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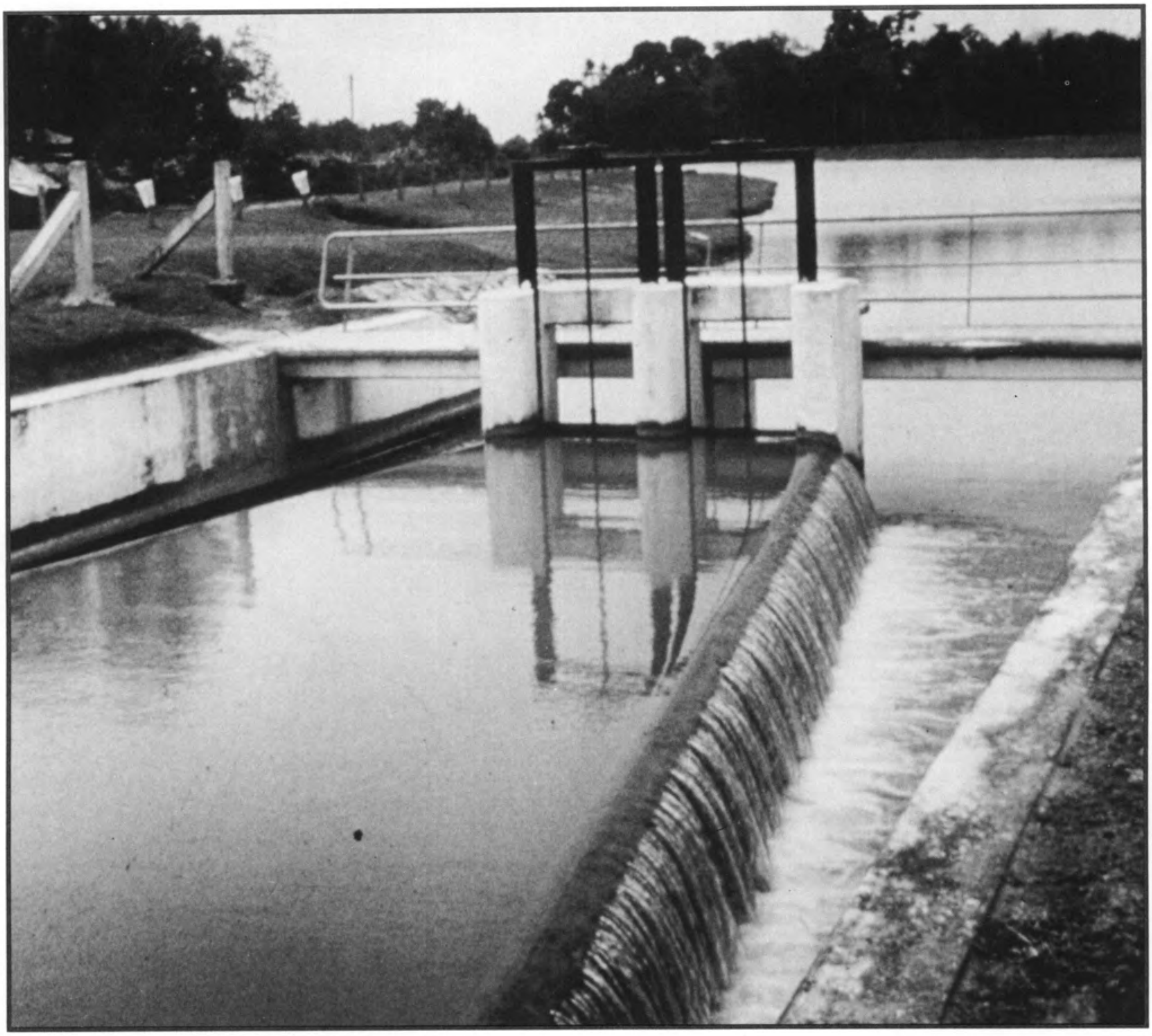
Using Water Efficiently

Technological Options

Mei Xie, Ulrich Küffner, and Guy Le Moigne



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(List continues on the inside back cover)

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ABSTRACT

The paper briefly examines sectoral water allocation in various countries and regions. It discusses and clarifies some of the definitions of water use efficiencies under various contexts, presents estimates of sectoral efficiencies in irrigation and domestic/industrial water use, and provides intensive country examples. By highlighting factors affecting water use efficiency, the paper reviews the technological and managerial options to improve water use efficiency, presents cost comparisons, and management implications of alternatives. The paper finally discusses the effectiveness of increasing water use efficiency from a river basin point of view, and presents conclusions and policy recommendations.

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FOREWORD

This review of the technological options for using water efficiently is a timely and valuable contribution to the work of the World Bank. Water Projects currently account for about 10-15% of the Bank's annual lending. Typically, such projects have focused on irrigation and drainage, water supply and sanitation, hydropower development, flood control, and river basin management. They play a vital role in the promotion of economic growth and reduction of poverty in the developing countries. Nevertheless, it has become apparent that increasingly complex design issues will need to be addressed in the coming years. Given the rapidly rising demand, water supplies are severely stretched. The situation can only worsen as the world's population grows, urbanization accelerates, standards of living rise, and human activities become more diversified. Issues of water use efficiency, always an important concern in water projects, will move to centerstage.

The World Bank's draft Water Policy Paper, discussed extensively both within and outside the Bank, addresses some of the new concerns. It emphasizes comprehensive water resources management. The promotion of water use efficiency through the adoption of appropriate technologies to increase water availability and efficiencies of water allocation and distribution is identified as an important element of water strategies designed to deal with growing water shortages, costly new supplies and environmental concerns.

This paper was prepared as an input into the process of developing the Bank's Water Policy. The Bank has also focussed squarely on environmental issues and on sustainable development. In the context of water, this has meant assisting the transition to an orientation towards conservation. The exploration of technological options for using water efficiently, discussed cogently and lucidly in this paper, is a step towards that objective.

Michel Petit

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TABLE OF CONTENTS

TABLES

FIGURES

I. INTRODUCTION

During the International Workshop on Comprehensive Water Management, held in June, 1991 in Washington D.C., participants from borrowing and donor countries repeatedly raised the issue of 'water use efficiency' (WUE). The promotion of WUE was identified as an important contribution eto the management strategy needed to address problems of water scarcity and costly new supplies. It was ranked high among the priority strategies that participants suggested the Bank should support.

As the concerns related to water scarcity, the high cost of new supplies, and pollution increase, 'increasing water use efficiency' has broadened in scope from the traditional irrigation sector to industrial, domestic and environmental areas.

Efficiency in water use can be measured in different ways. This paper focuses on technical efficiency --water required compared to water delivered. It will discuss the following questions:

- What are the current levels of WUE in the irrigation and urban sectors?
- What are the major causes of low WUE?
- What are some of the technological and managerial measures required to improve WUE? What are their cost implications? Are there limits to increases in efficiency?
- How should efficiency be considered from a river basin perspective? When is low efficiency appropriate? What are the economic and environmental implications of increasing efficiency at both project and basin levels?
- What are the policy changes required?

This paper starts with a brief examination of sectoral water allocation in various countries and regions. After clarifying definitions, the paper presents estimates of sectoral water use efficiencies (agriculture and urban), and illustrates findings with country examples. It highlights factors affecting WUE. The technological and managerial options to improve WUE are discussed next, followed by illustrative cost comparisons of alternatives. The paper also discusses the effectiveness of increasing water use efficiency from a river basin point of view. The last chapter concludes by making some policy recommendations.

II. SECTORAL WATER ALLOCATION IN COUNTRIES AND REGIONS

Worldwide, agriculture accounts for more than two-thirds of the total water resources used. Industrial uses amount to 23 percent and domestic use 8 percent. Table 1 shows global water allocation by sector in the six regions of the world: Africa, Asia, Europe, South America, North & Central America, and Oceania.

Table 1 Global Sectoral Water Allocation (%)

Region	Domestic	Industry	Agriculture
Africa	7	5	88
Asia	6	8	86
Oceania	18	16	66
South America	18	23	59
N/Cen.America	9	42	49
Europe	13	54	33
World	8	23	69

Source: World Resources Institute, 1990/91

Among the six regions, Africa takes the lead in allocating water to agriculture (88 percent), followed by Asia (86 percent). In this sense, both regions show a water use pattern that is strikingly different from the other regions. Industrial consumption dominates water use in Europe. This, in comparison to other regions, has led to a greater emphasis on reducing environmental pollution. South America and Oceania have the highest proportions of domestic water use.

Annex I (Table A1) presents information on sectoral water allocations in 145 countries. Data are obtained from the World Resources, 1990/91. Table A2 (a, b, c) ranks countries according to the share of water used in each sector.

Table A2a (agriculture): Most countries where agriculture uses more than 90 percent of water are in Asia and Africa. They include Pakistan, Sri Lanka, India and Nepal in Asia, and Sudan, Madagascar, Mali, Somalia and Senegal in Africa. A few South American countries, such as Guyana, Uruguay and Ecuador also have extremely high water allocations to agriculture. Countries which have allocated more than 60 percent of their water resources to agriculture are almost exclusively developing countries. Developed countries typically use less than 50 percent of their water resources in the agricultural sector.

Table A2b, A2c (industrial and domestic): Typically, countries with more than 70 percent of water distributed to industrial uses are developed rather than developing. Belgium and Finland have the highest percentage (85 percent) of water use in industry. Table A2c suggests that small states, such as Equatorial Guinea, Malta, Bahrain, Gabon, Kuwait and Togo, have a high share of water (more than 60 percent) allocated to domestic uses. This is due to the fact that agricultural activities are minor in such countries. While the complete data are given in Annex I, a few examples of countries with the highest (or the lowest) percentage of water use in each sector are shown in Table A2d.

There has been a noticeable trend of water allocation away from agriculture to urban uses. However, agriculture will continue to dominate water use for the foreseeable future. Table 2 presents some estimates of changes over time (both past and projected) in sectoral water allocation for a small sample of countries.

Although agriculture dominates water demands, especially in developing countries, water use efficiency in agriculture has always been lower than in other sectors. In many countries, water resources are becoming a limiting factor in agricultural production and economic development. Therefore, examining and improving WUE in various sectors, especially agriculture, is of crucial importance.

Table 2 Sectoral Water Allocations -historical/prediction comparison

Country	Year	Agri. (%)	Indus. (%)	Domes. (%)	Total (b.m^3)
Egypt	1990	88.0	5.0	7.0	59
	2000	86.7	8.8	4.5	69
Israel	1990	79.0	5.0	16.0	2
	2000	67.4	6.5	26.1	2
India	1974	92.7	4.0	3.3	424
	1990	93.0	4.0	3.0	552
	2000	91.6	4.0	4.4	750
Turkey	1990	74.6	11.8	13.6	43
	2000	71.9	12.6	15.5	58
China	1980	88.2	10.3	1.5	444
	1988	85.5	11.0	3.5	458
	1990	87.0	7.0	6.0	--
U.S.	1975	48.7	43.4	7.9	468
	1990	42.0	46.0	12.0	--
F.USSR	1975	63.2	32.0	4.8	331
	1990	65.0	29.0	6.0	--
Japan	1981	65.8	18.2	16.0	88
	1990	50.0	33.0	17.0	--
World	1975	74.0	21.0	5.0	3000
	1990	69.0	23.0	8.0	--

Sources: a) Proceedings of the June Water Workshop, 1991. b) World Resources, 1990/91

III. WATER USE EFFICIENCY

In distinguishing among the three major water using sectors--agriculture, industry and domestic--the difference between consumptive and non-consumptive water uses is often neglected and the concepts are often misused. Unlike most resources, water can be used repeatedly at different times and locations. The following examples may help to distinguish between the two.

- Examples of consumptive uses are: evaporation losses from reservoirs and during crop irrigation; evapotranspiration through plants and vegetation in agriculture and green urban areas; evaporation from cooling processes and water used in industrial products (e.g. soft drinks and food processing); and the drinking of water.

- Examples of non-consumptive uses are: hydropower generation; recreation; fishing; navigation; washing processes in industry; and cleaning in domestic uses.

- Changes in water quality, such as the concentration of pollutants, temperature and salinity level, affect water availability. Therefore, water quality deterioration during non-consumptive use reduces the availability of water for consumptive uses.

- Water losses through soil percolation and seepage in agriculture, or in urban environmental uses such as public parks and gardening, and maintaining flows in streams, can be classified in either group. It depends upon whether the water lost in one use is reused somewhere else.

What Efficiency Are We Talking About?

The word 'efficiency' relates outputs to inputs, and has different meanings in different contexts. In economics, efficiency usually relates financial (or adjusted financial) returns from water use to the cost of water supplies. In agronomy, efficiency relates the ratio of the volume of goods produced to the amount of water consumed.

In this paper, the concept under discussion is technical water use efficiency. It is the relationship between the amount of water required for a particular purpose and the quantity of water delivered. It is an important measure to guide conservation efforts for water resources. In addition, the effectiveness of water delivery can be another measure to evaluate the timeliness of supply, quantity, equity in allocation, and the quality of water. However, this concept of effectiveness is not covered in this paper.

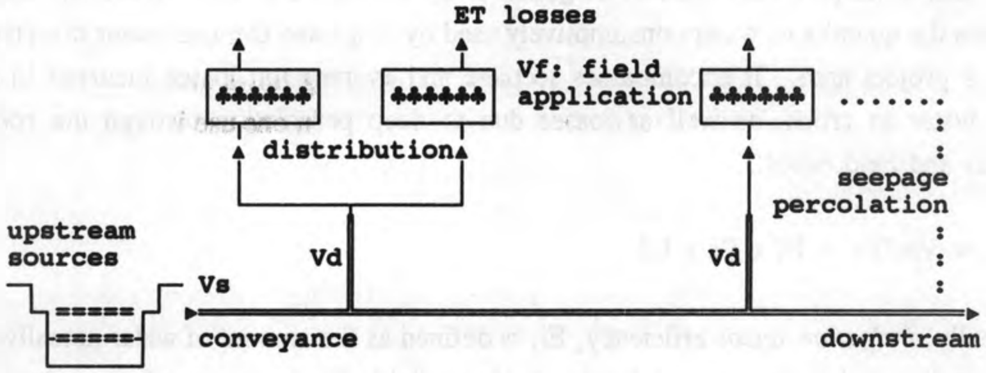
The technical efficiency criterion can be applied to different levels of water use, depending on how physical boundaries are defined. For instance, it can refer to a distribution system, a manufacturing enterprise, a field or an individual farm, a project area, a basin, or a sector. Debates about 'water use efficiency' are often based on an inadequate understanding and inconsistent use of the term 'efficiency'. In some cases, this confusion has led to faulty investment strategies, policies and actions.

The next section reviews the definitions of water use efficiency at various levels within different sectors. It then uses examples to illustrate the issues that are involved in evaluating WUE.

What Are Current Levels of Water Use Efficiency in Irrigation?

DEFINITIONS. In irrigation, the delivery of water from water sources to field crops depends on the efficiency in three main levels of an irrigation system: conveyance, distribution, and field (on-farm) application (Bos: 1983; 1990). Figure 1 illustrates the framework of analysis for a typical irrigation system.

Figure 1 An Irrigation Framework



i. *Conveyance* is the movement of water from its sources (reservoirs, river diversions, wells or pumping stations) through main and secondary canals to the tertiary offtake of a distribution system. Conveyance efficiency, Ec, is defined as:

Ec = Vd/Vs. where: Vs = volume diverted from sources plus inflows to the canal from other sources; Vd = volume delivered to the distribution system.

ii. *Distribution* is the movement of water from tertiary and distribution canals, channels or pipes to individual field inlets. Distribution efficiency, Ed, is defined as:

Ed = Vf/Vd. where: Vf = volume furnished to the field.

Often, the combined efficiency of a conveyance and distribution system is described as *irrigation network* efficiency, En. It is defined as the water delivered to farm field inlets divided by the water diverted from the prime source:

En = Vf/Vs = Ec x Ed.

iii. *Field application* is the movement of water from field inlets to crops. The field (or on-farm) efficiency, Ef, is defined as:

Ef = Vm/Vf. where: Vm = net volume needed to maintain the soil moisture, which is equal to the amount consumptively needed for evapo-transpiration, i.e. Vm = (crop water requirement) - (effective rainfall).

Another concept widely used in irrigation is the *overall* or *project* efficiency, Eo. It is the ratio between the quantity of water consumptively used by crops and the total water diverted from the sources to a project area. It encompasses seepage and evaporation losses incurred in physically conveying water to crops, as well as losses due to deep percolation through the root zone to groundwater and field runoff.

Eo = Vm/Vs = Ef x Ec x Ed.

Finally, *irrigation sector* efficiency, Ei, is defined as the amount of water actually consumed by the sector divided by the amount of water made available for the sector of a country.

EXAMPLES. Examples of WUE at different levels and project areas in selected countries are presented in Table 3 (a, b, c, d), incorporating data from several sources[1]. Later sections of this paper present a detailed analysis of the figures in Table 3. An overview comparing water use efficiencies between the developing countries and the United States is presented below.

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[1] The main sources are: a) "World Bank Experiences with Irrigation System Development", OED reports, 1990; b) Proceedings of the International Water Resources Management Workshop, June 1991; c) Asia Water Study, draft topic paper N.2, by H. Frederiksen, "Discussion of Some Misconceptions about Water Use Efficiency and Effectiveness", 1991; and d) "Improving Water Use Efficiency in the Agricultural Sector", EMENA Irrigation Sector Study, draft report by Van Tuijl W., 1992.

On average, the *network efficiency*, En, for developing countries has been estimated at 68 percent. Most countries show a range of 60-75 percent. The average En in the United States is estimated at 78 percent. According to the sources reviewed for this study, the *on-farm efficiency*, Ef, varies from 40-85 percent. In the United States, the Ef in the intensively developed areas ranges from 50-85 percent, with a national average of 53 percent. The average Ef in developing countries is around 40 percent. The *overall efficiency*, Eo, encompasses losses from conveyance, distribution and field application, and therefore varies widely. The Eo of many systems can be as low as 20 percent, such as in Yemen. Well-managed systems show efficiencies of 50 percent or more, such as in Cyprus. The average for developing countries is 30 percent. For pipe delivery systems in the United States, Eo varies from 30-80 percent, with a national average of 41 percent. Most cases cited in Table 3 show an Eo of less than 40 percent, except for Cyprus, Jordan and the two project areas in Doukkala in Morocco. All three cases, which have Eo values of more than 40 percent, reflect the impact of sprinkler, drip and advanced water control technologies. In Cyprus, for example, all irrigation water supplies in the public irrigation systems as well as all groundwater extractions are metered. This accounts for the high efficiency level. There is suggestive evidence that an overall efficiency of 45-55 percent may be a ceiling for a gravity system in the cultivation of non-paddy crops.

Table 3 Irrigation Water Use Efficiencies at Various Levels
Table 3a Network Level

Country	(%)	Specification
Cyprus	95	Pipe conveyance systems with sprinkler and drip[d]
U.S.	78	Average[c]
France	75-85	Bas-Rhone region, main canal 100% lined
Jordan	75	Open canals with manual control, on-farm storage & sprinkler/drip[d]
Morocco	74	Doukkala project with sprinkler system[a]
Morocco	72	Doukkala project with gravity system[a]
Morocco	70	Open canal systems with hydraulic control & surface irrigation[d]
West Bank & Gaza	74	Ec=87%, Ed=80-90% for distribution system of artesian wells[b]
Dev.g countries	68	Average[c]
Egypt	67	Ec=75% and Ed=89%[b]
Mexico	67	Sinaloa project[a]
Colombia	65	Coello project[a]
Mexico	61	Yaqui project[a]
Syria	60	Most schemes at 60% with upper limit of 75%[b]
Turkey	60	Traditional open canal systems with manual control[d]
Kyrghyzstan	55	poor design, built and maintenance of distribution canals[f]
Mexico	54	Panuco project[a]
Yemen	50	Large-scale spate irrigation[d]
Pakistan	45-60	Ec=75% and Ed=60-80%[b]

Table 3b On-farm Level

Country	(%)	Specification
East India	85	Rice irrigation on shallow soils over hard-rock areas[e]
Israel	75-80	nearly 100% by sprinkler irrigation[b]
Cyprus	70	Pipe conveyance systems with sprinkler and drip[d]
Jordan	70	Open canals with manual control, on-farm storage & sprinkler/drip[d]
Morocco	67	Doukkala project with sprinkler system[a]
Morocco	60	Open canal gravity systems with hydraulic control & surface irrigation[d]
Morocco	58	Doukkala project with gravity system[a]
Mexico	55	Both Yaqui and Sinaloa projects[a]
U.S.	53	50-85% in intensively developed areas[e]
Turkey	50	Traditional open canal gravity systems with manual control[d]
Syria	50	Basin irrigation method used[b]
Kyrghyzstan	50-60	15% by sprinkler system[f]
Mexico	48	Panuco project[a]
Colombia	45	Coello project[a]
Yemen	40	Large-scale gravity irrigation on the farm[d]
Dev.g countries	40	Average[e]

Table 3c Overall Level

Country	(%)	Specification
Cyprus	66	Pipe conveyance systems with sprinkler and drip[d]
Jordan	53	Open canals with manual control, on-farm storage & sprinkler/drip[d]
Morocco	49	Doukkala project with sprinkler system[a]
Morocco	42	Doukkala project with gravity system[a]
Morocco	42	Open canal gravity systems with hydraulic control & surface irrigation[d]
Kyrghyzstan	40-45	small stream reservoirs recapture part of drainage flow in Chu Valley, plus 10% groundwater use[e]
U.S.	41	Average[e]
Mexico	37	Sinaloa project[a]
Philippines	36	Upper Pampanga and Aurora projects[a]
Mexico	34	Yaqui project[a]
Turkey	30	Traditional open canal gravity systems with manual control[d]
Syria	30	[b]
Dev.g. countries	30	Average[e]
Colombia	30	Coello project[a]
Thailand	28	Two Lam Pao areas with high rainfall, low crop intensity in dry seasons[a]
Mexico	26	Panuco project[a]
Yemen	20	Large-scale gravity spate irrigation[d]

Table 3d Sector Level

Country	(%)	Specification
Egypt	89	Nile basin estimate[b]
U.S.	87	Based on data from 17 Western States of U.S.[c]
Israel	80	[b]
Ethiopia	60-80	[b]
Syria	60	Average[b]
Jordan	42	38% for surface distribution and 70% for direct pipe distribution[b]

Sources: a), b), c) and d) are reference sources referred before (see footnote 1); f) Le Moigne, 1992b

There is little data available on *sector efficiency* (Ei). In the United States, Ei has been estimated at 87 percent. Two reasons contribute to the high rate: i) the repeated use of water in different activities in a basin, or in several basins after inter-basin transfers take place, that results in improved efficiency. For example, in the seventeen Western States, 46 percent of irrigation waters are reused (Frederiksen, 1992). ii) intensive use of high irrigation technology. More than 40 percent of the irrigation lands are equipped with sprinkler systems and 3 percent with drip systems. Both systems use water more efficiently than other commonly used techniques. By contrast, the irrigation sector efficiency in Syria is 60 percent. The current flood irrigation method is the main cause of a low Ei. Water losses of 50 percent are common for such methods. Detailed analyses on Israel, Egypt and Jordan will be presented in the later sections of this paper.

Factors Affecting Irrigation Water Use Efficiency

Many factors affect WUE in the irrigation sector. They include seepage, percolation, soil depth and texture, evaporation and evapo-transpiration, design of irrigation structures and their operation and maintenance, and management skills. At various efficiency levels, climate and rainfall patterns, size of irrigated areas, and methods of water application also play important roles.

SEEPAGE AND PERCOLATION losses reflect irrigation water losses from unlined and poorly lined distribution canals, ditches, and from crop fields. In the Bas-Rhone region of France, main canals are entirely lined and well maintained. This results in a high network efficiency of 75-85 percent. In Pakistan, losses in conveyance systems are high. About 25 percent of the supplies diverted from rivers is lost in the canal system through seepage and evaporation before it reaches distribution inlets. From the inlets, losses through secondary watercourses have been measured at 20-40 percent. As a result, only 45-60 percent of the supplies diverted from rivers is actually delivered to the fields (Mulk, 1991). In Kyrghyzstan, seepage and leakage losses in the distribution system are also considerable. Only 24 percent of the canals are lined, resulting in a network efficiency of 55 percent (Le Moigne, 1992b). Seepage losses are sometimes reused elsewhere in the basin. This aspect will be discussed in Chapter V.

SOIL DEPTH AND TEXTURE can make a significant difference in efficiency levels. Two extreme examples are the Gezira scheme (Sudan) and East India. The Gezira irrigation system has an extremely high network efficiency of 93 percent (Plusquellec, 1990). Although the design of the minor canals is a contributing factor, the high efficiency is due mainly to the nature of the soil. The soil is highly impermeable and significantly reduces leakages from the system. These factors account for an overall efficiency level of 70 percent. In some areas in East India, soils are shallow and rice irrigation is performed over hard-rock areas. These effectively prevent water losses and lead to high field efficiency levels of about 85 percent (Frederiksen, 1992). Frederiksen's study also shows that water applications needed for rice production on heavy clay soils can be only a quarter of those on light textured soils. Canals passing through coarse materials, common in alluvial fans, can lose huge quantities of water.

EVAPORATION AND EVAPO-TRANSPIRATION losses are associated with open canals, irrigated fields and crop growth. In Egypt, the annual evaporation losses from irrigation canals are estimated at 2 billion m^3 (Abu Zeid, 1991). In Jordan, the high evaporation rates and seepage losses from open irrigation canals in the Jordan Valley are one of the main causes of water losses of up to 58 percent in the agricultural sector (Abu Taleb, 1991). The study by Abu Taleb shows that, if these losses are effectively reduced, the quantity of water savings could reach 50 million m^3 per year. Cyprus has a high network efficiency of 95 percent (Van Tuijl, 1992), due to complete pipe conveyance systems distributing water to the sprinkler and drip irrigated fields. The average on-farm efficiency is estimated at 70 percent, and overall efficiency 66 percent. The systems have successfully prevented losses from both seepage and evaporation.

FAILURES IN DESIGN OF IRRIGATION STRUCTURES contribute greatly to inefficient water use. Many systems were designed to meet only limited objectives, and are not suitable for modern agricultural practices. Technical constraints to these systems often limit the possibility for improvement through better management, such as in some areas of Ethiopia (Abate, 1991), where many canals in the small districts in the highland areas are unprotected against erosion. The headworks of canals are often washed away when floods occur.

Poor land leveling has been a constraint to proper on-farm water management. For instance, many areas in Upper Egypt that were converted to perennial irrigation after construction of the Aswan High Dam are not properly leveled. Fragmented land and small and separate holdings limit establishing efficient irrigation methods. Surface irrigation systems are used in most cultivated lands of the Nile Valley. The overall water use efficiency of individual farms is generally low. Farmers apply excessive irrigation water to reach areas at higher elevations. As a result, water which is not consumed by plants infiltrates and recharges groundwater or flows into the drainage system (Abu Zeid, 1991). Although downstream users along the Nile reuse a large part of the drained water, excess irrigation water leads to salinity problems by raising groundwater tables.

The main cause of high water losses in the irrigation systems of Kyrghyzstan is the poorly designed structure of distribution canals (Le Moigne, 1992b). As a result, the facilities for water control are underdeveloped. Most gates, manually operated, do not function because of poor maintenance and vandalism. Joints between units are often missing. By contrast, the main canals--particularly those downstream of large storage dams--are better designed and more advanced, with remote monitoring and automatic control. Maintenance of the equipment is of a high standard. Clearly, the appropriate design of irrigation systems is a prerequisite for effective operations and management.

LACK OF WATER CONTROL DURING NIGHT AND WEEKEND IRRIGATION is another problem in many developing countries. The study by Abu Zeid (1991) shows that, in Egypt, the average conveyance losses between main canal intakes and distribution outlets was 25 percent. That between the distribution outlets and fields was 11 percent. The combined effect leads to a network efficiency of 67 percent. The main reason for these losses was that farmers abstained from night irrigation. Irrigation networks were designed to operate for 24 hours a day. Thus, considerable amounts of water were drained wastefully at night, when irrigation was not practiced. As a result, some farmers faced water shortages during the day. A conservative estimate for Ethiopia shows that it is possible to increase the current irrigated area by 20-40 percent by reducing irrigation water losses during nights and weekends (Abate, 1991). In Sudan, the original design and operational concept of the Gezira scheme adopted night storage systems (Plusquellec, 1990). By adjusting water releases at the headworks according to demand, it was possible to reduce excessive water losses. Due to various reasons (see following section), the night storage system was not used for a period of time. It was re-introduced by the Government after revising the design of the minor canals (Zaki, 1991). The new system not only reduces operational water losses, but also reduces siltation in the minor canals downstream.

WEAKNESSES IN MANAGEMENT means poor implementation of water control regulations and operation rules, and inadequate maintenance. It is an important factor explaining water losses in the irrigation sector. Inadequate O&M has caused severe deterioration of irrigation canals in many countries. The two Lam Pao projects in Thailand are examples of losses due to poor maintenance of irrigation diversion structures (OED, 1990). The two projects showed lower than expected efficiencies (28 percent instead of the 55-58 percent estimated at appraisal). The main reason for water losses is seepage from the main canals. Although the canals were lined, cracks and breakages occurred all over the canal linings because of failures in maintenance and inadequate weed cleaning in the tertiary system. As a result, there was little difference in seepage losses between lined and unlined canals. The same is true for some project areas in the Philippines (AST, 1991). In Egypt, for nearly 25 percent of existing canals, the actual widths exceed the design widths due to degradation and the misuse of canal banks. This has consequently changed water levels and canal discharges (Abu Zeid, 1991).

The regulations for managing water systems are often inadequately designed to meet variable supplies and demands. In Sudan, for instance, irrigation management operates on the basis of 'upstream control'. The Ministry of Irrigation controls the delivery of water to the heads of minor canals. From there on, field inspectors have the responsibility for supervising the rotational delivery of water to the fields. Farmers or farmer organizations handle the on-farm water management. This division of responsibility has been problematic. Farming programs, which determine crops, cropped area, rotation and cropping intensity, often have not been reflected adequately in the water delivery programs (Zaki, 1991).

CLIMATE PATTERNS AND EFFECTIVE RAINFALL affect irrigation water use efficiency. Reviewing previous definitions, the actual irrigation requirement, Vm, is the crop water requirement minus effective rainfall. Under-irrigation or over-irrigation in different seasons artificially affects efficiency levels.

The Philippines Upper Pampanga River Integrated Irrigation System (UPRIIS) is a typical example. Table 4 shows the overall efficiency, Eo, during both seasons for three continuous years. Eo is higher in the dry season. In the wet season, Eo is low due to high rainfall. There were apparently not enough incentives for farmers to save excess water from the run-of-river system. In fact, project staff reported that during wet seasons farmers complained more often about flooding from uncontrolled river flows and high rainfall than about water shortages. The low efficiency level of 20-30 percent reflected more the virtual absence of a need to use river flows and rainfall effectively, than the actual technical inefficiency in the system. Under-irrigation during dry seasons also artificially increased efficiencies.

Table 4 Overall Efficiency for Two Seasons
(Philippine UPRIIS projects)

	1986	1987	1988
Wet season	23.3	32.5	28.0
Dry season	54.6	46.9	52.0

Source: OED report, 1990

A similar phenomenon has been seen in areas of Lam Pao in Thailand and in the Panuco basin in Mexico (OED, 1990). In some project areas, high rainfall occurs in the wet season and low cropping intensity is practiced during dry seasons. The average overall irrigation efficiencies in those areas is below 30 percent. In Thailand, the estimated overall irrigation efficiency varied widely, from 8-51 percent in the wet season, and from 17-70 percent in the dry season (Vadhanaphuti, 1991), depending on the physical condition of the infrastructure and the availability of water.

Under these circumstances, a distinction should be made between water diverted and water pumped or released from reservoirs. If water is released at the expense of a storage or reservoir, pumping costs and delivery operations, it will affect the operational efficiency of these facilities. Will surplus water cause problems of drainage, flooding, water logging, and salinity in downstream areas? Alternative indicators need to be used to measure water use efficiency in such cases.

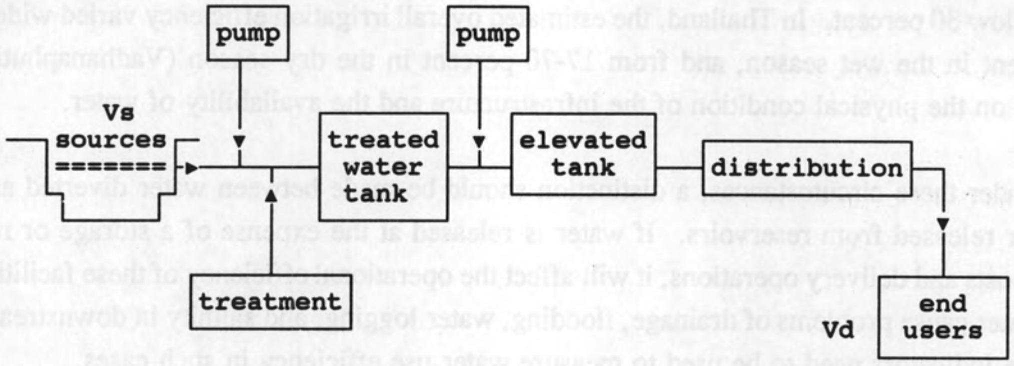
METHODS OF WATER APPLICATION are an integral part of optimal water use. There are many references on WUE levels under different application methods. Syria is an example where the technique of basin (flood) irrigation is widely practiced. This method can cause water losses of more than 50 percent (Bakour, 1991). Irrigation network efficiencies are 60 percent in most of the agricultural schemes of the country. Of the total water use of currently 10.3 billion m^3 in the agricultural sector, more than 4 billion m^3 is lost every year. Excessive irrigation without well-designed drainage networks causes a rise in groundwater levels, leading to increased salinity and lower agricultural productivity. In Yemen, the spate irrigation method is widely practiced. According to a study by Van Tuijl (1992), the overall WUE is 20 percent, much lower than the developing country average. Although spate irrigation has a low efficiency, it is a commonly practiced method to economically capture flood waters for irrigation. It also recharges the groundwater aquifer, from which the water is pumped for reuse in irrigation.

Water Use Efficiency in the Urban Sector: Definitions

DEFINITIONS. Urban water use encompasses both industrial and domestic activities. The latter includes residential and commercial (services, office buildings, and public parks) uses. Figure 2 illustrates a typical urban water supply system. Similar to the descriptions used in irrigation, *conveyance* efficiency, Ec, in this setting is defined for systems between water sources and water treatment centers. *Distribution* efficiency, Ed, which is the main indicator of the overall effectiveness and operation and maintenance performance of an urban water supply system (usually in pipes), is defined for systems between treatment centers and end-users (households, factories, public standbys),

$$E_d = Vd/Vs$$

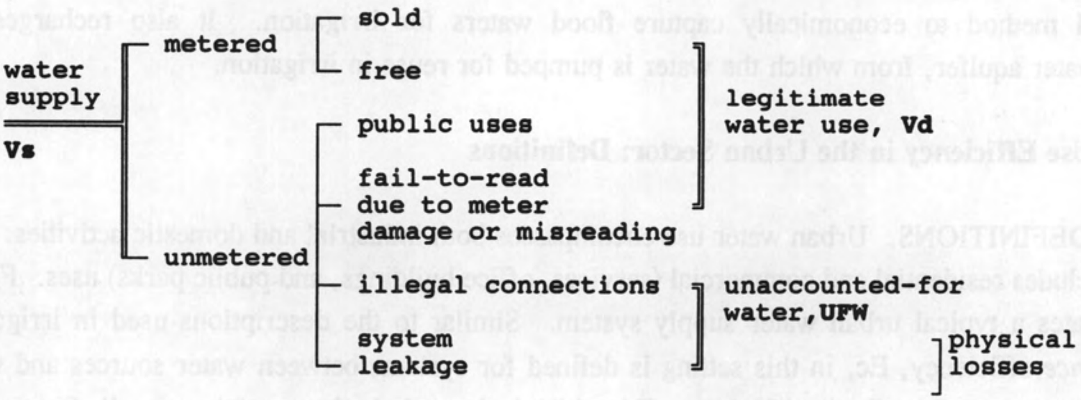
Figure 2 Urban Water Supply System



In urban water supply projects, one common measure of Ed is through use of an indicator called *unaccounted-for* water (UFW), i.e. UFW = Vs - Vd (see Figure 3), therefore,

$$E_d = (Vs-UFW)/Vs = 1-UFWr$$

Figure 3 Losses and Illegal Water Use



where: UFWr = UFW/Vs, standing for the ratio of unaccounted-for water.

However, there seem to be different ways of defining Vd in urban sector water use, which has led to the inconsistent use of the term, UFW. Here are some examples from Bank documents.

- The Bank's Working Guidelines on 'The Reduction and Control of Unaccounted-for Water', prepared by the INU Department (Jeffcoate, 1987), defines UFW as the difference between the volume of water delivered into a supply system, Vs, and the volume of water accounted for by legitimate consumption, Vd, whether metered or not. As illustrated in Figure 3, by this description UFW consists of two parts: i) physical leakages from distribution pipelines, house connections, valves, and hydrants; and ii) illegal connections (non-physical losses). Since un-metered water is not necessarily lost, legitimate consumption, Vd, includes the amount of water metered, intentionally un-metered for public uses (such as fire service, street cleaning, construction, and public buildings), and the amount of water unrecorded due to meter damage and lapses in reading.

- However, there seems to be some ambiguity about including un-metered public water uses as part of unaccounted-for water. The Working Guidelines also state that the UFW includes "water consumed but not recorded by consumer's meters or otherwise accounted for by government/public use".

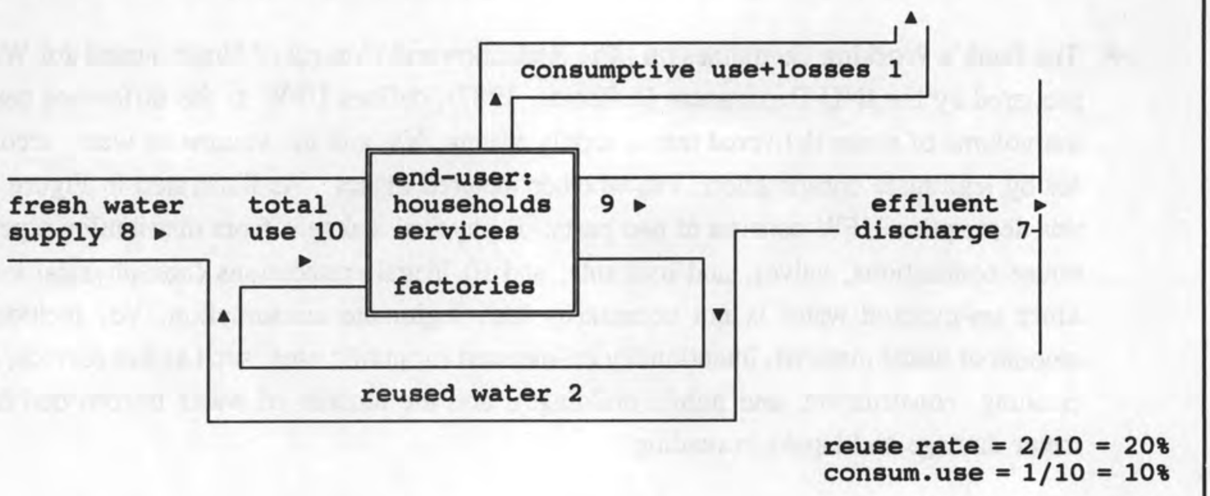
- A Planning Manual published by the Bank (Okun, 1987) defines UFW as the difference between the measured produced water and the metered water used.

- A recent OED report (1992) defines UFW as 'the difference between the measured volume of water input into a system and the amount of water sold'.

This inconsistency in the definition of unaccounted-for water may lead to non-comparable evaluations of efficiencies in urban water supply projects. A generally agreed definition would avoid such problems.

Unlike the field efficiency in irrigation, end-user efficiencies in the urban sector are classified into: *industrial consumptive use*, Eic; *domestic consumptive use*, Edc; and *overall urban sector use*, Eu. Figure 4 illustrates the concepts with simple numerical examples. Consumptive use of water in industry includes evaporation losses (such as cooling processes in thermal, steel and manufacturing industries), the amount used in products (such as food processing and beverage industries), and unaccounted-for losses (such as leakage). Although the leakage losses should be differentiated from consumptive uses, it is usually difficult to separate them out because the estimate of consumptive water use is usually obtained from the amount of water supplied less the amount discharged into the sewers or rivers.

Figure 4 Water Use, Reuse and Consumption in Urban Systems



Factors Affecting Urban Water Use Efficiency: Examples

Table 5 presents some statistical data on the distribution network efficiency of urban water supply systems in several countries. Israel has the highest efficiency of 87 percent, or 13 percent for unaccounted-for water (Schwarz, 1991). This can be attributed largely to the highly flexible and integrated national water supply system, the National Water Carrier. The Carrier distributes about 2,000 million m^3 of water annually. Because the system is energy-intensive, the unit cost of water supply is high. The costs vary from US$0.03/m^3 at low lifts with short distance conveyance schemes, to US$0.50/m^3 at high lifts with long distance conveyance schemes, and reach US$4/m^3 for desalinated water. These high costs of water production provide strong motivation for efforts to achieve a high level of efficiency. In the United States, distribution efficiency is also high, around 83-88 percent, or UFWr at 12-17 percent (Frederiksen, 1992). The main reasons are the highly developed distribution networks and metering systems. By contrast, high levels of UFW of up to 50 percent are common in many developing countries (e.g., Turkey and Egypt). The network efficiency of the urban sector in many developing countries ranges between 50-75 percent.

Poor operation and maintenance of supply facilities cause leakages in supply systems. The inappropriate implementation of regulations, failure to meter and illegal tapping are also causes for inefficiencies in the urban water sector.

LEAKAGE is a critical problem in urban water supply. It accounts for a large part of water losses, especially in areas where metering regulations are weak. Old or poorly constructed pipelines, inadequate corrosion protection, poorly maintained valves and mechanical damage are major contributing factors. One effect of water leakage, besides the loss of water resources, is the reduction in pressure in the supply system. Raising pressure to make up for such losses increases energy consumption. Not only does that make leaking worse, it also has adverse environmental impacts.

Table 5 Urban Water Distribution Network Efficiency (%)

Country	Effi.	UFW	Note
Israel	87	13	1990 data
United States	83-88	12-17	1984 data[a]
Jordan	75	25	1990 data
Sudan	75-77	23-25	most cities
Ethiopia	70	30	Addis Ababa
Turkey	50	50	Ankara,Istanbul,1990
Egypt	50	50	1990 data
Dev'g. country	50-75	25-50	average[a]

Sources: Le Moigne, et.al. 1992a; a) Frederiksen, 1992

Studies carried out by the Addis Ababa Water and Sewerage Authority in Ethiopia (Abate, 1991) show that leakages from the urban distribution system could reach 30 percent. In Turkey, in most municipalities, water leakages in the distribution network have reached levels that are far from acceptable (Bilen, 1991). Urban water supply losses in Ankara and Istanbul were estimated at 50 percent in 1990. The main reason was inadequate renewal and maintenance of the system. Interruptions in water delivery were usual. Many cities in Sudan experience considerable losses of water supplies. The average water losses were estimated at 25 percent (Table 6). These figures are relatively low compared with other developing countries. They are, however, costly, especially when there are serious shortages of water in the country. In some countries of the Nile basin, urban water losses are almost twice as high. In Egypt, urban domestic water use was 3.1 billion m^3 in 1990. Distribution losses were 50 percent (Abu Zeid, 1991). The country is planning to maintain the present level of domestic water use in the year 2000 (with an increase of 14 million people), mainly by reducing losses from 50 percent to 20 percent.

WATER METERING is still inadequate in many towns and cities. Users are charged a flat fee no matter how much water they consume. Illegal tapping and un-metered public uses are more significant in areas where there is metering but regulations are not adequately enforced. The inefficiencies result partly from large government subsidies that vary among users. Even where metering is carried out, inadequate testing, meter reading and maintenance continue to be severe problems in many countries. For example, in Jordan, the municipal supply systems serve more than 440,000 recorded residential, commercial and light industrial users. The urban demand in 1990 was 210 million m^3, with per capita water use of 190 l/day. The losses in the municipal and industrial sectors were 25 percent (Abu Taleb, 1991), due to aging pressure pipes and inaccurate meters. The illegal diversion of water to bypass meters was significant. If the losses can be reduced to 15 percent, for example, by investing in the rehabilitation of supply networks, potential water savings are estimated at 100 million m^3 per year.

Table 6 Urban Water Losses
(Sudan, 1990) (m^3)

Region	Demand	Losses	(%)
Khartoum	250,000	62,500	25.0
Eastern	41,250	10,200	24.7
Northern	21,860	5,400	25.0
Darfur	6,800	1,700	25.0
Kordofan	22,700	5,500	24.0
Central	67,560	16,000	23.8
Total	410,170	101,300	24.6

Source: Zaki, 1991

Studies by Okun (1987) show that, in general, a 10-20 percent allowance for unaccounted-for water is normal. But a ratio of more than 20 percent requires priority attention and corrective actions. A review of 54 Bank-financed water supply and sanitation projects found that the average ratio of unaccounted-for water was 34 percent (Jeffcoate, 1987). The recent Bank review of 120 urban water supply and sanitation project completion reports identifies unaccounted-for water as a severe problem in urban water supply projects. This problem requires substantial corrective investment (OED, 1992).

THE EFFICIENCY OF CONSUMPTIVE WATER USES in the domestic and industry sectors is usually affected by technologies used in the production processes, structure of industry, and the style of living and standards of urban households. Pricing policies also play a role at this level.

A study by Frederiksen (1992) shows that, in the United States, the efficiency of consumptive water use, Eic, in industry as a whole is 16 percent and that of thermal power generation is 3 percent. In Beijing (China), the Eic is estimated at 29 percent (Xie, 1986). As water becomes scarcer, the development of new technologies in industrial processes has to be directed towards producing more goods with less water. Efficiency of domestic consumptive water use, Edc, in developing countries is estimated at 35-85 percent, with a per capita water use of 15-40 l/day (Frederiksen, 1992). This efficiency level is higher than in some industrialized country cities, whose average Edc is 10-20 percent with per capita water use at 350-600/day. The explanation for low urban sector efficiency levels in the developed countries may lie in the style and higher standards of living. For example, developed countries use more water to water public parks, green areas, yards and gardens, in environment and recreation, and in residences for water appliances.

IV. MEASURES TO IMPROVE EFFICIENCY: TECHNOLOGICAL OPTIONS

Improving WUE is a critical aspect of comprehensive water resources management. Technological options include use of better technologies and improvements in management skills. A study carried out by OED and AGR (Plusquellec, 1990) found that, despite the extent and range of Bank investment in the water sector, little analysis had been undertaken to compare the efficiency of alternative engineering approaches. The following section focuses on the technological aspects of improving water use efficiency, which consist of preventing losses and promoting reuse. Both efforts increase the availability of water at user levels.

Reducing Seepage, Leakage and Percolation Losses in Irrigation

Technological measures to reduce seepage, leakage and percolation losses in irrigation include the lining of canals and watercourses, and promoting modern irrigation technologies such as pipe, sprinkler and drip systems.

CANAL LINING. The study by Frederiksen (1992) indicates that in dry climates a well operated lined system delivering water to well organized farmers can reduce network losses to less than 5-10 percent. The conveyance and distribution efficiency (En) can reach 90-95 percent. Mountain type irrigation systems, involving river diversions with unlined canals in pervious soils, often show water losses of over 30-35 percent, i.e., an En of 65-70 percent. Groundwater supply suffers lower network losses due to short conveyance distances and frequent use of pipe delivery systems.

Some examples are illustrative. The irrigation canal system in the Bas-Rhone region of France has an En of 75-85 percent due to complete lining of canals. In some areas of the North China Plain, the En of lined canals reaches 75-80 percent (El-Hanbali, 1990). In Pakistan, efforts to improve WUE have been made by lining the minor canals and small distribution channels under a pilot project in the Command Water Management Program. Noting the scarcity of water resources, many areas have the potential to absorb the high costs of lining, especially because of the improved potential for growing high value crops (Mulk, 1991). However, with today's technology, in many places it may not be economical nor practical to line all canals. The key is to determine the type of technology most suitable to local conditions.

LOW PRESSURE PIPES. Low pressure pipe irrigation is technically viable. It has been introduced recently in several developing countries. For example, in the North China Plain, where water shortages are severe, it is the main water-saving technique that has been adopted. Systems using low-pressure buried pipes have water conveyance and distribution efficiencies as high as 90 percent, compared to 50-60 percent for earth canals (El-Hanbali, 1990). In Anhui and Shangdong provinces, compared with earth canals, water savings of 40 percent have been achieved at the field level. Where groundwater is used, the water savings are 20-25 percent. This has also led to a reduction in energy consumption for pumping by 20-40 percent. The complete pipe conveyance systems in Cyprus produce a network efficiency of 95 percent (Van Tuijl, 1992). Such systems successfully prevent unnecessary losses from both seepage and evaporation.

SPRINKLER SYSTEMS. Sprinkler irrigation sprays water over the fields. A sprinkler system consists of a pumping unit, a pressurized pipe conveyance network, and a set of nozzles. Its favorable features are: high level of field WUE; uniform water distribution over the field, which increases yields; and minor dependence on the condition of the soil surface. When sprinkler irrigation is practiced during the night, water losses can be further reduced due to lower evaporation losses. However, sprinkler systems have high initial capital costs and require good maintenance. Running costs are high due to energy consumption during operation. Moreover, sprinkler irrigation is not equally effective for all crops.

Experience in Israel shows that through sprinkler irrigation, field efficiency levels can reach 75-80 percent (Schwarz, 1991). According to studies by the U.S. Soil Conservation Service in California, the on-farm efficiency of sprinkler irrigation is 60 percent for hot dry areas, 70 percent for areas with temperate climates and 80 percent for areas with humid or cool climates. The figures in Table 3b illustrate high rates of field irrigation efficiency in Cyprus (70 percent), Jordan (70 percent) and Morocco (67 percent), mainly due to the application of sprinkler and drip irrigation. Irrigation sector efficiency is estimated at 87 percent in the United States, where more than 40 percent of the irrigated areas have sprinkler systems and 3 percent have drip systems.

DRIP SYSTEMS. Drip irrigation is the slow drop-by-drop, localized application of water, at a grid just on top of the soil surface. There are also subsurface drip systems, in which drip irrigation laterals are buried 20-60 cm below the soil surface (Phrone, 1992). Drip irrigation saves water by reducing the size of the wet soil surface, thus decreasing the amount of direct evaporation and excess percolation through the root zone. Unlike sprinklers, drip irrigation is practically unaffected by wind conditions, nor is it affected by soil surface conditions. Soil is maintained in a continuously moist condition. Nutrients can be applied through the drip systems, thus reducing use of fertilizers and improving quality of returned water. Increases in water use efficiency in drip irrigation, compared to conventional basin/furrow irrigation, are attributed to both water savings and the increase in yields resulting from favorable soil moisture and nutrient regimes.

Israel has achieved a modernization of irrigation techniques and increased irrigation efficiency by introducing drip systems and computerized automatic water control. The improvements over the past years have made it possible to increase significantly both the area under irrigation and agricultural production, without increasing water use (Schwarz, 1991). Table 7 illustrates the significant reduction of water requirements per unit of production in 1984, due mainly to application of modern irrigation technologies, compared with conventional irrigation used in 1970. For example, the reduction of water demand is about 60 percent for the production of potatoes, apples and bananas, and about 30 percent for avocadoes and cotton. In the San Joaquin Valley of California, where there is no precipitation during most of the growing season for tomatoes, subsurface drip irrigation has been recommended. Experiments show that a yield as high as 150-200 tons/ha can be achieved by using the subsurface drip system together with accurate water and fertilizer management (Phrone, 1992).

Jordan has converted 60 percent of its total irrigated area in the Jordan Valley to drip systems (Abu Taleb, 1991). As a result, average yields for vegetables and fruits more than doubled. The use of drip irrigation techniques in Syria resulted in a 45 percent reduction in water consumption, compared to sprinkler techniques, where the reduction was 20 percent (Bakour, 1991).

Table 7 Comparison of Water Requirements in Israel
(liters/kg yield)

	Potato	Cotton	Citrus	Avocado	Apple	Banana
1970	250	1400	240	1220	550	1700
1984	100	1000	200	800	250	650
Reduction (%)	60	29	17	34	55	62

Source: Schwarz, "Israel Sector Water Study", 1991

The capital costs of drip irrigation systems are higher than for sprinkler systems, because large quantities of pipes, tubes, filters, emitters and ancillary devices are required to deliver water to the crops. Routine maintenance requirements are also high. Due to the higher water quality required in such systems, water may need to be treated. Drip emitters must be inspected regularly, and cleaned or replaced whenever blockages or damages occur. Changes in water pressure easily affect discharges. However, the long-term operating costs of drip systems could be reduced through the savings in water and energy compared to sprinkler irrigation.

Worldwide, modern technologies such as sprinkler and drip systems have been applied to only about 3 percent of the land under irrigation. However, this varies significantly by country. In Morocco, sprinkler irrigation accounts for 12 percent of the total irrigated area (Van Tuijl, 1992). In Kyrghyzstan, it is estimated at 13 percent (Le Moigne, 1992b). In Egypt, it is 21 percent (Abu Zeid, 1991). In Israel, it reaches nearly 100 percent. The Asia Region is currently conducting an identification study of sprinkler and drip irrigation development in India. Preliminary information shows an area of about 600,000 ha irrigated by sprinkler and drip methods (drip accounts for 4 percent) (El-Hanbali, 1992). This is about 1 percent of the total irrigated area in the country. The Government projects this area to grow to 1.7 percent in the year 2000.

Cost Comparisons of Sprinkler and Drip Systems

Three examples in India, U.S. and Israel can give an indication of the costs involved in installing and operating these modern technologies.

Table 8 presents estimates of costs of alternative irrigation systems in the U.S. (California), Israel and India. The capital costs of sprinkler systems in the United States average at $2,000/ha, which is slightly lower than $2,200/ha in the Israel, but much higher than $800-900/ha in India. The annual costs of sprinkler systems in the United States is $440/ha, compared with $580/ha in Israel.

Table 8 Costs of Alternative Irrigation Systems in U.S. (California), Israel and India ($US/ha)

Method of Irrigation	Initial costs			Annual costs	
	U.S.	Israel	India[a]	U.S.	Israel
Sprinkler:					
wheel line	1,620	--	--	350	--
center pivot	2,400	--	--	390	--
hand move	1,150	--	790/900	410	--
field crops	--	1,220	--	--	170/350
truck crops	--	2,700	--	--	500/850
citrus trees	--	1,600	--	--	350/850
tow move	1,500	1,400	--	510	250/550
permanent set	3,340	--	--	550	--
truck crops	--	4,120	--	--	700/1,200
Average	2,000	2,200	850	440	580
Drip:					
fruit trees	--	--	460/710	--	--
crops & vege.	--	--	890/1,430	--	--
Surface:					
Border checks	1,400	--	--	300	--
Furrows	1,000	--	--	480	--

Source: Hillel, 1987; a) El-Hanbali, 1992

In India, a recent survey (El-Hanbali, 1992) shows that the capital cost of the widely used portable sprinkler system is Rs.10,000-12,000/ha (about US$360-430 at Rs.28.0/US$ exchange rate) excluding pumps and motors, and Rs.22,000-25,000/ha (US$790-900/ha) including pumps and motors. Drip irrigation systems cost Rs.13,000-20,000/ha (US$460-710/ha) for fruit trees, and Rs.25,000-40,000/ha (US$890-1,430/ha) for row crops and vegetables. The range of costs largely depends on spacing and the type of equipment used. Most of the areas were developed by the private sector using subsidies from the Government. The Government has been promoting the use of these modern technologies by giving capital subsidies to small farmers in several States, such as Maharashtra, Karnataka and Tamil Nadu. The current value of the subsidy for using drip irrigation is 50 percent of capital costs. The installation of both drip and sprinkler systems has been expanded quickly in these states as a result of effective policies, incentives and financial subsidies.

The benefits of applying these modern technologies include potential savings in water, fertilizer, and possible increases in crop yields. The total benefits estimated in the study in India was at Rs.6,000-20,000 per ha per year (about US$200-700), depending on crops and market prices. The high capital cost of installation is justified in the United States and Israel by intensive cultivation of high-valued cash crops. The ready availability of qualified personnel, technical services and spare parts help the adoption of these technological improvements.

Preventing Evaporation and Evapotranspiration Losses

Evapotranspiration (ET) losses are too costly to recover under present technological conditions. Most ET losses occur in agricultural water use. Little can be done to decrease evapotranspiration from crops. The use of chemical sprays, known as 'anti-transpirants', have not been very successful in large scale applications.

However, there are several ways to reduce losses from evaporation. Experience in some countries shows that controlling evaporation losses from the water surface of small reservoirs can achieve large savings. It is especially true for sources for industries and domestic water supplies. Attempts to reduce evaporation from the surface of large reservoirs have not been successful. This is mainly because winds break up protective layers on the water surface. During the droughts of 1987/88 in India, 30 percent of the water, which would otherwise have been lost by evaporation from small reservoirs, was saved by spreading chemicals or plastics on the surface of the water (Chitale, 1991). The cost was about Rs. 3/m^3 (US$0.11), which was far less than the cost of transporting water from elsewhere. By contrast, in agriculture, a more effective way to conserve irrigation water is at the farm level rather than at the sources. Evaporation losses from exposed farm surfaces are usually at least 10 times greater than those from small reservoirs (Chitale, 1991).

Experience shows that evaporation losses during water distribution are not significant in comparison with the amount of water delivered to irrigation fields. In long canals located in arid zones, evaporation losses may be less than 2-8 percent (Frederiksen, 1992). Sometimes, long canals loose no water or even gain from effective rainfall during the wet seasons. Thus, it is the crop evapotranspiration and field evaporation losses that require most attention.

One technique to prevent evaporation losses from field surfaces is the porous pots irrigation. This technique employs a series of interconnected unglazed porous pots. These pots are buried in the soil with only the openings of the pots above the ground for filling them with water. Seeds are planted around each pot, which slowly releases moisture into the soil near plant roots. This is similar to a drip system which minimizes evaporative losses, but more economical regarding capital investment and O&M.

The technique can be traced back several hundred years to Northern Africa. Recently, UNESCO (1984) started major promotional efforts under regional projects on the Use and Conservation of Water Resources in the Rural Areas of Latin America and the Caribbean. Because of its simplicity, the technique appears to be preferable, in many regions (such as Brazil and Argentina), to high-investment, high-technology irrigation approaches. Because the pots can be manufactured locally, the method proves to be cost-effective. It also creates jobs in local communities.

A similar technique was applied successfully in the south-east areas of Zimbabwe, where the climate is semi-arid. In 1988, the Institute of Hydrology of United Kingdom, the Lowvelt Research Station of Zimbabwe, and the British Geological Survey began a collaborative project on the 'Development of Small-Scale Irrigation Using Limited Groundwater'. Irrigation trials were conducted to quantify water use efficiencies of alternative low-cost methods for small-scale schemes. These methods included using of unglazed porous clay pots, surface clay pipes, and mulch covered irrigation. Their results showed that a high efficiency was possible using these simple and low-cost methods. Each method was potentially more efficient than the traditional flood irrigation (Lovell, 1992). For example, the mulch covered irrigation used only 43 percent of the water used by traditional flood irrigation.

Promoting Water Reuse

As water problems become more critical and an increasing constraint to the further expansion of agricultural areas in many regions, the reuse of urban and industrial wastewater and agricultural drainage water is likely to become a major issue. For many developing countries, water reuse will go hand in hand with seeking new sources of water.

The following statistics illustrate the relative importance of wastewater as a source of irrigation water in arid regions of the world. Extensive agricultural areas surrounding major cities are irrigated with wastewater, to give some examples--1.3 million ha in China, 10,000 ha in Melbourne (Australia), 16,000 ha in Santiago, Chile (which represents 70 percent of the total amount of dry season irrigation), 90,000 ha around Mexico City (which is 80 percent of the total dry season irrigation) (Bartone, 1991).

Another example is the case of Beijing, China. The percentage of reused industrial water rose from 46 percent to 72 percent from 1978 to 1984. While total industrial output increased by 80 percent, the corresponding water consumption actually declined slightly (Chen, 1991). Table 9 shows the reuse rates of water in different subsectors of industry in Beijing. For instance, the water reuse rates in the metal and chemical products industries were higher than 80 percent, and in thermal power generation 78 percent (Xie, 1991). Given the large amount of water consumed in these subsectors, significant water savings were achieved through water reuse. The machine manufacturing industry had a reuse rate of 36 percent, which was still low compared with 70 percent in the United States[2]. Experience in Beijing shows that water recycling can be cheaper than providing additional water over long distances.

The promotion of water reuse leads to the essential question of water quality control. Since the reuse of water has environmental and health implications, effective monitoring is essential. The lack of adequate water treatment standards is a problem in many countries. In India, cities such as Pune, Ahmedabad, Madras, and Delhi have begun to use sewage for irrigation. But there are no standards determining the levels of treatment of domestic and industrial effluent and their use for irrigating crops. Therefore, the introduction and enforcement of monitoring and quality control must be part of policies for promoting water resources reuse.

Table 9 Water Reuse in Beijing (million m^3, 1984)

Sector	Fresh Water Use	Reused Water	Reuse (%)
Metal and metal products	100.6	540.2	84.3
Chemical products	195.8	816.6	80.7
Power generation (thermal)	296.5	1090.3	78.6
Coal	22.0	44.6	67.0
Textile	55.1	79.9	59.2
Paper and paper products	25.1	20.1	44.5
Construction materials	45.4	30.1	39.8
Machine manufacturing	106.0	60.1	36.2
Wood manufacturing	6.4	2.2	25.6
Food & beverage manufacturing	44.4	13.2	23.0
Leather	3.7	0.6	12.9
Cloth	3.9	0.1	3.0

Source: Mei Xie, 1991

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[2] US Department of Commerce, Statistical Abstract of the United States, 1987.

Improvement of Efficiency Through Better Management

Appropriate water management is crucial for obtaining high water use efficiency and reliable water supplies. Although offering opportunities for water saving and increasing yields, modern irrigation technologies will not be effective without a reliable operational system. Effective management is not a post-construction matter. It should be integrated into the planning, design and construction process. Here are some critical considerations to improve management skills.

ENSURING A RELIABLE WATER SUPPLY from main conveyance systems to tertiary units in irrigation sector should be a primary operational goal of an irrigation project, either from run-of-river flows or from regulated storage supplies. Adequate management of the main system is a prerequisite to achieve good farmers' participation in O&M. Measures include flow control, scheduling delivery (also quick responses to sudden drops in demand to avoid wasting water), staff training and motivation, and appropriate communications and transportation facilities. Experience shows that a system designed to minimize the frequency of staff intervention and simplify operating procedures and technical training usually contributes to efficient water distribution (Plusquellec, 1988).

THE SOIL-WATER-PLANT RELATIONSHIP is a critical consideration in on-farm water management. Through an understanding of interactive relationships governing the soil-crop-water regime, farming systems can maximize the production per unit of water. Different physical properties of soils have different holding capacities and water intake rates, which will influence decisions on the method of field application, frequency, flow rate, and duration of irrigation water delivery. Crop zoning is a management option for improving WUE. New developments in water control, such as high-frequency but low-volume water applications, have made it possible to provide water in response to crop needs in a timely manner.

THE LEVEL OF ON-FARM WATER MANAGEMENT SKILLS can be more important for high field efficiency than the method of application. For example, Egypt launched a national program in 1985 for optimization of water use to reclaim new lands and improve land productivity. Farmer organizations were established to improve on-farm management skills to ensure the successful operation and maintenance of the irrigation system (Abu Zeid, 1991). The water saving through the implementation of this program was between 10-15 percent. The average increase in agricultural productivity was 30 percent. The study by OED (1990) shows that proper management could sometimes be more appropriate than the introduction of a sophisticated irrigation system. In Morocco, the network efficiency was raised from 74 percent to 80 percent, and field application efficiency from 67 percent to 70 percent, through better water management practices, rehabilitation of land levelling and quaternary canals.

GOOD MAINTENANCE through periodic clearance of silt and weeds in distribution systems is critical to efficient water use. The Gezira scheme in Sudan is an example where poor maintenance has led to the malfunctioning of the system operation. The scheme functioned well for 40 years until the early 1970's (Plusquellec,1990). From the 1970's, shortly after the scheme reached its present extension, a steady deterioration of the irrigation system took place. Due to lack of maintenance and breakdown of communication systems, the canals were infested with weeds and silt started to accumulate. The problems became so serious that the water transit capacity in the canals, especially in the minors, was reduced significantly. Improper use of the system, inadequate rehabilitation of deteriorating movable weirs made it more difficult to maintain the indented discharge into the minor canals. In some places, no water reached the farmers' fields. As a result, the original design of night storage system gave way to a continuous water delivery to the fields.

CONJUNCTIVE USE OF SURFACE AND GROUNDWATER has also been identified as one of the means for improving WUE. Effective conjunctive use usually requires policy changes to rationalize the interaction among reservoir regulations, groundwater pumping, canal diversions, and the physical response of aquifer systems. One such example is the Krishna-Godavari basins in India (Chitale, 1991). To reduce water losses and to cope with water scarcity in the basins, crops were limited to areas where the irrigation water required between January-May could be obtained from groundwater. Paddy production was limited to the rainy season, to areas of high rainfall, or to valleys to take advantage of seepage from upland irrigation. Crop patterns that did not require stored water after February were adopted because, by then, the reservoirs could be emptied to prevent high evaporation losses that mostly occurred between March-May. In Pakistan, 20 percent in production output have been observed from effective conjunctive water use (Mulk, 1991).

DISSEMINATION through public campaigns and model demonstration of improved practices and better management should not be neglected. The approach of model demonstrations has been effective in Israel. The country launched a four-year national campaign, aiming at information dissemination on efficient water systems and devices. The campaign included field trials, demonstrations, and financial support for purchasing and installing new devices. It has resulted in water savings of about 10 percent, mostly from improved sprinkler and/or drip irrigation (Schwarz, 1991).

DEMAND MANAGEMENT through transparent and enforceable legislation, administration and pricing measures can regulate water use and improve WUE. The instruments include rational water pricing, water allocation through regulating and licensing, and specifying the quantities and the timing of water application. Improved planning mechanisms help to allocate water to high economic efficiency uses. Personnel training and setting up reliable data networks are needed to assure accurate monitoring of the performance of water supply systems. These aspects are, however, beyond the scope of this paper.

V. RIVER BASIN MANAGEMENT: WHEN IS LOW EFFICIENCY APPROPRIATE ?

Basin Water Use Efficiency

Improving WUE can often offer opportunities for conserving water and increasing water availability. Therefore, governments have made great efforts and investments to improve water resources management through the application of technologies in the urban and agricultural sectors. Such investments are intended to reduce water losses and to increase water availability at local levels. However, when entire river basins are considered, the issues become more complex.

In a river basin, how will increased local water use efficiency affect the availability of water for other users? From a basin point of view, how much water is actually saved by using better technologies such as lining, pipes, sprinkler and drip systems? WUE may be viewed differently for farmers, management of an irrigation project, or a river basin authority. The answer is usually positive at project, irrigation network or farm levels. At the level of an entire basin, however, the answer depends on specific basin hydrogeological and socio-economic characteristics.

The hydrological processes of a basin provide downstream users with return flows from upstream uses. For any given level of water use efficiency, E, we define the 'loss' by (1-E). The lower E is, the greater is(1-E). However, much of (1-E) in the upstream areas may be reused downstream. The sequential location of irrigation projects from the upper reaches down to the basin tributaries and rivers allows for the recovery and reuse of most water 'lost' through low project efficiencies at different levels upstream. Thus, within a basin, when water is 'lost' through one use but can be reused downstream, it is not actually lost.

The interrelationship between water diversion by users upstream and users and aquifers downstream leads to another important concept--the WUE at a basin level. *Basin water use efficiency*, Eb, is the ratio of the amount of water beneficially consumed in the basin to the amount of utilizable water resources entering the basin.

For example, using the overall water balance in the Nile Basin in Egypt, the basin efficiency is estimated at 89 percent (Keller, 1992), although the WUE of individual irrigation projects are generally lower, as discussed previously. Similarly, for the UPRIIS project in the Philippines, only a small amount of water leaves the downstream part of the Upper Pampanga Basin. The basin efficiency is high due to reuse of water, despite relatively 'low' efficiencies of individual schemes (Israel, 1990).

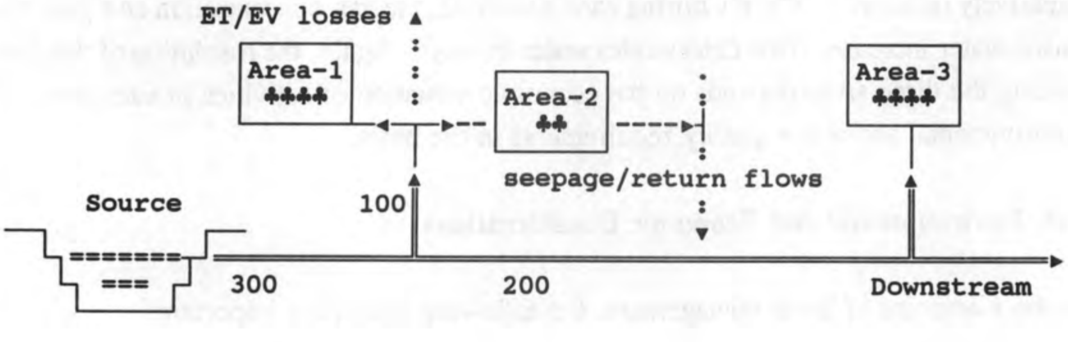
Impact of Increasing Local WUE of a Basin

Some studies argue that a high basin water use efficiency leaves little room for conserving water by simply increasing efficiencies at local levels (Keller, 1992; Frederiksen, 1992). This implies that localized increases in WUE may have little effect on basin wide efficiency if there is potential for reuse of the seepage and runoff losses within the basin.

However, the evaluation of whether a certain level of local WUE is undesirable or appropriate, or of whether only basin efficiency matters, should be related to an evaluation of a basin's hydrogeological features and the pattern of its water resources utilization and development.

A simple example is given below to illustrate the impact--both favorable and unfavorable--of increasing localized WUE in the context of a basin. The concept underlying this example is simple to grasp. A detailed numerical simulation is given in Annex II.

Figure 5 Impact of Increasing Water Use Efficiency



Let us assume that the source (e.g., a reservoir) provides 300 units of water to various users in the basin (Figure 5). Of this, 100 units are diverted through conveyance and distribution canals for irrigation to Area-1, the remainder flows downstream to Area-3. An intermediate section, Area-2, does not receive water directly from the source (as do Area-1 and 3). Instead, it relies on return flows from Area-1, after using the water for irrigation. It is also assumed that Area-1 has an initial irrigation network efficiency of 60 percent (i.e., of the 100 units diverted from the source, only 60 reach the field). What happens if we raise the efficiency level to 70 percent? Let us examine alternative water use configurations in the basin:

i. The irrigated land in Area-1 is either expanded, or kept constant to make a larger volume of water available to reach downstream users (e.g. Area-3).

ii. Since Area-2 depends on return flows from Area-1, a higher efficiency of 70 percent in Area-1 in either of the above cases would result in a decline in water availability in Area-2.

iii. There is, therefore, a trade-off among Area 1, 2 and 3. Production levels can be maintained or increased in Area-1, and will fall in Area-2, and will either increase or be maintained in Area-3 depending on the choice made for Area-1. The resolution of this trade-off depends on the socio-economic valuation of activities in each area of the basin.

iv. Let us assume that some of Area-3's water supply is also derived from return flows from Area-2. The increase in efficiency in Area-1 could either lead to expanding the irrigated area and reducing return flows to Area-2, and by extension to Area-3, or result in increased water savings and increases in direct water supplies to Area-3. An obvious benefit of the latter is improved water quality downstream due to increased direct water flows in the river or canal, as opposed to return flows. Water lost due to seepage, percolation, spills and runoff during each use-cycle can be reused as long as its quality is not severely degraded. As water is progressively reduced by EV/ET during each use-cycle, the salt concentration and pollutants in reused water increase. This deteriorates water quality[2]. Again, the resolution of the trade-off among the three areas depends on the economic valuation of activities in each area, and on environmental and water quality requirements in the basin.

Technological, Environmental and Economic Considerations

From the viewpoint of basin management, the following points are important:

i. Where there is little return flow or little recharge to be reused by downstream users, increasing WUE through technological and managerial improvements is recommended. For instance, near coastal areas, waters are discharged to the sea. In some areas, return flows enter saline groundwater or salt sinks, resulting in salinity and water quality problems for reuse. In neither case can the water be reused for irrigation, industrial or urban consumption without treatment. Under these circumstances, since the lost water cannot be recovered, increasing localized WUE results in an increase in water availability of a basin.

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[2] A recent study by Keller (1992) shows how the salinity of drainage water and irrigation water build up as a result of ET/EV.

ii. However, the sole measurement of water availability is not enough to decide whether a local WUE should be increased and, if so, to what extent. One environmental dimension of situation i) is the problems of salinity and preservation of estuary ecosystems. An environmentally sound decision needs also to consider protection of aquatic life and wetlands in coastal deltas and estuaries. A minimal stream flow should be maintained in the rivers. An extreme example is the deterioration of the Aral Sea. The massive diversions of the Syr Dar'ya and Amu Dar'ya rivers, which originally flowed into the lake, took place since the 1960s to expand irrigated areas for cotton cultivation. As the rivers dried up slowly, the lake shrank by 66 percent. Fishery production collapsed. The lake became famous for its extremely high salt concentration (Levintanus, 1992). Even the basin climate changed as a result of the reduced surface of the lake, and the high soil salinity.

iii. Localized increases in WUE may have little effect on basin wide efficiency if there is a potential for seepage water or runoff losses to be reused elsewhere in the basin. This is even truer in cases where the return flows and runoff can be repeatedly used downstream. Under these situations, increasing agricultural production per unit of water used in the upstream areas of a basin may not serve the purpose of water conservation in the whole basin. Increasing WUE upstream, thus making more water available to upstream users, has to be traded off against lower water supplies to downstream users who depend on return flows.

iv. Increasing WUE upstream has a merit of improved water quality downstream, as illustrated earlier. That is, by releasing more fresh water to downstream areas, higher WUE in the upstream area has a favorable environmental impact on water quality.

Another technological dimension of water reuse is for conjunctive water use. In some places, water use efficiencies are intentionally kept low and irrigation canals are intentionally unlined. The purpose is to increase seepage recharging to groundwater for conjunctive operations, especially during low runoff years.

The criteria of technical efficiency should not be the only ones on which to judge water use. At the basin level, the concept needs to be expanded by an evaluation of economic efficiency, especially when high pumping costs are involved. The following factors should be considered in the evaluation: costs of physical improvements of water supply systems; benefits from production increments; and costs of water pumping and re-pumping. From the farmers' perspective, the financial returns are directly affected by benefits from water use, the prices achieved for crops, costs of high water use efficiency, water charges, and taxes. In addition, other factors such as groundwater table, salinity, water rights, water availability, and timing of delivery are also important. Together, these factors eventually determine optimal efficiency.

VI. CONCLUSIONS AND POLICY RECOMMENDATIONS

There is evidence that a worldwide shift in water resources allocation from agriculture to the urban sector is taking place, especially in developing countries. However, agricultural water use will continue to dominate in the foreseeable future. Major water savings are most likely to come from improving efficiencies in agriculture. Consequently, the Bank's water policy should, in dealing with water use efficiency issues, be focused on these aspects.

Technologically, there is great potential to improve water use efficiency in both the agriculture and urban sectors. Despite demonstrated success in water saving and favorable experience in many developing countries, advanced technologies, such as sprinkler and drip systems, are applied to less than 3 percent of the world's irrigated lands.

A focus on the technological dimension of water use leads to the following conclusions:

- At the basin level, investment decisions need to be based on more comprehensive views of basin water use when considering whether a certain level of local efficiency --for example, conveyance and distribution, field, or overall project -- is appropriate or should be increased.
- In areas, where there is little return flow or little recharge to be reused by downstream users, increasing local WUE through technological applications and managerial improvements is recommended. However, consideration should be given to the environmental dimension of the decision on issues such as preservation of aquatic life and wetlands in coastal deltas and estuary ecosystems.
- In areas, where there is potential for the reuse of seepage water or runoff losses elsewhere in the basin, especially where return flows are used repeatedly downstream, the technological solutions and investments in the upstream areas to improve localized water use efficiency, thereby making more water available to upstream users, has to be traded off against lower water supplies to downstream users. Such investments should be evaluated from the viewpoint of water conservation in the whole basin. Improving low efficiency upstream to release more fresh water to downstream areas has a favorable environmental impact on water quality. It also generates economic benefits/savings in areas where costs for water pumping are high.

Before adopting technical options for improving WUE, the economic, technical, social and environmental objectives need to be specified clearly. It is important, at this stage, to understand the hydrogeological and hydrological linkages among the different project areas of a basin. Water conservation projects should be appraised considering the impact of projects on the water balance of river basins, based on adequate hydrological information. Efficiency levels and technologies should be selected to meet the specified objectives to avoid uneconomic investments, and to achieve sustainable and successful water development.

Technological decisions need to be integrated closely with evaluations of economic efficiencies. Water conservation should be viewed in a cross-sectoral rather than sectoral context. For instance, the premium on water saving in irrigation water should be evaluated not merely on the basis of the productivity of saved water in agriculture. Increases in crop production are only the first order of benefits to be evaluated. The contribution to additional industrial growth and the development of other water dependent activities that can be generated, particularly in areas where further development is hampered by shortage of water, needs to be incorporated into such measurements.

The Bank should promote policies that accelerate the transition from water-consuming to water-saving economies. These policies should lead to the strengthening of management approaches to optimize overall water use, considering the contribution of water to the productivity in the various sectors; and the promotion of water reuse as an integral part of water resource development projects. In view of the potential impact of water reuse on health and environment, the reinforcement of monitoring and quality control should be part of design of water resources reuse programs. To evaluate Bank financed projects, technological measures to increase water use efficiency at the basin level should be determined based on the overall water use in the whole basin, and at the local level should be selected based on costs, social and environmental consequences.

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ANNEX I

Sectoral Water Allocation by Country

(145 countries)

Table A1 Sectoral Water Allocation (%)

Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.
Afghanistan	1	0	99	Ghana	35	13	52	Nigeria	31	15	54
Albania	6	18	76	Greece	8	29	63	Norway	20	72	8
Algeria	22	4	74	Guatemala	9	17	74	Oman	3	3	94
Angola	14	10	76	Guinea	10	3	87	Pakistan	1	1	98
Argentina	9	18	73	Guinea-Bissau	31	6	63	Panama	12	11	77
Australia	16	7	77	Guyana	1	0	99	Papua N.Guinea	29	22	49
Austria	19	73	8	Haiti	24	8	68	Paraguay	15	7	78
Bahrain	60	36	4	Honduras	4	5	91	Peru	19	9	72
Bangladesh	3	1	96	Hungary	9	55	36	Philippines	18	21	61
Barbados	52	41	7	Iceland	31	63	6	Poland	16	60	24
Belgium	11	85	4	India	3	4	93	Portugal	15	37	48
Benin	28	14	58	Indonesia	13	11	76	Qatar	36	26	38
Bhutan	36	10	54	Iran	4	9	87	Romania	8	33	59
Bolivia	10	5	85	Iraq	3	5	92	Rwanda	24	8	68
Botswana	5	10	85	Ireland	16	74	10	Saudi Arabia	45	8	47
Brazil	43	17	40	Israel	16	5	79	Senegal	5	3	92
Bulgaria	7	38	55	Italy	14	27	59	Sierra Leone	7	4	89
Burkina Faso	28	5	67	Jamaica	7	7	86	Singapore	45	51	4
Burundi	36	0	64	Japan	17	33	50	Solomon Island	40	20	40
Cameroon	46	19	35	Jordan	29	6	65	Somalia	3	0	97
Canada	18	70	12	Kampuchea	5	1	94	South Africa	16	17	67
Cape Verde	9	2	89	Kenya	27	11	62	Spain	12	26	62
Central Africa	21	5	74	Korea, Dem Peo	11	16	73	Sri Lanka	2	2	96
Chad	16	2	82	Korea, Rep	11	14	75	Sudan	1	0	99
Chile	6	5	89	Kuwait	64	32	4	Suriname	6	5	89
China	6	7	87	Lao	8	10	82	Swaziland	5	2	93
Colombia	41	16	43	Lebanon	11	4	85	Sweden	36	55	9
Comoros	48	5	47	Lesotho	22	22	56	Switzerland	23	73	4
Congo	62	27	11	Liberia	27	13	60	Syria	7	10	83
Costa Rica	4	7	89	Libya	15	10	75	Tanzania	21	5	74
Cote d'Ivoire	22	11	67	Luxembourg	42	45	13	Thailand	4	6	90
Cuba	9	2	89	Madagascar	1	0	99	Togo	62	13	25
Cyprus	7	2	91	Malawi	34	17	49	Trinidad/Tobag	27	38	35
Czechoslovakia	23	68	9	Malaysia	23	30	47	Tunisia	13	7	80
Denmark	30	27	43	Mali	2	1	97	Turkey	24	19	57
Djibouti	28	21	51	Malta	76	8	16	Former U.S.S.R	6	29	65
Dominican Rep	5	6	89	Mauritania	12	4	84	Uganda	32	8	60
Ecuador	7	3	90	Mauritius	16	7	77	United Arab Em	11	9	80
Egypt	7	5	88	Mexico	6	8	86	United Kingdom	20	77	3
El Salvador	7	4	89	Mongolia	11	27	62	United States	12	46	42
Equator.Guinea	81	13	6	Morocco	6	3	91	Uruguay	6	3	91
Ethiopia	11	3	86	Mozambique	24	10	66	Venezuela	43	11	46
Fiji	20	20	60	Myanmar	7	3	90	Viet Nam	13	9	78
Finland	12	85	3	Nepal	4	1	95	Yemen Arab Rep	4	2	94
France	16	69	15	Netherlands	5	61	34	Yemen, People'	5	2	93
Gabon	72	22	6	New Zealand	46	10	44	Yugoslavia	16	72	12
Gambia	7	2	91	Nicaragua	25	21	54	Zaire	58	25	17
Germany	12	69	19	Niger	21	5	74	Zambia	63	11	26
								Zimbabwe	14	7	79

Table A2a Sectoral Water Allocation by Country - Ranked by proportion used in agriculture (%)

Country	Domest.	Indust.	Agricu.
Sudan	1	0	99
Madagascar	1	0	99
Afghanistan	1	0	99
Guyana	1	0	99
Pakistan	1	1	98
Mali	2	1	97
Somalia	3	0	97
Bangladesh	3	1	96
Sri Lanka	2	2	96
Nepal	4	1	95
Kampuchea	5	1	94
Yemen Arab Rep	4	2	94
Oman	3	3	94
India	3	4	93
Yemen, People'	5	2	93
Swaziland	5	2	93
Iraq	3	5	92
Senegal	5	3	92
Honduras	4	5	91
Morocco	6	3	91
Gambia	7	2	91
Cyprus	7	2	91
Uruguay	6	3	91
Myanmar	7	3	90
Ecuador	7	3	90
Thailand	4	6	90
El Salvador	7	4	89
Cuba	9	2	89
Dominican Rep	5	6	89
Costa Rica	4	7	89
Cape Verde	9	2	89
Sierra Leone	7	4	89
Chile	6	5	89
Suriname	6	5	89
Egypt	7	5	88
Guinea	10	3	87
Iran	4	9	87
China	6	7	87
Mexico	6	8	86
Ethiopia	11	3	86
Jamaica	7	7	86
Lebanon	11	4	85
Botswana	5	10	85
Bolivia	10	5	85
Mauritania	12	4	84
Syria	7	10	83
Chad	16	2	82
Lao	8	10	82
United Arab Em	11	9	80
Tunisia	13	7	80
Zimbabwe	14	7	79
Israel	16	5	79
Paraguay	15	7	78
Viet Nam	13	9	78
Australia	16	7	77
Mauritius	16	7	77
Panama	12	11	77
Albania	6	18	76
Indonesia	13	11	76
Angola	14	10	76
Libya	15	10	75
Korea, Rep	11	14	75
Tanzania	21	5	74
Guatemala	9	17	74
Niger	21	5	74
Algeria	22	4	74
Central Africa	21	5	74
Argentina	9	18	73
Korea, Dem Peo	11	16	73
Peru	19	9	72
Rwanda	24	8	68
Haiti	24	8	68
South Africa	16	17	67
Cote d'Ivoire	22	11	67
Burkina Faso	28	5	67
Mozambique	24	10	66
Jordan	29	6	65
Former U.S.S.R	6	29	65
Burundi	36	0	64
Greece	8	29	63
Guinea-Bissau	31	6	63
Mongolia	11	27	62
Spain	12	26	62
Kenya	27	11	62
Philippines	18	21	61
Fiji	20	20	60
Liberia	27	13	60
Uganda	32	8	60
Italy	14	27	59
Romania	8	33	59
Benin	28	14	58
Turkey	24	19	57
Lesotho	22	22	56
Bulgaria	7	38	55
Nigeria	31	15	54
Nicaragua	25	21	54
Bhutan	36	10	54
Ghana	35	13	52
Djibouti	28	21	51
Japan	17	33	50
Papua N.Guinea	29	22	49
Malawi	34	17	49
Portugal	15	37	48
Malaysia	23	30	47
Saudi Arabia	45	8	47
Comoros	48	5	47
Venezuela	43	11	46
New Zealand	46	10	44
Colombia	41	16	43
Denmark	30	27	43
United States	12	46	42
Brazil	43	17	40
Solomon Island	40	20	40
Qatar	36	26	38
Hungary	9	55	36
Trinidad/Tobag	27	38	35
Cameroon	46	19	35
Netherlands	5	61	34
Zambia	63	11	26
Togo	62	13	25
Poland	16	60	24
Germany	12	69	19
Zaire	58	25	17
Malta	76	8	16
France	16	69	15
Luxembourg	42	45	13
Yugoslavia	16	72	12
Canada	18	70	12
Congo	62	27	11
Ireland	16	74	10
Czechoslovakia	23	68	9
Sweden	36	55	9
Norway	20	72	8
Austria	19	73	8
Barbados	52	41	7
Equator.Guinea	81	13	6
Iceland	31	63	6
Gabon	72	22	6
Kuwait	64	32	4
Belgium	11	85	4
Bahrain	60	36	4
Switzerland	23	73	4
Singapore	45	51	4
United Kingdom	20	77	3
Finland	12	85	3

Table A2b Sectoral Water Allocation by Country - Ranked by proportion used in indutry (%)

Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.
Belgium	11	85	4	Argentina	9	18	73	Jordan	29	6	65
Finland	12	85	3	Albania	6	18	76	Dominican Rep	5	6	89
United Kingdom	20	77	3	Guatemala	9	17	74	Thailand	4	6	90
Ireland	16	74	10	South Africa	16	17	67	Tanzania	21	5	74
Switzerland	23	73	4	Brazil	43	17	40	Iraq	3	5	92
Austria	19	73	8	Malawi	34	17	49	Chile	6	5	89
Yugoslavia	16	72	12	Colombia	41	16	43	Suriname	6	5	89
Norway	20	72	8	Korea, Dem Peo	11	16	73	Egypt	7	5	88
Canada	18	70	12	Nigeria	31	15	54	Honduras	4	5	91
France	16	69	15	Korea, Rep	11	14	75	Niger	21	5	74
Germany	12	69	19	Benin	28	14	58	Burkina Faso	28	5	67
Czechoslovakia	23	68	9	Equator.Guinea	81	13	6	Israel	16	5	79
Iceland	31	63	6	Liberia	27	13	60	Central Africa	21	5	74
Netherlands	5	61	34	Ghana	35	13	52	Bolivia	10	5	85
Poland	16	60	24	Togo	62	13	25	Comoros	48	5	47
Hungary	9	55	36	Kenya	27	11	62	Sierra Leone	7	4	89
Sweden	36	55	9	Venezuela	43	11	46	Algeria	22	4	74
Singapore	45	51	4	Cote d'Ivoire	22	11	67	India	3	4	93
United States	12	46	42	Zambia	63	11	26	Mauritania	12	4	84
Luxembourg	42	45	13	Indonesia	13	11	76	El Salvador	7	4	89
Barbados	52	41	7	Panama	12	11	77	Lebanon	11	4	85
Bulgaria	7	38	55	Lao	8	10	82	Oman	3	3	94
Trinidad/Tobag	27	38	35	Angola	14	10	76	Guinea	10	3	87
Portugal	15	37	48	Mozambique	24	10	66	Morocco	6	3	91
Bahrain	60	36	4	Libya	15	10	75	Ecuador	7	3	90
Romania	8	33	59	New Zealand	46	10	44	Senegal	5	3	92
Japan	17	33	50	Botswana	5	10	85	Ethiopia	11	3	86
Kuwait	64	32	4	Bhutan	36	10	54	Myanmar	7	3	90
Malaysia	23	30	47	Syria	7	10	83	Uruguay	6	3	91
Formal U.S.S.R	6	29	65	Iran	4	9	87	Yemen Arab Rep	4	2	94
Greece	8	29	63	United Arab Em	11	9	80	Sri Lanka	2	2	96
Italy	14	27	59	Viet Nam	13	9	78	Yemen, People'	5	2	93
Congo	62	27	11	Peru	19	9	72	Swaziland	5	2	93
Mongolia	11	27	62	Haiti	24	8	68	Cape Verde	9	2	89
Denmark	30	27	43	Rwanda	24	8	68	Cuba	9	2	89
Qatar	36	26	38	Mexico	6	8	86	Chad	16	2	82
Spain	12	26	62	Malta	76	8	16	Gambia	7	2	91
Zaire	58	25	17	Saudi Arabia	45	8	47	Cyprus	7	2	91
Gabon	72	22	6	Uganda	32	8	60	Mali	2	1	97
Papua N.Guinea	29	22	49	Costa Rica	4	7	89	Pakistan	1	1	98
Lesotho	22	22	56	Paraguay	15	7	78	Bangladesh	3	1	96
Nicaragua	25	21	54	Mauritius	16	7	77	Kampuchea	5	1	94
Philippines	18	21	61	Jamaica	7	7	86	Nepal	4	1	95
Djibouti	28	21	51	China	6	7	87	Sudan	1	0	99
Fiji	20	20	60	Tunisia	13	7	80	Guyana	1	0	99
Solomon Island	40	20	40	Zimbabwe	14	7	79	Afghanistan	1	0	99
Turkey	24	19	57	Australia	16	7	77	Somalia	3	0	97
Cameroon	46	19	35	Guinea-Bissau	31	6	63	Burundi	36	0	64
								Madagascar	1	0	99

Table A2c Sectoral Water Allocation by Country - Ranked by proportion used in domestic sector (%)

Country	Domest.	Indust.	Agricu.
Equator.Guinea	81	13	6
Malta	76	8	16
Gabon	72	22	6
Kuwait	64	32	4
Zambia	63	11	26
Congo	62	27	11
Togo	62	13	25
Bahrain	60	36	4
Zaire	58	25	17
Barbados	52	41	7
Comoros	48	5	47
Cameroon	46	19	35
New Zealand	46	10	44
Singapore	45	51	4
Saudi Arabia	45	8	47
Venezuela	43	11	46
Brazil	43	17	40
Luxembourg	42	45	13
Colombia	41	16	43
Solomon Island	40	20	40
Bhutan	36	10	54
Qatar	36	26	38
Burundi	36	0	64
Sweden	36	55	9
Ghana	35	13	52
Malawi	34	17	49
Uganda	32	8	60
Guinea-Bissau	31	6	63
Iceland	31	63	6
Nigeria	31	15	54
Denmark	30	27	43
Jordan	29	6	65
Papua N.Guinea	29	22	49
Burkina Faso	28	5	67
Djibouti	28	21	51
Benin	28	14	58
Liberia	27	13	60
Trinidad/Tobag	27	38	35
Kenya	27	11	62
Nicaragua	25	21	54
Turkey	24	19	57
Haiti	24	8	68
Rwanda	24	8	68
Mozambique	24	10	66
Switzerland	23	73	4
Czechoslovakia	23	68	9
Malaysia	23	30	47
Lesotho	22	22	56
Algeria	22	4	74
Cote d'Ivoire	22	11	67
Central Africa	21	5	74
Niger	21	5	74
Tanzania	21	5	74
Fiji	20	20	60
United Kingdom	20	77	3
Norway	20	72	8
Austria	19	73	8
Peru	19	9	72
Canada	18	70	12
Philippines	18	21	61
Japan	17	33	50
Ireland	16	74	10
Israel	16	5	79
South Africa	16	17	67
France	16	69	15
Chad	16	2	82
Poland	16	60	24
Yugoslavia	16	72	12
Mauritius	16	7	77
Australia	16	7	77
Paraguay	15	7	78
Libya	15	10	75
Portugal	15	37	48
Italy	14	27	59
Zimbabwe	14	7	79
Angola	14	10	76
Viet Nam	13	9	78
Indonesia	13	11	76
Tunisia	13	7	80
Spain	12	26	62
United States	12	46	42
Mauritania	12	4	84
Panama	12	11	77
Germany	12	69	19
Finland	12	85	3
Mongolia	11	27	62
United Arab Em	11	9	80
Korea, Rep	11	14	75
Belgium	11	85	4
Ethiopia	11	3	86
Lebanon	11	4	85
Korea, Dem Peo	11	16	73
Bolivia	10	5	85
Guinea	10	3	87
Guatemala	9	17	74
Cuba	9	2	89
Cape Verde	9	2	89
Hungary	9	55	36
Argentina	9	18	73
Romania	8	33	59
Lao	8	10	82
Greece	8	29	63
Sierra Leone	7	4	89
El Salvador	7	4	89
Gambia	7	2	91
Cyprus	7	2	91
Syria	7	10	83
Ecuador	7	3	90
Myanmar	7	3	90
Jamaica	7	7	86
Bulgaria	7	38	55
Egypt	7	5	88
Mexico	6	8	86
Morocco	6	3	91
Uruguay	6	3	91
Suriname	6	5	89
Chile	6	5	89
Albania	6	18	76
China	6	7	87
Former U.S.S.R	6	29	65
Kampuchea	5	1	94
Yemen, People'	5	2	93
Dominican Rep	5	6	89
Botswana	5	10	85
Swaziland	5	2	93
Senegal	5	3	92
Netherlands	5	61	34
Thailand	4	6	90
Nepal	4	1	95
Honduras	4	5	91
Iran	4	9	87
Yemen Arab Rep	4	2	94
Costa Rica	4	7	89
Bangladesh	3	1	96
Somalia	3	0	97
Oman	3	3	94
Iraq	3	5	92
India	3	4	93
Mali	2	1	97
Sri Lanka	2	2	96
Madagascar	1	0	99
Afghanistan	1	0	99
Pakistan	1	1	98
Sudan	1	0	99
Guyana	1	0	99

Table A2d Sectoral Water Allocation by Country - Ranked by proportion used in agriculture (%)

Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.
Sudan	1	0	99	Kampuchea	5	1	94	Equator.Guinea	81	13	6
Madagascar	1	0	99	Yemen Arab Rep	4	2	94	Iceland	31	63	6
Afghanistan	1	0	99	Oman	3	3	94	Gabon	72	22	6
Guyana	1	0	99	India	3	4	93	Kuwait	64	32	4
Pakistan	1	1	98	Yemen, People'	5	2	93	Belgium	11	85	4
Mali	2	1	97	Swaziland	5	2	93	Bahrain	60	36	4
Somalia	3	0	97	Iraq	3	5	92	Switzerland	23	73	4
Bangladesh	3	1	96	Senegal	5	3	92	Singapore	45	51	4
Sri Lanka	2	2	96	Honduras	4	5	91	United Kingdom	20	77	3
Nepal	4	1	95	Morocco	6	3	91	Finland	12	85	3

Sectoral Water Allocation by Country - Ranked by proportion used in indutry (%)

Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.
Belgium	11	85	4	Germany	12	69	19	Pakistan	1	1	98
Finland	12	85	3	Czechoslovakia	23	68	9	Bangladesh	3	1	96
United Kingdom	20	77	3	Iceland	31	63	6	Kampuchea	5	1	94
Ireland	16	74	10	Netherlands	5	61	34	Nepal	4	1	95
Switzerland	23	73	4	Poland	16	60	24	Sudan	1	0	99
Austria	19	73	8	Hungary	9	55	36	Guyana	1	0	99
Yugoslavia	16	72	12	Sweden	36	55	9	Afghanistan	1	0	99
Norway	20	72	8	Singapore	45	51	4	Somalia	3	0	97
Canada	18	70	12	United States	12	46	42	Burundi	36	0	64
France	16	69	15	Luxembourg	42	45	13	Madagascar	1	0	99

Sectoral Water Allocation by Country - Ranked by proportion used in domestic sector (%)

Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.	Country	Domest.	Indust.	Agricu.
Equator.Guinea	81	13	6	Comoros	48	5	47	Oman	3	3	94
Malta	76	8	16	Cameroon	46	19	35	Iraq	3	5	92
Gabon	72	22	6	New Zealand	46	10	44	India	3	4	93
Kuwait	64	32	4	Singapore	45	51	4	Mali	2	1	97
Zambia	63	11	26	Saudi Arabia	45	8	47	Sri Lanka	2	2	96
Congo	62	27	11	Venezuela	43	11	46	Madagascar	1	0	99
Togo	62	13	25	Brazil	43	17	40	Afghanistan	1	0	99
Bahrain	60	36	4	Luxembourg	42	45	13	Pakistan	1	1	98
Zaire	58	25	17	Colombia	41	16	43	Sudan	1	0	99
Barbados	52	41	7	Solomon Island	40	20	40	Guyana	1	0	99

ANNEX II

Implications of Increasing Water Use Efficiency in a Basin

(A numeric example)

Annex II Implications of Increasing Water Use Efficiency in a Basin

The following four schemes are designed to illustrate the impact (both favorable and adverse) of increasing local water use efficiency (WUE) in the context of a basin. The concept is demonstrated through a numerical example.

We assume that a source (say a reservoir) provides 300 units of water to various users in the basin. Of this, 100 units are diverted for irrigation through conveyance and distribution canals to Area-1, the remainder (200 units) flow downstream to Area-3. An intermediate point, Area-2, does not get water directly from the source (as do Area-1 and 3). Instead, it relies on return flows from Area-1. Area-1 has an initial irrigation network efficiency of 60 percent (i.e. of the 100 units diverted from the river, only 60 units reach the field inlets). What happens, under alternative water use configurations in the basin, if this efficiency level is raised to 70 percent?

Four alternative outcomes are discussed in this example (see Figures I-VI).

i. Return flows cannot be reused by downstream users (Figure I)

Assuming irrigation network efficiency, En, of 60% and ET/EV losses of 10 units, the remaining 30 units are leaked from the distribution canals through seepage processes. When En increases to 70%, 70 units out of 100 reach the fields in Area-1. The irrigated land in Area-1 is either expanded (see Figure Ib), in which case production increases, or it is kept constant. Of the latter is the case Figure Ic, the increased efficiency level of 70% allows a larger volume (215 units instead of 200) of water to go to downstream users, that is, to Area-3. Because the seepage water is not reused, the reduction in seepage from Area-1 has added to total water availability in the basin.

ii. Return flows are only used by Area-2 (Figure II)

Since Area-2 relies, for its water supply, on seepage from Area-1, increased efficiency in Area-1 is clearly reflected in the reduction of return flows in Area-2 (from 30 to 20 or 15). As shown in Figure IIb, Area-1 obtains 10 units more at the field inlets as a result of increasing En to 70%. If this water is used within Area-1 to expand irrigation, Area-2 will receive 10 units of water less to support whatever water using activities exist in that area. If the irrigated Area in Area-1 does not increase, 15 more units of water are delivered to the downstream Area-3 (see Figure IIc), and Area-2 still receives less water supply. A trade-off occurs among the three users, i.e. increases in production upstream or downstream through improved WUE are based on reduction in production in Area-2.

iii. Return flows can be reused by both Area-2 and Area-3 (Figure III)

Assume now that some of Area-3's water supply is also derived from return flows from Area-2. Then the increase in efficiency in Area-1 could either lead to expanding its own irrigated area, reducing return flows to Area-2 and, by extension, reducing return flows to Area-3 (Figure IIIb), or it could result in an increase in direct water supplies to Area-3 (Figure IIIc). An obvious benefit of the latter is the improved water quality downstream due to increased direct water flows, rather than secondary return flows, in the river or canal. The resolution of the trade-off between the three areas depends on economic valuations of activities in each area and environmental and water quality requirements in the basin.

iv. Return flows can be reused directly by Area-3 (Figure IV)

Note now that only Area-3 depends on seepage flows from Area-1. Higher local efficiency (70 percent) in Area-1 results in seepage losses falling and reduces water flows into the river. Clearly, if the supply to Area-1 is reduced to take account of this increased efficiency, Area-1 continues to irrigate the same amount of land, and maintains at the old level production. However, more fresh water can now be released to downstream users. Not only does the downstream area get the same amount of water, water quality will also be improved. There is a trade-off between production in Area-1 and Area-3. Again, the resolution of this trade-off depends on economic valuations of activities in these two areas.

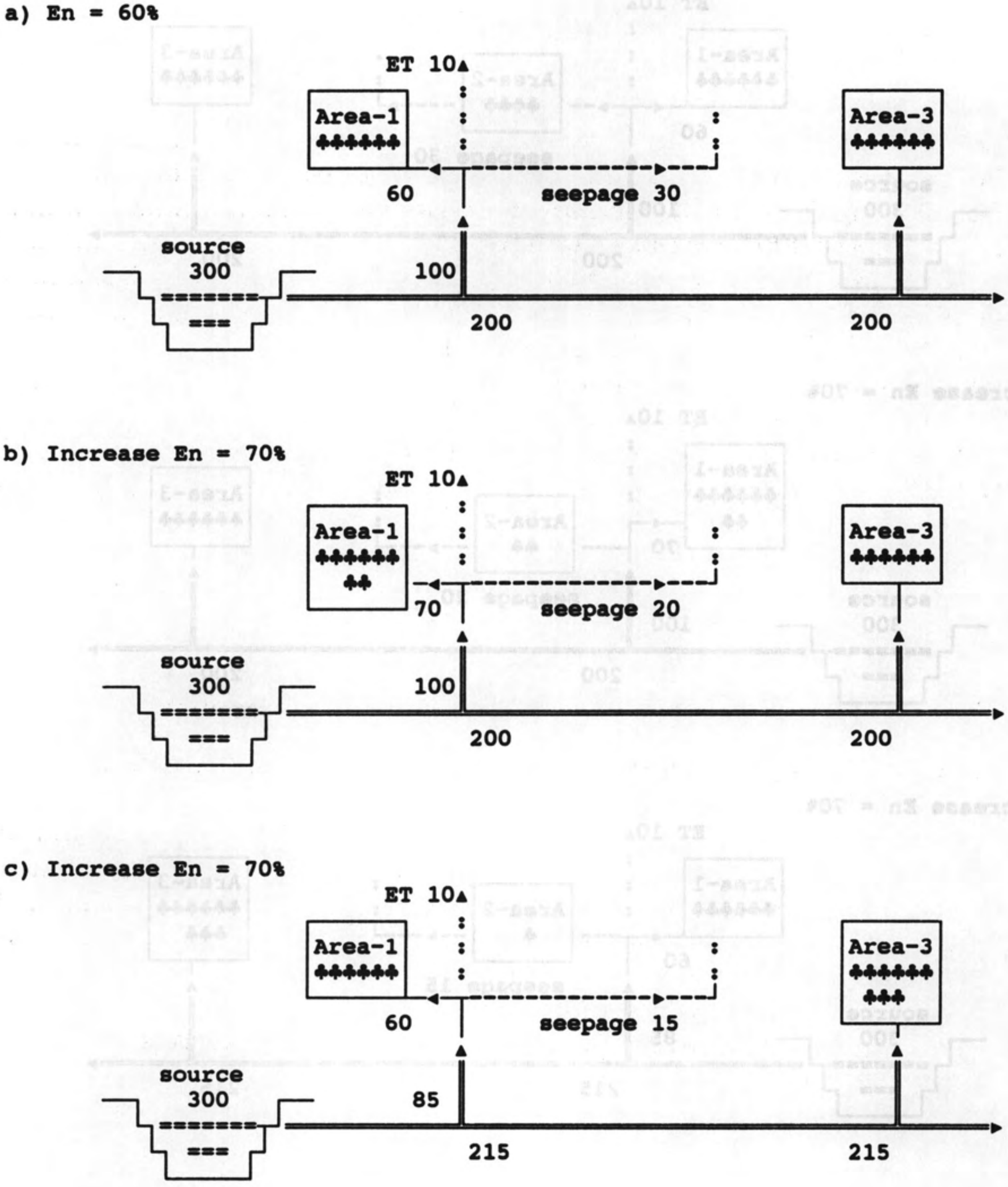
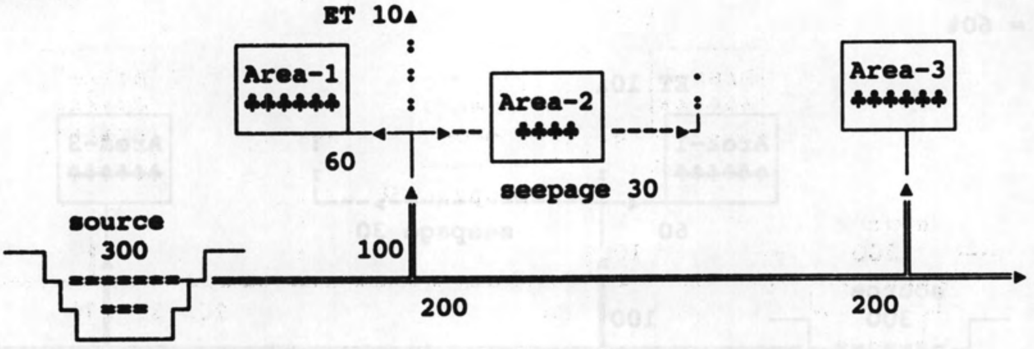
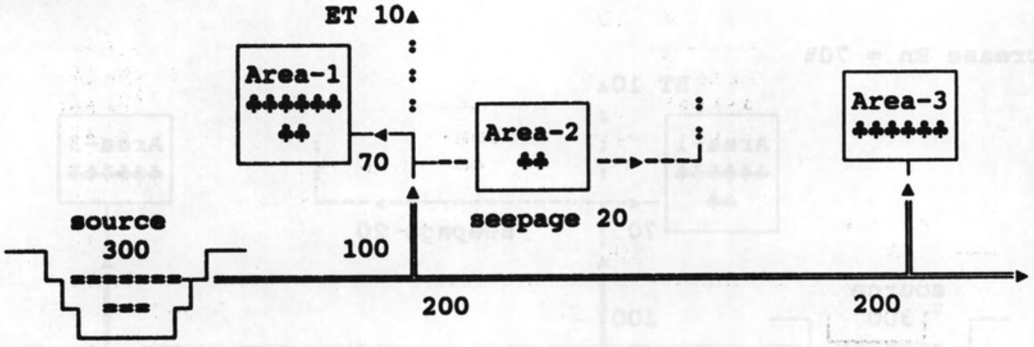


Figure I Impact of Increasing Efficiency En
(i) Return flows are not reused by downstream users

a) En = 60%



b) Increase En = 70%



c) Increase En = 70%

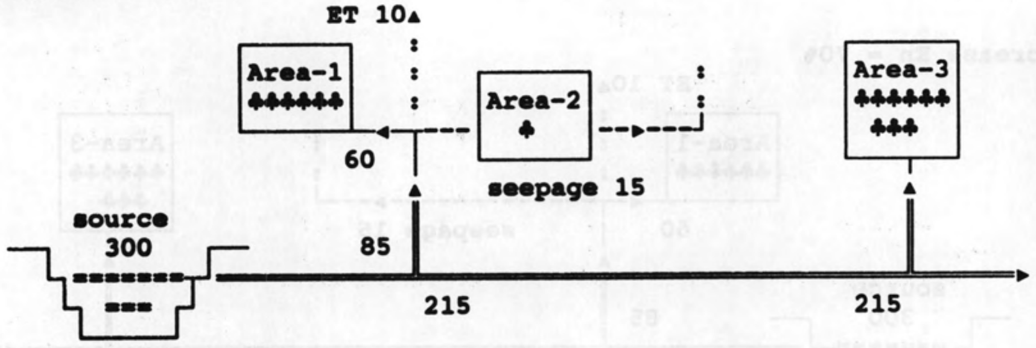
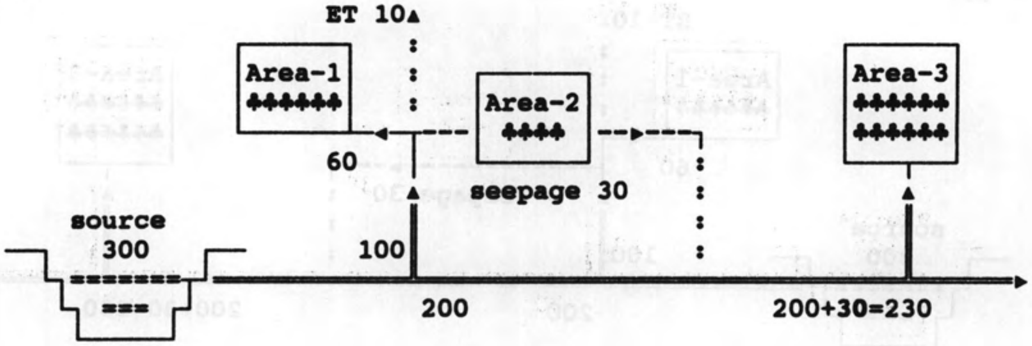
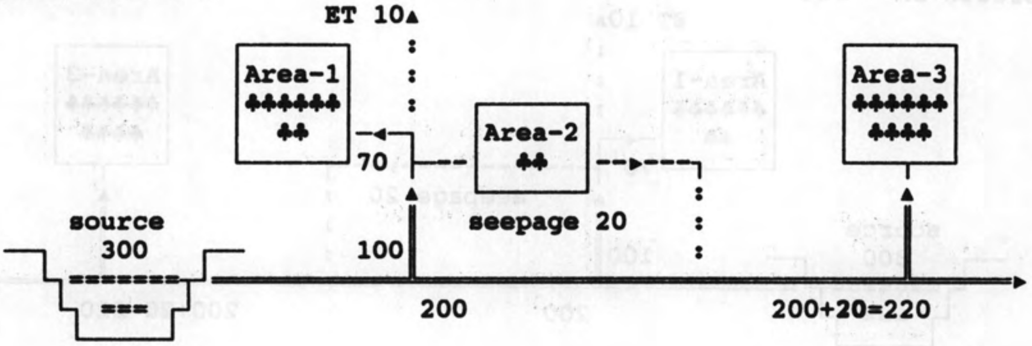


Figure II Impact of Increasing Efficiency En
(ii) Return flows are reused by Area-2 only

a) En = 60%



b) Increase En = 70%



c) Increase En = 70%

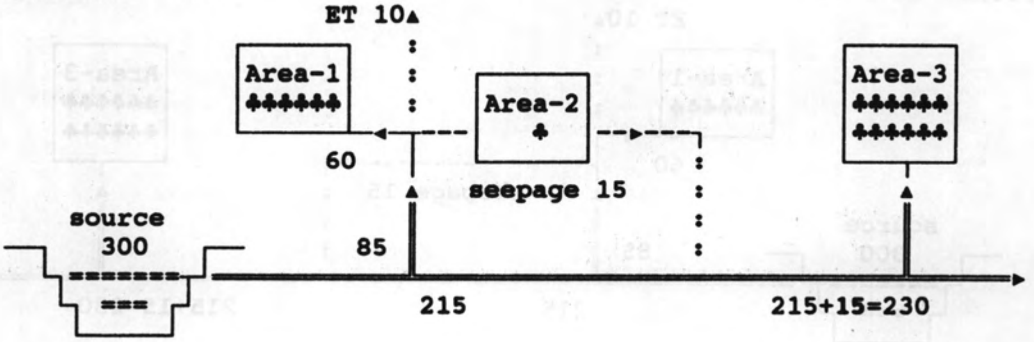
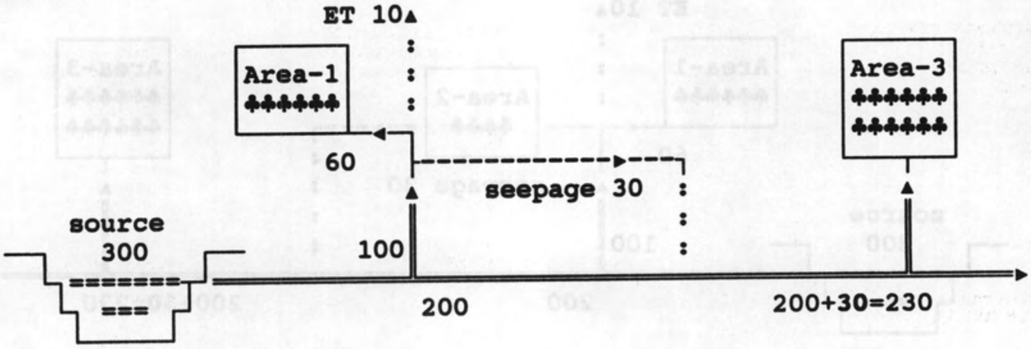
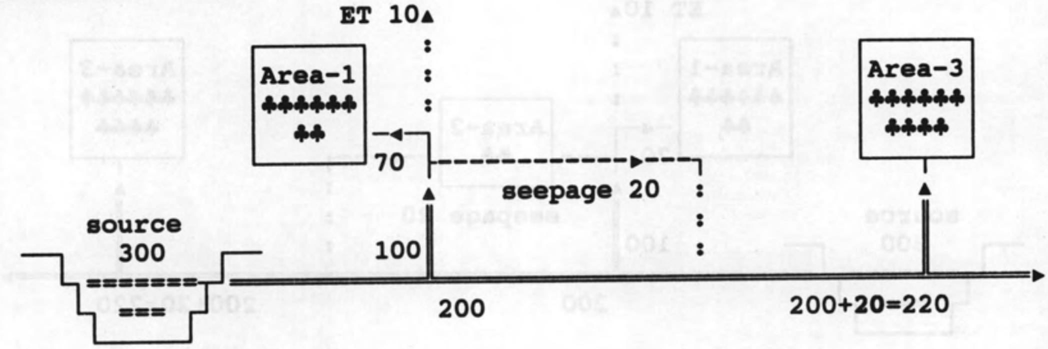


Figure III Impact of Increasing Efficiency En
(iii) Return flows are reused by more than one downstream users

a) En = 60%



b) Increase En = 70%



c) Increase En = 70%

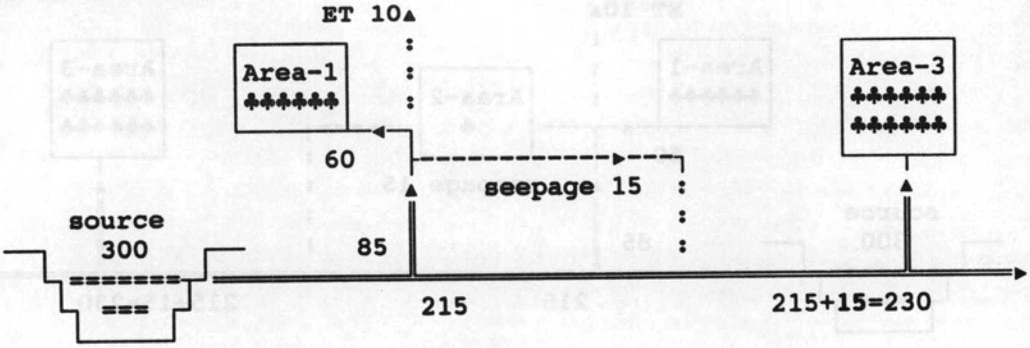


Figure IV Impact of Increasing Efficiency En
(iv) Return flows are reused by downstream user Area-3

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