) the delivery of the water on a pre-arranged demand or on actual demand. Both conditions are rarely met in most large-scale public irrigation systems (Box 9). Most irrigation systems around the world have not been designed to adjust the delivery of water to the real-time demand of individuals or groups of farmers. Water is delivered on pre-arranged demand in most Latin America countries, including Mexico, Colombia, Brazil, and Argentina. In most parts of China, water delivery is based on scheduling that is pre-established with stakeholders.

In the 1970s and 1980s, a number of donor-financed projects supported the installation of simple measuring devices–such as staff gauges, weirs, or flumes–at the farm or group level to improve the management of canal irrigation systems. Today, most of these devices are not used and/or are not in working condition because of the manpower required for the repetitive reading of these manual devices. Additionally, these devices could only measure the flows, whereas in practice volumetric pricing requires devices that can both measure and control the flow of water, or at least total the volumes delivered.

In principle, it is easier to measure volumes used in pressurized irrigation systems using commercial meters with totalizers of volumes, similar to those used in the urban sector. However, in some projects, many of these devices become damaged if they are not under the responsibility of individual farmers, making it impossible to levy individual water charges. In the modernized Jordan Valley project, volumetric charges are applied, but water

BOX 9.
VOLUMETRIC WATER MEASUREMENT IN MOROCCO

User-friendly measuring devices, known as modular baffle distributors, that are insensitive to fluctuations in upstream water levels have been installed in surface irrigation projects in Morocco and other Mediterranean and Middle East countries. These devices only require readings of timings of opening and closings of constant-flow gates in order to calculate volumes. In Morocco, the project authorities generally use a fixed rotation for water delivery. The fixed rotation system was introduced when the schemes were set up because many of the farmers were new to irrigated agriculture and needed a simple water delivery method. Since the only option for users is to either take their turn in the imposed weekly rotation or forgo it, there is little incentive for water conservation in spite of the volumetric charging. These modern canal irrigation projects apply volumetric water charges and have the capacity to deliver water on pre-arranged demand. However, this capacity is not utilized.

To assess water bills in some sprinkler-irrigated areas in Morocco, the total volume measured at the pumping stations is divided between all the users, since the individual meters are generally not in working condition. Thus, Morocco is in the unusual situation of applying volumetric pricing to surface irrigation but not to pressurized systems where, in theory, it should be simpler to introduce.

is delivered on a rotational basis to control the use of very scarce resources, since the present water rate is too low for volumetric charging to have any effect on water consumption at the farm level. Consequently, this low-price, volumetric charging has no effect on water conservation.

Volumetric wholesaling of water from main canals to user groups provides a compromise between areal based and volumetric charges. Volumetric wholesaling to user groups is particularly effective because the farmers are collectively responsible for paying for the water, and so they conserve and equitably distribute water within the user group, often without individual measurements.

WATER RATIONING

Water rationing can have an immediate effect when annual or seasonal allocations exceed the irrigation crop requirements. Thus, irrigation deliveries for cotton cultivation in Uzbekistan were reduced from about 17,000 to 13,000 m^3/ha in the early 1990s without any significant effect on the crop yield.

PARTICIPATORY IRRIGATION MANAGEMENT

Public irrigation management organizations have little incentive to improve the performance of irrigation projects. On the other hand, users have a direct interest in efficiency and flexibility of water delivery because of their influence on profitability. Users would also be more likely to pay for the costs of I&D systems if they had influence over its operations, and their involvement in the management of I&D schemes would provide an opportunity to improve conservation of water.

By the mid-1980s, several countries started to implement irrigation management programs in which irrigators were encouraged to participate in operation and maintenance activities. Box 10 discusses two types of user associations. In Asian countries, such as the Philippines, Indonesia, and Pakistan, such programs consisted of a large-scale transfer of the lower level of canal irrigation systems to user groups, each one covering a few hundred hectares (from 50 to 200 hectares).

Participatory irrigation management took a different orientation in the late 1980s with the implementation of the 2-phase transfer programs in Mexico. In a first phase, now completed, user associations took over the financial and managerial responsibilities for operating the irrigation systems below the main canals. These associations cover areas ranging from 5,000 to 25,000 hectares. In the second phase, the responsibilities for managing the main canals are being handed over to limited-responsibility companies. The success of the transfer program in Mexico has encouraged other coun-

BOX 10.
SOCIAL AND BUSINESS USER ASSOCIATIONS

User associations can be formed as either "social" and "business" groups. The business associations are responsible for water distribution, fee collection, maintenance, conflict resolution, and representation of farmers in discussions with public agencies. These associations are legal entities that can enter into contracts. They have the power to enforce rules and regulations. The farmers are not directly involved in the management of their I&D systems; these associations hire professional staff for the actual management. On the other hand, members of social associations are expected to be involved in maintenance activities of the lower level of canal systems, and in some cases to assist government agencies in collecting irrigation service fees.

Many of the business associations have modernized their maintenance and administrative activities through acquisition of specialized equipment. They have also dramatically improved the collection rates of water charges.

tries, such as Turkey, to adopt the same approach with similar success.

Despite the widespread adoption of water user involvement programs, there is still little information about their impact on the performance of irrigation systems or on water conservation. Business-type associations have been much more successful than government agencies in recovering annual costs through higher charges and higher collection rates, and maintenance activities by the associations have stopped the deterioration of infrastructure in these systems. Nevertheless, the impact is not noticeable in terms of agricultural production, at least for projects that were previously managed by irrigation agencies according to well-established rules.

Some projects that were performing at a low level of efficiency before the transfer of responsibilities to user organizations have claimed a substantial increase in agricultural productivity. For example, in the state of Andhra Pradesh, India, the irrigated areas in individual schemes increased by between 5 to 10 percent after statewide irrigation reforms, including the creation of user organizations, were introduced in 1997.

Overall, the experience of the last 20 years shows that most institutional improvements are not fully effective without the right physical environment, and that physical and institutional improvements in irrigation need to be designed in a coordinated manner. Thus, the introduction of volumetric charging requires that the monitoring equipment and control techniques that are installed need to be commensurate with the staffing and skill levels of the irrigation authority.

COMMUNICATIONS STRATEGY

An effective communications strategy can serve a useful purpose–to instill positive attitudes and behavior changes–that can contribute to successfully implementing a water conservation program. It can contribute to a better understanding of institutional reforms and technological intervention by the water users, and facilitate greater participation of the stakeholders in the design and implementation of water conservation programs. Since the stakeholder interests are varied, an effective communication strategy needs to be able to reach and engage stakeholders through, but not limited to, processes involving consultations and communication in order to disseminate information, build consensus, and encourage sustainability of the reforms among stakeholders. Important elements of a good communications strategy are that it must be culturally sensitive, acceptable, and context specific for effective dissemination of information on the broader water sector reforms and how water conservation plays a central role in the reform process.

CONCLUSION

Agricultural water use will continue to dominate as the largest worldwide water user in the future and so major water savings are most likely to come from improved efficiencies in agriculture. These will require the application of both technical and institutional improvements. However, in all cases, water conservation in irrigation needs to be undertaken as part of basin-wide decisionmaking. Thus:

- In areas where there is little return flow or little groundwater recharge to be reused by downstream users, water conservation through technological improvements or policy changes is particularly desirable. However, the effect of water conservation on downstream water uses and the preservation of aquatic life and wetlands in coastal areas must be factored into these decisions.
- In areas where there is potential for the reuse of seepage water or runoff losses elsewhere in the basin, the solutions to conserve water in the upstream areas have to be traded off against reduced water supplies to other users within the irrigation areas.

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