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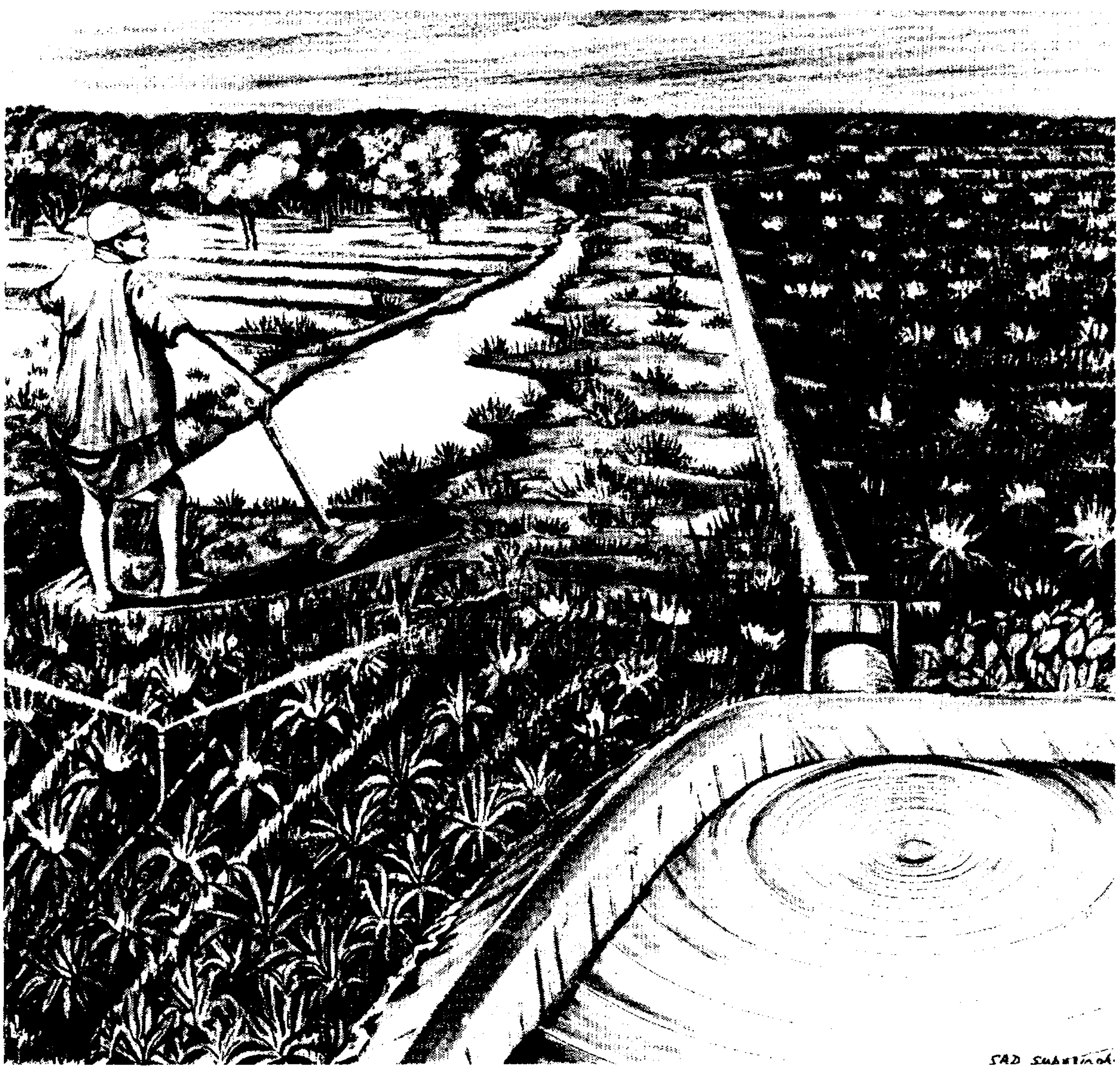
# Improving Water Use in Agriculture

## Experiences in the Middle East and North Africa

Willem Van Tuijl



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# ABSTRACT

Emerging water shortages are of great concern in many countries of the region. As the agricultural sector is generally by far the most important water consumer and higher priority is given to meeting domestic and industrial water demands, it is to be expected that gradually less water will be available for agriculture. An overview is given of present system and on-farm water use efficiencies and the potential for water savings and yield increases through the use of improved distribution networks and more appropriate irrigation technologies for smallholders. The water conservation efforts of Israel, Cyprus and Jordan are examined in detail with respect to institutions, the irrigation infrastructure, water charges and demand management, operation and maintenance, irrigation scheduling and extension, technology development and transfer, the role of the private sector, quality control on irrigation equipment, land tenure and land consolidation, and water users associations. The World Bank's experience with lending for the irrigation sector in the region is also described. The elements that would need to be considered for inclusion in a national program for water conservation in the agricultural sector are identified.

# FOREWORD

Water is a scarce commodity in many Middle Eastern and North African countries. More water will have to be diverted from agriculture to meet the growing demand for domestic and industrial water use. Less water will be available for irrigation, although the demand for food will increase because of population growth. To meet this challenge, water use in the agricultural sector will have to become much more efficient, and yields will have to increase substantially. Fortunately, considerable technological advances have been made since the 1960s in the development of efficient irrigation techniques, such as drip irrigation. Existing irrigation techniques, such as sprinkler and surface irrigation, have continued to improve and have been adapted to changing economic environments, most often in response to rapidly increasing labor and fuel costs in the western hemisphere. However, despite the growing water shortages, traditional and inefficient surface irrigation techniques still prevail in most developing countries, and many constraints still hinder the adoption of more advanced and efficient irrigation technologies.

Reducing water use on the farm is not merely a matter of selecting the best irrigation technology. A farmer's choices can be affected by the physical and socio-economic environment, the quality of the main irrigation infrastructure, the performance of the institutions responsible for operation and maintenance, the available support services, the expected costs and benefits of the use of improved techniques, the measures of demand management, etc.

This study was sponsored by the Technical Department of the World Bank as part of a water resource management study. The study was conducted in order to learn from past experiences with irrigation development in the Middle East and North Africa Region (MENA). Case studies from Israel, Cyprus and Jordan, where irrigation development is most advanced, have been examined and recommendations for future activities throughout the MENA Region have been made. The paper does not provide a specific solution for every water shortage problem, but will hopefully provide "food for thought" for people who design projects, programs or campaigns to use available water resources more efficiently in agriculture.

Anil Sood
Director
ECA and MNA Technical Department

# LIST OF ACRONYMS

| | |
|---|---|
| CIP | Cheliff Irrigation Project (Algeria) |
| ICID | International Commission on Irrigation and Drainage |
| IPTRID | International Program for Technology Research in Irrigation and Drainage |
| ICWE | Israel Center of Water Works Equipment |
| IMIP | Irrigation Management Improvement Project (Tunisia) |
| JVA | Jordan Valley Authority |
| LWCP | Land and Water Conservation Project (Yemen) |
| LSIIP | Large-Scale Irrigation Improvement Project (Morocco) |
| MANR | Ministry of Agriculture and Natural Resources (Cyprus) |
| M&I | Municipal and Industrial |
| MENA | Middle East and North Africa |
| MIP | Mitidja Irrigation Project (Algeria) |
| MIS | Management Information System |
| NGO | Non-Governmental Organization |
| 0&M | Operation and Maintenance |
| SCP | Southern Conveyor Project (Cyprus) |
| SMSI | Small and Medium Scale Irrigation Project (Morocco) |
| WUA | Water Users Association |

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# EXECUTIVE SUMMARY

Many countries in the Middle East and North Africa Region (MENA) experience absolute water scarcity or water stress, and available water resources are becoming more and more costly to mobilize. In most countries, agriculture consumes more than 85 percent of water demand. Because higher priority is given to demands for domestic and industrial water supplies, the agricultural sector must continually produce more food with less water for a growing population. Traditional gravity irrigation is still the main irrigation method on the farm. On-farm irrigation efficiency with this technology is typically 50 percent and project efficiencies are in the range of 30 to 40 percent. However, in areas with heavy soils, such as Egypt, traditional techniques can be quite efficient. In principle, however, the potential for water savings can be substantial in the agricultural sector. Still, care must be taken in evaluating the effects of water conservation projects. The water savings in river basins may be considerably less than in projects because of possible recycling of infiltration losses through groundwater pumping or the reuse of the surface runoff within or downstream from the project areas.

Technical interventions to save water can take place in river basins, in projects and on farms; water savings on farms offer the largest potential. The efficiency of on-farm water use can be increased with improved surface irrigation techniques or with sprinkler or micro-irrigation (also called localized irrigation, which includes drip/trickle systems and micro-spray systems). Micro-irrigation has great potential to conserve water on the farm (30 to 50 percent when compared with surface irrigation). Important yield increases per hectare are generally obtained. The potential yield increases per cubic meter of water are even more substantial (often two or three-fold). However, the selection of an appropriate technology for smallholders will be site specific and will depend on the local socio-economic environment, the farmers' educational levels, whether there are demands and market mechanisms for profitable crops to justify on-farm investments in irrigation, whether farmers are willing to innovate, the availability of agricultural credit and the agricultural support services (training, extension, after sales services, etc.) the government or the private sector is able to provide. None of the advanced technologies are "easy". Micro-irrigation requires high skill levels; nevertheless, it has been successfully introduced in several traditional farming communities.

The modern on-farm irrigation technologies require a very reliable water supply at the farm-turnout and a continuous water supply for micro-irrigation. This may require in many cases: (i) the upgrading of the existing irrigation infrastructure; or (ii) modifications to the interface between the main distribution and the on-farm system, possibly through farm ponds. The issue of whether to rehabilitate existing projects to existing standards only or to upgrade them to standards for future adoption of improved irrigation technologies on the farm has, so far, not been sufficiently addressed in rehabilitation projects.

There is no panacea for improving water use efficiencies, especially in existing projects, and financing institutions will have to continue to persuade governments to: (i) improve their policies and institutions to achieve more efficient operation and maintenance; (ii) upgrade their

irrigation infrastructure to ensure a more reliable water supply at the farm-turnout to accommodate the demands of modern agriculture; and (iii) promote improved on-farm irrigation technologies, whether improved surface irrigation, sprinkler or micro-irrigation.

The experience with absolute water scarcity has been reviewed in case studies of Israel, Cyprus and Jordan. Because their use of efficient irrigation practices is well advanced, lessons can be drawn for application elsewhere. The most crucial pre-conditions for the adoption of modern irrigation technologies on the farm have probably been: (i) water shortages and the search for solutions--especially in Israel; and (ii) a strong local or export market for agricultural produce so that sufficient financial incentive was available to the farmers to invest in advanced irrigation technologies. In Israel, national water resource development and utilization plans were prepared at an early stage. Moreover, the national consensus on the importance of water led to the early enactment of a comprehensive code of water laws and the allocation of the water resources, the establishment of a strong research program to develop water saving irrigation technologies, and an appropriate system of demand management, consisting of water metering, a system of graduated water pricing and water allocations based on carefully researched crop water norms. In Jordan land reform, land consolidation, expropriation of water rights and rural development were also key actions undertaken by government to underpin its efforts in modernizing agriculture. Land consolidation was also an important feature of irrigation development in Cyprus.

The case studies reconfirmed the need for strong programs in irrigation extension (including irrigation scheduling) and research in irrigation agronomy, and access to agricultural credit. The construction of national or regional pressurized pipe networks for water distribution were incentives for the adoption of sprinkler or micro-irrigation. Special water conservation campaigns contributed to quicker adoption of water saving measures. The most obvious lesson to be drawn from the case studies is that strong institutions are required to plan and design efficient irrigation systems, allocate water, control water use and impose sanctions when necessary.

A review of irrigation in MENA, including the Bank's experience with lending in the sub-sector suggests several recommendations for future activities:

- **Adaptive Research Programs.** Adaptive research programs should be promoted for the identification of appropriate on-farm irrigation technologies. The selection of technologies should take into account all relevant technical, financial, socio-economic and marketing aspects. Programs may be developed in cooperation with the International Program for Technology Research in Irrigation and Drainage (IPTRID), administered by the Bank, and should include: (i) an adaptive research period (possibly guided by a panel of multi-disciplinary experts); (ii) testing on farmers' fields; and (iii) the promotion of proven systems through demonstrations and other extension efforts. The adaptive research should preferably include the whole range of irrigation technologies, including micro-irrigation, unless the absence of markets for fairly valuable crops precludes their feasibility. Farmers' participation in identifying and evaluating new technologies is recommended.

- **Diagnostic Work as the Basis for Rehabilitation.** Project preparation for rehabilitating or improving existing irrigation schemes needs more detailed diagnostic field work to analyze the present situation and determine the criteria for upgrading the distribution system. The proposed upgrading should take account of the on-farm technologies that should be promoted to allow existing cropping patterns to evolve.

- **Pilot and Demonstration Schemes.** More consideration should be given to the construction of pilot and demonstration schemes before introducing radically different design concepts in a particular socio-economic and cultural environment. Pilot schemes of 5,000 to 10,000 hectares may be needed to test the effect of advanced canal technology. Smaller pilot schemes of 50 to 500 hectares would be used to test new designs of tertiary and quaternary systems at the end of the distribution systems. The pilot schemes should monitor farmers reactions, assess water, energy and labor savings, effect on yields, etc. A testing and demonstration period is essential for proposed rehabilitation projects where improved on-farm irrigation technologies are planned to be introduced and may require changes in the interface between the main distribution and on-farm irrigation systems. Pilot projects with improved irrigation technologies should be established quickly in areas where (i) water balance studies indicate that water shortages exist or are expected to exist soon; and (ii) potential markets exist for the cultivation of more remunerative crops, in other words, close to potential markets such as main population centers.

- **Irrigation Scheduling.** Projects aiming to promote the introduction of improved irrigation technologies on the farm should be accompanied by detailed proposals for improved irrigation scheduling. Alternatively, nationwide irrigation extension and research projects may be undertaken in parallel with irrigation improvement projects. A guide should be prepared for the establishment and operation of an irrigation scheduling service.

- **Agronomic Research.** More intensive agronomic research in irrigated agriculture should be undertaken to identify more remunerative crops and to formulate better cultural and irrigation practices, including research on crop water requirements and water-crop yield functions.

- **Manufacturing and Quality Control.** After appropriate irrigation technologies have been identified and the demand for irrigation materials and products has been ascertained, governments should promote local manufacturing and should ensure quality control for these products and on-farm system designs.

# 1. BACKGROUND AND INTRODUCTION

### *Emerging Water Shortages*

Water scarcity has been reflected in traditional social and economic systems in arid areas of the Middle East and North Africa (MENA) for centuries. During the past thirty to forty years population growth and economic development have depleted the Region's economically exploitable water resources. Water scarcity, exacerbated by deteriorating water quality and the lack of effective water management, has become a major problem in several countries, even in humid areas along the coast of North Africa. Water scarcity can be measured by the number of people per unit of available freshwater (see table 1-1). Significant water stress occurs with population densities of 500 to 1,000 people per million cubic meter of water ($Mm^3$) and requires large investments to meet needs. Absolute water scarcity occurs when densities increase to more than 1,000 persons per $Mm^3$. Eight of the sixteen countries shown in table 1-1 meet the

*Table 1-1: Water Availability[a]*

| Country | Total renewable water resources (1000 $Mm^3$/yr)[b] | Persons per $Mm^3$ per year[c] | | |
|---|---|---|---|---|
| | | *1990* | *2000* | *2025* |
| Algeria | 18.4 | 1368 | 1812 | 2835 |
| Cyprus | 0.9 | 779 | 841 | 984 |
| Egypt | 55.5 | 948 | 1183 | 1750 |
| Iran | 117.5 | 442 | 597 | 1098 |
| Iraq | 100.0 | 189 | 262 | 490 |
| Israel | 2.2 | 2115 | 2476 | 3260 |
| Jordan | 0.9 | 3508 | 5005 | 9758 |
| Lebanon | 3.8 | 705 | 785 | 1076 |
| Libya | 0.7 | 6494 | 9274 | 20037 |
| Morocco | 29.7 | 844 | 1070 | 1580 |
| Oman | 2.0 | 777 | 1129 | 2376 |
| Saudi Arabia | 2.2 | 6421 | 9236 | 19096 |
| Syria | 5.5 | 2280 | 3246 | 6609 |
| Tunisia | 3.8 | 2151 | 2659 | 3710 |
| Turkey | 134.0 | 419 | 506 | 679 |
| Yemen | 2.5 | 4635 | 6540 | 14006 |

*Notes:*
a. Measures of Water Scarcity in Persons per million $m^3$ per year: 100 to 500 = Water management problems; 500 to 1000 = water stress with large investments required; more than 1000 = water scarcity with significant adjustments required.
b. Total renewable water resources equal internal renewable water resources plus inflows from other countries less outflows to other countries.
c. Based on World Bank population projections for Europe, Middle East and North Africa Region (1990-91)
*Source:* World Resources Institute, "World Resources 1991-92" and "World Resources 1992-93" and World Bank data for Egypt, Jordan and Tunisia.

criterion for water scarcity and another five meet the criterion for water stress. The number of countries experiencing water scarcity will increase to eleven by the year 2000, and to thirteen by the year 2025.

Water scarcity can occur for many reasons: (i) current usage reaches the physical limits of available water resources (in Cyprus, Israel and Jordan); (ii) physical conditions make it increasingly difficult and costly to balance supply and demand, and require costly inter-basin transfers if they are technically feasible (in Morocco and Tunisia); and (iii) pollution and environmental degradation cause the loss of usable and affordable water resources (in Algeria). The numbers in table 1-1 are crude indicators and illustrate the average situation; they do not reveal serious regional water shortages, such as in the Souss Valley in Morocco. (The Souss Valley produces about 60 percent of Morocco's agricultural exports.)

Institutions are increasingly unable to cope with the explosive growth in aggregate demand for water for municipal and industrial (M&I) and agricultural use, while protecting the environment and preventing the over-exploitation of water resources. Managing water scarcity will require the reallocation of water among uses, price changes, and other policy interventions. These changes will probably result in structural changes or economic adjustments, and will have pervasive effects on individual sub-sectors. Significant structural adjustments in the economy may be necessary if rising costs and water shortages cause decreased sector performance, or if changes in strategy alter or reduce output.

The agricultural sector will be affected seriously by increases in water prices and decreases in available water. Sector strategies that stress food grain production with extensive irrigation using cheap and abundant water resources will have to be changed to strategies that stress a more balanced mix between food grain production and intensive irrigation of high value crops. Intensive irrigation has major investment and technological implications, and could have major impacts on employment, incomes, and output.

### *Meeting Water Demands*

Estimates of water withdrawal and water use are summarized in table 1-2. Data on economically available water are very difficult to obtain, but the volume of water is smaller than the estimate of total availability given in table 1-1. Hence, the withdrawal percentages shown in table 1-2 would be much higher than if they were based on the amount of water that is economic or cost-effective to develop.

Table 1-2 shows that the aggregate demand in the domestic and industrial sectors is considerably less than the demand in the agricultural sector. In nine of the sixteen countries, agriculture consumes 85 percent or more of the total demand. Under conditions of water scarcity, priority is normally given first to the demand for domestic water supply, and second to industrial water supply, although some industries may receive lower priority in water allocation than some perennial crops. Logically, because of the lower value of water for agriculture than for M&I water supply, water resources are normally reallocated from agriculture to other sectors when water scarcity develops. Hence, the agricultural sector in several countries will need to produce more food with less water for a growing population.

*Table 1-2: Water Withdrawal and Use*

| | *Water Withdrawal* | | *Percent of water used for* | |
|---|---|---|---|---|
| | *Total ($km^3$ per year)* | *Percent of available water*[a] | *M&I*[b] | *Agriculture* |
| Algeria | 3.0 | 16 | 26 | 74 |
| Cyprus | 0.54 | 60 | 9 | 91 |
| Egypt | 54.0 | 97 | 12 | 88 |
| Iran | 70.0 | 39 | 13 | 87 |
| Iraq | 42.8 | 43 | 8 | 92 |
| Israel | 2.0 | 91 | 21 | 79 |
| Jordan | 0.8 | 89 | 35 | 65 |
| Lebanon | 0.8 | 21 | 15 | 85 |
| Libya | 2.8 | 404 | 25 | 75 |
| Morocco | 11.0 | 37 | 9 | 91 |
| Oman | 0.4 | 22 | 6 | 94 |
| Saudi Arabia | 2.3 | 106 | 96 | 4 |
| Syria | 3.3 | 61 | 17 | 83 |
| Tunisia | 2.3 | 61 | 10 | 90 |
| Turkey | 15.6 | 8 | 42 | 58 |
| Yemen | 3.4 | 129 | 7 | 93 |

*Notes:*
a. Available water from table 1-1, column 1.
b. M&I includes all uses supplied from public facilities plus self-supplied industrial uses.
*Source:* World Resources Institute, "World Resources 1992-93" and World Bank data for Egypt, Cyprus, Iran and Israel.

Although the agricultural sector is the largest user of water, the sector uses water inefficiently. (Efficiency is discussed in detail in Chapter 2.) A small percentage increase in efficiency in the agricultural sector can go a long way toward meeting the growing demand for M&I. For example, if 20 percent of a country's gross withdrawals are used for M&I, and 80 percent are used for agriculture, and overall water use efficiency in the agricultural sector is 75 percent, a 10 percent increase in agricultural water use efficiency would provide 50 percent more water (gross) for M&I. If the net consumptive use for M&I is about 5 to 10 percent of gross use (depending on the degree of industrialization and the types of industries), the additional water would supply about 5 to 10 times the net requirements for M&I. This underlines the importance of improving water use efficiencies in agriculture and undertaking wastewater treatment and reuse.

Because conditions vary from country to country and riverbasin to riverbasin, no standard strategy can be formulated to meet the growing demand for water in agriculture to feed a growing population, and meet the demand for domestic and industrial use. In principle, a well-balanced strategy would: (i) mobilize untapped water resources; (ii) reuse waste water; (iii) use marginal waters and desalination; and (iv) conserve water and increase efficiency in the agricultural sector for production per cubic meter of water used. This report focuses on water conservation and increased efficiency in the agricultural sector. Integrated water resources development will be discussed, but an exhaustive treatment of this subject is not intended.

### *Improving Water Use Efficiencies in Agriculture*

Improved water management in agriculture is important not only for water conservation, but for obtaining high yields. Modern irrigation technologies, such as sprinkler and micro-irrigation, are highly efficient and have the potential to increase yields substantially. Reported yield increases obtained from micro-irrigation and improved agricultural practices are substantial. Unfortunately, the high costs may prevent small farmers from using the systems. Thus, the use of modern irrigation techniques may be restricted to production of high value crops so that the systems may be financially viable.

Although improved irrigation technologies on the farm seem to offer the best opportunity to save water and increase yields, the main conveyance and irrigation distribution systems must be operated efficiently. Irrigation distribution systems in the region are efficient compared to systems in Africa and Asia, but still require improvements to meet the standards of reliability for modern on-farm irrigation technologies. The two objectives of improving system and on-farm irrigation technologies will require: (i) improvements in policies for land tenure, water charges, operation and maintenance (O&M) budget allocations, water users associations, etc.; (ii) strengthening institutions for O&M and agricultural support services, including extension services, research and agricultural credit; and (iii) where necessary, irrigation system rehabilitation and improvement.

### *Outline of the Report*

Chapter 2 reviews water use efficiencies and describes the potential for water savings and yield increases through the use of modern and intermediate, more appropriate technologies for smallholders. Chapter 3 summarizes water conservation efforts through the use of modern irrigation techniques in Israel, Cyprus and Jordan. Chapter 3 also summarizes the suggested elements for national water conservation programs. Chapter 4 draws upon the lessons from

Chapter 3, reviews irrigation in MENA, including the Bank's experience with lending for irrigation in the sub-sector, and makes suggestions and recommendations for future activities. Chapter 5 provides conclusions and recommendations.

# 2. PRESENT WATER USE EFFICIENCIES AND POTENTIAL FOR WATER SAVINGS AND YIELD INCREASES

The MENA Region is characterized by diverse practices and traditions for irrigation distribution and on-farm irrigation. Systems range from crude irrigation methods, such as spate irrigation in Yemen, to sophisticated conveyance systems, such as pipes with sprinkler and drip irrigation in Cyprus. In between, traditional gravity irrigation distribution systems are used in Turkey and Egypt and modern hydraulically controlled canal systems are used in Morocco and Tunisia. Traditional irrigation is the most frequent irrigation method employed on the farm, but sprinkler or drip irrigation is also used in some areas.

### *Defining Water Use Efficiencies*

Water use efficiency may be defined quite differently by a farmer, a manager of an irrigation project, or a riverbasin authority. For example, on-farm irrigation efficiencies and project efficiencies may be low, but substantial water losses may infiltrate in the soil, recharge the aquifers and may be pumped up again for reuse, either in the same project area or in another downstream. Other losses, such as overland flow, may feed drainage systems or rivers, and may be pumped or diverted for reuse. By recycling losses, river basin efficiencies could become very high. The water savings gained from introducing new technologies would be restricted to savings in evaporation losses from wetted land surfaces and water puddles, and evaporation losses from non-beneficial vegetation, which may be substantially less than the savings experienced on the farm. Clearly, any water conservation project should be carefully appraised by using adequate geo-hydrological information to study the project's effect on the water balance in the riverbasin.

A distinction should be made between technical efficiency and economic efficiency in the use of water. On the one hand, technical efficiency may be low in a project area, but may be high in the riverbasin if water is recycled. On the other hand, water losses in the project area and recycling (especially when high pump lifts are involved) may reduce economic efficiency. Initial water losses may lead to other undesirable effects, such as waterlogging and salinity. A third way to express water use efficiency is through production per cubic meter of water.

### *Typical Irrigation Efficiencies in the MENA Region*

Table 2-1 shows the technical irrigation efficiencies that could be expected for conveyance and distribution efficiency, on-farm application efficiency, and project efficiency for various projects in the MENA Region. Project efficiencies range from about 20 to 70 percent, depending on the sophistication of the irrigation system and the on-farm irrigation technology in use. However, care should be taken in interpreting these figures. For example, spate irrigation in Yemen may not be wasteful because it is the only method available to prevent flash floods from spilling into the sea. Spate irrigation also recharges the groundwater aquifer, from which water can be pumped for irrigation, enriches the soils with silt, and provides leaching of salts. Although the irrigation distribution efficiency in Egypt is low, a high overall efficiency is being achieved. The irrigation canal network consists of low level canals that pump water directly to the field and provide some storage for the mismatch between supply and demand. Moreover, spills from the canals and the field flow into the drainage system, from which water is pumped again for reuse. In addition, deep infiltration losses are recovered through groundwater pumping. The overall effect is high water use efficiency for the Nile basin between Aswan Dam and the Mediterranean; the annual average is about 65 percent (comparable to pipe systems and drip irrigation) and reaches 80 percent in summer when water demand reaches its peak.

*Table 2-1: Typical Project Irrigation Efficiencies*
*(by percent)*

| *Category* | *Conveyance and Distribution* | *Field Application* | *Project* [a] |
|---|---|---|---|
| *A. Large-scale irrigation*<br>1. Spate Irrigation (e.g. Yemen) | 50 | 40 [b] | 20 |
| 2. Traditional open canal system (manual control) (e.g. Turkey) | 60 | 50 [b] | 30 |
| 3. Open canal systems with hydraulic control and surface irrigation (e.g. Morocco) | 70 | 60 [b] | 40 |
| 4. Open canal systems with manual control, on-farm storage and sprinkler/drip (e.g. Jordan) | 75 | 70 | 55 |
| 5. Open canal systems with hydraulic control, buffer or on-farm storage and sprinkler/drip | 85 | 70 | 60 |
| 6. Pipe conveyance systems with sprinkler/drip (e.g. Cyprus) | 95 | 70 | 65 |
| *B. Groundwater irrigation*<br>7. Lined field channels and on-farm surface (gravity) | 80 | 50 | 40 |
| 8. Pipe systems and on-farm sprinkler/drip | 95 | 70 | 65 |

*Notes:*
a. Gravity (surface) irrigation on the farm.
b. Project efficiencies are rounded to nearest 5 percent.

Table 2-2 provides irrigation statistics for MNA countries, excluding the Gulf states. In countries with incomplete data, less than 10 percent are served by sprinkler or micro-irrigation. Traditional on-farm surface (gravity) irrigation is still the predominant on-farm method used by most countries receiving Bank lending for irrigation. These methods provide low water management with on-farm application efficiencies of about 40 to 60 percent. Consequently, crop yields are relatively low. Low yields also result from the use of poor quality seeds, poor cultural practices and lack of inputs, but without efficient and flexible water management on the farm (providing the right doses of water at the right time) yields will never increase significantly.

***Table 2-2: Irrigated Areas in the MNA Region***

| *Country* | *Total irrigated ('000 ha)* | *Sprinkler and/or micro-irrigation* | |
|---|---|---|---|
| | | *('000 ha)* | *Percent* |
| Algeria | 400 | NA[a] | NA |
| Cyprus | 55 | 27 | 49 |
| Egypt | 2,920 | 680[b] | 23 |
| Iran | 5,900 | NA | NA |
| Iraq | 4,750 | NA | NA |
| Israel | 213 | 213 | 100 |
| Jordan | 50 | 43 | 86 |
| Morocco | 853 | 135[c] | 16 |
| Oman | 40 | NA | NA |
| Saudi Arabia | 420 | NA | NA |
| Syria | 700 | NA | NA |
| Tunisia | 394 | 45 | 11 |
| Turkey | 700 | NA | NA |
| Yemen | 475 | NA | NA |

*Notes:*
a. Not available.
b. Out of which 68,000 hectares under micro-irrigation.
c. Out of which 15,000 hectares under micro-irrigation
*Source:* ICID.

Traditional surface irrigation methods yield low irrigation efficiencies on the farm for many reasons: (i) unreliable supply at the farm-turnout caused by inefficiencies in the operation and maintenance of the main system; (ii) irrigation with either too small flows causing excessive seepage or irrigation with too large flows causing excessive runoff at the end of the field; (iii) uneven fields causing ponding in low spots and uneven water distribution; and (iv) the farmers' insufficient knowledge about crop water requirements, irrigation practices, and soil characteristics.

*Possible Technical Interventions to Save Water*

Technical interventions to save water could take place at the basin level, the project level, and the farm level. Interventions cannot be standardized throughout the Region--especially at the basin level--because they will vary from country to country and riverbasin to riverbasin. Interventions at the project or on-farm level would have to be analyzed to determine to what extent projected water savings would also constitute savings in the riverbasin.

At the basin level, a new storage reservoir could prevent the outflow of flood water to the sea. The construction of link canals between reservoirs could improve system operation efficiency and provide optimal mixing of different quality waters. Savings could also be gained from the integrated operation of surface and groundwater.

At the project level, canal lining or upgrading the technology for water control in the irrigation distribution system (by moving from category to category as shown in table 2-1) could save 10 to 30 percent of water for each 10 percent increase in efficiency. Spate irrigation is a very special category that cannot be upgraded to another category unless upstream storage facilities are constructed. Compared to the Asia Region, the MENA Region uses efficient irrigation distribution systems, especially in the Maghreb. Most canals are lined with concrete, and automatic hydraulic control gates are used, with downstream control for large canals and upstream control for small canals. These systems, combined with surface irrigation on the farm (see category A.3 in table 2-1), have performed well, considering their original design objectives.

At the farm level, traditional surface irrigation can be improved or replaced by sprinkler irrigation or micro-irrigation (also called localized irrigation, which includes drip/trickle irrigation and micro spray systems). Water savings from micro-irrigation on the farm are reported to be about 30 to 50 percent, compared to surface irrigation, and yield increases can be substantial (see annex C, table C-4). Irrigation systems in the MENA Region provide water on rotation or pre-arranged demand and would require upgrading to make them suitable for advanced irrigation technologies on the farm (see table 2-1, categories A.2 and A.3).

*Modern On-Farm Irrigation Technologies*

Modern on-farm irrigation technologies are required to increase water productivity on the farm. The technologies can be sub-divided into three groups: (i) (improved) gravity irrigation (annex C, table C-3); (ii) sprinkler irrigation; and (iii) micro-irrigation (annex C, table C-2). Irrigation efficiencies drawn from experience in the U.S. are shown in annex C, table C-1. Operating efficiencies depend on whether the system design fits local soil and crop characteristics and the level of management. Many different sprinkler and micro-irrigation systems are available, but no single system suits all conditions. The best system is the one that accounts for all conditions, such as topography, climate, soil conditions, crop characteristics, expected yield levels, crop values, investment costs, maintenance costs (including energy), labor requirements, and the management skills required and available.

In areas where sprinkler irrigation has been introduced, interest in gravity irrigation systems has been renewed. For example, in Southern France and Morocco, sprinkler irrigation systems are costly to operate because energy prices are high. Morocco has also experienced unsatisfactory performance with sprinkler systems (see box 4-3). This paper does not attempt to describe the technical details of all the available systems; the main characteristics of the major sub-systems are described briefly.

**Improved Surface Irrigation**

Surface irrigation can be improved through: (i) land leveling; (ii) better distribution of water among individual furrows in furrow irrigation, with the size and time of furrow flow selected by the desired depth of irrigation, soil characteristics and slope of the field. In theory, irrigation efficiencies of more than 80 percent can be obtained with modern surface irrigation methods if design and management are reliable.

Techniques for achieving high irrigation efficiencies include: (i) land leveling by using laser techniques; (ii) syphoning irrigation water from a head ditch into the furrow; (iii) flexible or rigid PVC pipe to distribute water into the furrows; and (iv) buried PVC pipe with risers. A recent development in trans-irrigation employs a moving piston in a rigid pipe to irrigate several furrows at a time; however, this system is too sophisticated to be used by smallholders in developing countries. Large-scale land leveling in projects in the fields of smallholders has proved to be very difficult. There are few, if any, successful land leveling projects in non-rice growing areas. Land leveling also must be maintained every two years and this is not always done.

**Sprinkler Irrigation**

The two most widely used sprinklers are the rotary sprinkler and the sprayline; the sprayline is a pipe with small holes that spray water when under pressure. Several sprinkler systems are available: (i) conventional systems (portable, permanent and semi-permanent) used since the 1930s; (ii) mobile rainguns that spray large quantities of water over wide areas; (iii) spraylines (stationary, oscillating and rotating); and (iv) mobile lateral systems (center-pivot and side-move systems).

**Micro-Irrigation**

The most important breakthrough in on-farm irrigation technology--drip irrigation--was developed in the early 1960s. The technology maintains optimum moisture conditions around the root zone by irrigating with small, frequent supplies of water. Because only a fraction of the soil is watered, water savings are substantial. Although the technology developed and spread slowly, Decroix (1988) reports that, according to ICID surveys, the total area of the world equipped with micro-irrigation systems increased from 0.4 M hectares in 1981 to 1.1 M hectares in 1986. However, only seven countries (USA, Israel, Spain, South Africa, Egypt, Australia and France) made up 84 percent of the total area. ICID survey estimates by crop type showed the following distribution: fruit trees, 55 percent; vineyards, 13 percent; vegetables, 13 percent; flowers, 1.5 percent; and industrial crops, such as cotton, sugarcane, and corn, 12.5 percent. Drip irrigation also prevents desertification and reduces the environmental hazards of surface irrigation, such as soil erosion, run-off and deep infiltration of fertilizers and agro-chemicals.

Micro-irrigation has spread rapidly because it has several advantages (Decroix, 1988):

- Agronomic efficiency increases because micro-irrigation improves uniformity in the water supply. Micro-irrigation regulates the water dose and frequency of application precisely. Thus it can be adjusted to meet the optimum water requirements (not necessarily the maximum) for crops. The flowering stage of most crops is triggered by a certain degree of water stress; small doses of water applied daily are especially useful during germination. The potential yield increases for agricultural production, expressed in product weight per unit of water applied, are often two times higher than the yields obtained from surface irrigation (annex C, table C-4).

- Micro-irrigation's versatility, considerable under normal conditions, has been remarkable in areas where soil conditions (heavy or permeable soils) and water conditions (brackish water) have either made the use of other irrigation methods marginal or impossible.

- Micro-irrigation is an independent technology. Thus irrigation can continue during other traditional practices, such as harvesting. Because the spaces between crops or trees are not watered, access in the fields continues.

- Micro-irrigation can be automated and can lead to additional labor savings and improved irrigation scheduling with the use of microcomputer controlled tensiometers.

- Considerable savings in operation and maintenance costs can be achieved on the farm. Water savings increase in absolute terms and in the value of production per cubic meter of water used. Labor savings increase because equipment is moved less frequently. Compared to sprinkler irrigation, micro-irrigation decreases energy costs. Chemicals can be mixed directly with the water (chemigation) or fertilizers (fertigation).

Micro-irrigation also has its disadvantages. Micro-irrigation systems need a reliable, almost continuous water supply at the farm-turnout. A disruption in the water supply can cause serious problems for agricultural production. Systems may therefore need to be upgraded or farm ponds may have to be constructed before micro-irrigation can be introduced. Each system must be designed precisely in accordance with the crops to be grown and local soil and climate conditions. Skilled irrigation management is needed in order to profit from micro-irrigation's potential advantages. Water treatment, such as filtration and mixing water with fertilizer, is needed and the system requires maintenance. The main problem reported in the ICID survey was that the drippers clogged. Nevertheless, the existence of both simple and sophisticated systems is proof of the versatility of micro-irrigation.

### *Appropriate Technologies for Smallholders*

Most sophisticated sprinkler and drip systems have been developed in the U.S. and Europe in order to decrease labor costs. Therefore many systems are unsuitable for use in developing countries where labor costs and skill levels are lower. Annex A lists several appropriate irrigation technologies that would be suitable for use on small farms (including surface, sprinkler and micro-irrigation). Sprinkler or drip irrigation system costs are still high for the smallholder. Hopefully the continuing development of these systems and stronger and cheaper materials will bring them within the reach of more farmers.

# 3. LESSONS FROM IMPROVING WATER USE IN ISRAEL, CYPRUS AND JORDAN

Israel, Cyprus and Jordan use the most advanced modern irrigation technologies and water savings techniques. Case studies were carried out for these three countries as part of this study (Kahana, Aletraris and Haddadin; 1992). A summary description of the irrigation infrastructure, institutions, system O&M, regular and special government programs, the role of the private sector and other developments are given in annex B.

### *Common Elements*

Water shortages have caused Israel, Cyprus and Jordan to search for innovative solutions to irrigation problems. Another common element that has contributed much to the adoption of advanced technologies on the farm has been the presence of strong local or export markets for agricultural produce, which provide sufficient financial incentives to farmers to invest in new technologies. In both Israel and Jordan traditional farmers have learned to manage and operate modern irrigation systems because the farmers had access to skilled support services (see box 3-1).

### *Case Studies*

In Israel the area under irrigation increased from 30,000 hectares in 1948 to 213,000 hectares in 1990. Water use (metered gross supply to consumers) in the early 1950s was about 8,700 cubic meters per hectare, and decreased to 5,700 cubic meters per hectare in the late 1980s. At the same time, production per hectare increased significantly and the yield per unit of water increased from 1 kg per $m^3$ to about 2.5 kg per $m^3$ (annex B, charts B-2 and B-3).

Irrigation development in Israel has been facilitated by farmers' receptiveness to innovation. (Most settlers had no previous agricultural experience.) The farmers' receptiveness was also linked to their sense of security, which resulted from strong government support for the agricultural sector. (For example, the Irrigation and Soil Field Service advises farmers on irrigation practices.)

Early on, the government developed a water master plan and enacted a comprehensive code of water laws. The Water Commissioner has an extensive array of legal powers to allocate water, control water use, plan new schemes, and impose sanctions. Israel has relied heavily on demand management through metering, pricing and allocation to reduce water use. All water use is licensed and licenses must be renewed each year.

The government has also launched special initiatives, such as a four-year campaign in the early 1970s to disseminate information on water efficient on-farm irrigation systems, conducting field trials and equipment demonstrations, and financing purchase and installation. The government has supported the development of water saving devices, and has encouraged the development of a strong irrigation equipment industry. The government has also supported the

***Box 3-1: Introducing Drip Irrigation to a Traditional Agricultural Community in the Jordan Valley***

JORDAN VALLEY (The West Bank). In Jiftlik, the total arable land was about 1,800 ha, and was supplied from a spring through a system of concrete canals. The large land owners allocated water to the tenant farmers (previously nomadic) on a fixed rotation--once every 8 to 10 days in accordance with traditional water rights. Water was wasted, soils eroded, and yields declined yearly.

In the early 1970s drip irrigation hardware was provided to tenant farmers by the Ministry of Agriculture through a loan from an NGO (the Menonite Church). As the system gained popularity, farmers began to purchase the equipment themselves. The hardware components included: (i) small, earth-built water reservoirs with capacities of 1,000 to 5,000 m3 to enable uninterrupted flow for the drip systems; (ii) simple, modular, portable drip systems that did not require investments in land not belonging to the tenant farmers; (iii) peripheral components, including pumps, fertilizer units, filtration system, fittings, and valves; and (iv) seeds, plastic sheets (for mulching, low tunnels, etc.), farm machinery, fertilizers and chemicals.

The farmers soon mastered the technology with assistance from a limited extension program. Extension workers and the equipment manufacturer's field service team instructed the farmers in cropping and irrigation practices and in the O&M of drip systems. Within seven years, yields increased three to four times, water use declined from 12,000 to 6,000 m3 per hectare and the area under irrigation doubled.

*Source*: Eldar, M.; Irrinews No.35, 1987; D. Rymon and U. Or.

JORDAN VALLEY (The East Bank, Kingdom of Jordan). Jordan's experience with the introduction of drip irrigation was quite similar. The traditional surface irrigation system and the practice of rotational irrigation was no constraint to the development of drip irrigation. Here the farmers built small on-farm storage reservoirs, lined with plastic sheets to prevent seepage losses.

formulation of irrigation equipment standards, and research on all major irrigated crops, which formed the basis for legally enforced crop water allocations.

In Cyprus the total irrigated area in public schemes reached 28,200 hectares in 1990; 27,000 hectares were equipped with modern technologies, such as sprinkler and drip systems. Farms are small and fragmented in Cyprus--on average less than one ha. In modern public schemes farm plots have been grouped in units of 7.5 hectares and are served by outlets on hydrants (up to four units per hydrant). Each outlet is connected by pipes to farm outlets serving 2.5 hectare sub-units. Land has been consolidated in feasible areas. All irrigation water supplied in public schemes and all groundwater extractions are metered.

Like Israel, Cyprus has launched special campaigns to improve water use efficiency on the farm. Its extension service has provided farmers with free technical assistance and advice for on-farm irrigation system design and irrigation scheduling. The government subsidizes credit for system installation. Agricultural credit has been an integral component of on-farm development.

In Jordan surface irrigation was practiced until the mid-1970s; 60 percent of the farm land in the Jordan Valley (27,700 ha) is now under drip irrigation. A primary feature of the

Jordan Valley development was the enactment of a land distribution law in 1960. The law permitted the expropriation of land and water rights within project areas and revised farm layouts to meet the requirements of an efficient irrigation system. The law also stipulated that the farm unit would be physically indivisible, although it could have joint ownership.

Jordan also made substantial investments in the economic and social infrastructure in rural areas, which must have contributed greatly to the agricultural transformation of the Valley. However, the credit for the rapid introduction and development of drip irrigation in the Jordan Valley should go to the private sector, which provided both technical advice and credit to the farmers.

***Essential Elements in a Program for Efficient Water Use***

Based on the experiences of Israel, Cyprus and Jordan, the following elements contribute to efficient water use or water savings in the agricultural sector and are recommended for consideration in the design of national water conservation programs:

- a strong central organization, supported by a comprehensive code of water laws, empowered to plan and design efficient irrigation systems, allocate water, control water use and impose sanctions;

- planning, where feasible, regional or national grids for water distribution and joint operation of both surface water supplies and groundwater resources;

- for individual irrigation projects, well founded decisions on the design of conveyance and distribution systems (whether to select pipe or open canal systems or use both systems) taking into account the on-farm irrigation technologies to be promoted; decisions should based on long-term water supply and demand projections in the project area and marketing prospects for crops;

- implementing, with the irrigation infrastructure, a comprehensive social and economic development plan for rural areas promoting the general well-being of the population,

- appropriate land reform and land consolidation programs to overcome land tenure problems and improve the efficiency of irrigation layouts and operations (in the main system and on the farm);

- implementing a strong research program to develop or adapt on-farm irrigation technologies and practices for local conditions;

- a program for testing, demonstrating and disseminating recommended technologies;

- a strong irrigation extension service (irrigation advisory service) to advise farmers on irrigation technologies, practices and scheduling;

- a strong irrigation agronomy program to assist the irrigation extension service in determining optimal crop water requirements and developing recommendations for new remunerative crops;

- a program to train irrigation engineers, technicians, government workers, and water user association (WUAs) workers;

- an appropriate system of demand management consisting of water metering, water pricing and, possibly, water allocations based on carefully researched crop water norms. A system of graduated water prices may be adopted so that the excess use of water is heavily penalized;

- strong private sector involvement in manufacturing irrigation equipment and possibly provide irrigation extension services to the farmers (to be initially supported by the government if necessary);

- quality control of irrigation equipment through standardization and issuance of quality marks for locally manufactured products by a national institute of standards;

- access to agricultural credit so that farmers can purchase modern irrigation equipment; this may have to be subsidized initially or may contain a grant element to provide sufficient incentive; and

- the promotion of WUAs especially where the supply of water in bulk would be possible.

# 4. IRRIGATION IN MENA AND RECOMMENDATIONS FOR IMPROVED PERFORMANCE

Bank-financed irrigation projects have included several policy, institutional and technical interventions in order to ensure proper planning, design, implementation and efficient operation and maintenance, including proper water management on the farm. The purely technical features of the projects have been easy to implement. Improvements requiring policy or institutional reform were more difficult to accomplish. The Bank's experience with interventions (directly or indirectly linked to efficiency of water use) and observations on the performance of irrigation sub-sectors have formed the basis for the recommendations made in this chapter.

### *Changing Policies*

**Water Charges.** Project maintenance often declines because funds are lacking and because water charges are politically complex. Water charges can be levied successfully if the O&M organization is strong, financially independent and accountable to farmers for the services it provides. Water charges are collected in order to achieve two objectives: (i) to collect funds from beneficiaries for O&M and capital cost recovery; and (ii) to use the charges as a tool to promote water use efficiency. Bank projects have focussed on the first objective, although funds are not normally retained by the irrigation authority for O&M. Adherence to agreed covenants has been poor and the covenants have been renegotiated for several subsequent projects.

The range and scope of interventions in Bank projects has varied widely among projects and countries.[1] Volumetric water charges have been applied in Algeria, Cyprus, Jordan, Tunisia and Morocco. In contrast, in Egypt water is measured where it enters one of the ten Governorates. In the proposed Large-Scale Irrigation II Project (LSI II) in Morocco, water delivery contracts are being considered that would establish mutual obligations between the irrigation authorities and the farmers. It may be difficult to administer contracts with numerous individual smallholders, and without strong WUAs the farmers may have little bargaining power.

**Recommendations.** The financial autonomy and accountability of O&M institutions in relation to WUAs should be promoted along with efforts to improve cost recovery systems. Lending institutions should insist that project appraisals include realistic cost estimates of O&M financing and capital cost recovery. Loan recipients should be required to budget for O&M costs, indexing for inflation (see the On-Farm Development Project in Turkey). Water charges collected by the irrigation authority should remain in the irrigation authority's account for O&M. Water charges should correspond to the level of service. To improve water use efficiency, the following measures may be adopted: (i) where feasible, volumetric water charges should be introduced at levels high enough to encourage water use efficiency and cultivation of high value

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1/ An interesting pilot effort in Indonesia has introduced four different Irrigation Service Fees; the fees are determined by agreed (or absence of) O&M plans and the condition of the distribution system. Formal agreements have been made between the irrigation authority and WUAs, who play an active role in fee determination and collection (Gerards, 1991).

crops; (ii) with volumetric measurement, graduated water charges may be introduced with a system of crop water norms; and (iii) without volumetric measurement, water charges for crops should be levied per hectare, and should take into account the consumptive use of water by the crops.

**Legal, Regulatory and Administrative Measures**

**Inheritance Law.** Small and fragmented farm holdings present restrictions for improving the irrigation infrastructure in the MENA Region. Land consolidation will not necessarily resolve the issue in the long-term. Traditional inheritance laws may cause the land to be reparcelled, despite a minimum farm size fixed at the time of land consolidation (see box 4-3). Inheritance laws may need to be modified and smaller land holdings (both within and between families) may have to be purchased.

**Laws for WUAs.** Morocco experienced difficulties with implementation for the Small and Medium Scale Irrigation Project (SMSI)-Stage II. A new law to establish WUAs was approved by parliament, but was not announced for eight years. This law was pivotal to the project; the law formed the basis for obliging farmers to formally associate themselves, to undertake O&M, and to repay part of the rehabilitation and improvement costs of their traditional irrigation systems. The cost recovery between projects under the SMSI and similar schemes managed by the regional development authorities (ORMVA's) was also inconsistent.

**Water rights** are an important element in project design. The Wadi Al Jawf Agricultural Development Project in Yemen has not progressed because of tribal disputes over water rights. A detailed analysis of water rights and a socio-economic study during project preparation could have identified this problem.

The ownership of potential water savings, such as savings gained from canal lining, could affect project design. In public irrigation schemes, water savings become government property and can be used elsewhere. In traditional schemes, the water is owned by the farmers. The farmers have specific water rights expressed as portions of total flow for specific times and may want to intensify their cropping patterns or extend their irrigated area.

Project development within existing water rights may also lead to inequities. In Yemen the upstream riparians have prior water rights. The water rights caused problems in Tihama for downstream farmers because new spate irrigation schemes constructed in upper parts of the basin seemed to have reduced both surface and groundwater flows in the lower parts of the basin.

**Cropping Pattern Controls.** Regulatory measures, such as government controlled cropping patterns, have led to inefficient water use in Egypt and Morocco. In Egypt high water demanding crops, such as sugarcane and rice, are grown with low returns to water. Although 35 percent of total water use is diverted for these crops, they constitute only 14 percent of the agricultural value added. In Morocco, mandatory cropping patterns for non-industrial crops have only recently been removed.

**Groundwater Exploitation.** Groundwater reservoirs are being over-exploited by several countries. In the Yemen Water and Land Conservation Project, the Bank is trying to stop over-exploitation by licensing wells, operating drilling rigs, and introducing more efficient on-farm irrigation systems. Specific aquifer management and metering of well discharges, such as in Cyprus, seem to be rare.

**Recommendations.** Attention should be given to the problem of continuing land fragmentation in the design of on-farm development projects. When essential, the legal framework and administrative measures to meet project objectives should be in place before project financing is finalized. Water rights of beneficiaries should be clearly established and should be considered in project design. Irrespective of water rights, project hydrological effects on downstream users should be studied thoroughly. The liberalization of cropping patterns should be pursued. The licensing of wells, drilling rigs and permissible amounts of groundwater to be pumped should be promoted to avoid over-exploitation of aquifers.

### *Strengthening Institutions for O&M*

Strong institutions are crucial for effective O&M. A reliable water supply at the farm inlet is important for effective water management and for the adoption of modern irrigation technologies on the farm. Two projects incorporated far-reaching measures into the project design in order to strengthen irrigation institutions: the Large-Scale Irrigation Improvement Project (LSIIP) in Morocco (see box 4-1), and the Irrigation Management Improvement Project (IMIP) in Tunisia (see box 4-2). These two projects and other Bank-financed projects show that strengthening institutions requires strong political commitment and that more than one project is necessary to achieve this objective.

**Recommendations.** Objectives, preliminary criteria and procedures for improving O&M should be defined during project preparation, including details on service and accountability of O&M institutions to farmers and WUAs. Service contracts between the irrigation agencies and WUAs seem to be useful vehicles to promote this objective. Criteria and procedures for financial management and management information systems should also be established during project preparation. Detailed terms of reference should be written for consultants to prepare a comprehensive O&M manual during project implementation. The manual should be prepared in the format provided in the ICID Guide for "Planning the Management, Operation and Maintenance of Irrigation and Drainage Systems" (World Bank Technical Paper No. 99). This topic has been generally been inadequately treated in project preparation and needs more formal attention.

### *The Major Irrigation Infrastructure*

In the Maghreb, the infrastructure design and efficiency is adequate. Automatic operating gates for water level control and modules for water measurement are widely used for open canal systems. In smaller canals, duckbill weirs are often used for water level control. These systems are normally operated on pre-arranged demand. Conveyance and distribution efficiency is about 70 percent.

In Egypt, in the "old lands" of the traditional Nile Valley and Delta, canal water levels are below field level and the farmers use low lift pumps to irrigate their fields. The main canals and larger branch canals are operated on a continuous flow and the distributaries on an on-off schedule. Water is managed by controlling water levels. The canals provide some night storage and spills are collected in the drainage system and reused downstream, either through pumping stations or informally by the farmers. Despite a minimum of management, this traditional irrigation system has a high overall efficiency. The high degree of drainage reuse has helped the system between the Aswan Dam and the Mediterranean to achieve an average annual efficiency of 65 percent and up to 80 percent in summer. However, under conditions of water scarcity, the system would experience serious problems. The irrigation infrastructure in the newly reclaimed lands from the desert ("new lands") is designed along the same lines as the "old lands", except that canals are lined. In the "new lands", however, the lack of water management devices, night or buffer storage and the inability to recycle spills has led to very low efficiencies. The heavy losses have caused water logging in adjacent "old lands."

***Box 4-1: MOROCCO–Large-Scale Irrigation Improvement Project***

> The large scale public irrigation schemes in Morocco are managed by semi-autonomous, state owned agencies supervised by the Ministry of Agriculture and Land Reform (MARA). One main objective of LSIIP-I was to make the ORMVs more independent from government and promote their function as public utilities. The following interventions were introduced in LSIIP-I: (i) program contracts between the government and the ORMVAs that defined mutual obligations and set development targets; (ii) improved ORMVA management techniques, including reorganization, and introduction of an MIS for financial management and O&M; (iii) improved O&M and prepared O&M manuals; (iv) divestiture from commercial activities; and (v) cost recovery improvements.
>
> Although some success was achieved with diversiture and cost recovery, little has been achieved elsewhere. The main reason for the lack of success was the conflict of interest between parties. MARA wanted to retain control and obtain more funding for ORMVAs activities; the Ministry of Finance wanted more control, but less funding; and the ORMVAs wanted more funding, but less control.
>
> Developing only the concepts for change during project preparation will not necessarily obtain real commitments. Detailed letters of intent would need to be ready for signature between parties before loan negotiations so that the parties would be fully aware of their commitments. Detailed proposals setting out the criteria and procedures for financial management and O&M would need to become part of project preparation.

In most projects in Iran and Turkey, conveyance efficiencies are still low because of the manual control of structures and insufficient numbers of water measurement devices. In Iran the exceptions are the Isfahan and Guilan plain projects, which use modern canal technology.

*Box 4-2: TUNISIA–Irrigation Management Improvement Project*

This project aimed at increasing the efficiency and self-financing of the Irrigation Development Offices (OMVs). The following interventions were included in the project: (i) strengthening the role of WUAs in O&M; (ii) establishing MIS systems; and (iii) improving financial and operation procedures and preparation of O&M manuals. Unfortunately, little progress has been made with strengthening the irrigation institutions. In addition, a set-back occurred in 1989 when the government decided to transform the OMVs into regular line agencies (CRDAs) of the Ministry of Agriculture. Although this project was not short of objectives, it lacked carefully prepared proposals for the interventions.

**Rehabilitating and Improving Existing Systems**

Whether systems should be rehabilitated to original standards of operation or to meet improved standards depends on the expected evolution of cropping patterns (in turn, dependent on markets) and available water supplies. If water scarcity occurs and it is possible to cultivate high value crops--a situation most likely to occur near large cities--an open canal system should be equipped to accommodate modern technologies, such as sprinkler or micro-irrigation. Two solutions can be offered to overcome the mismatch in the supply of the main system and the demand on the farm. Buffer storage should be provided: (i) at the head of a group of farms (the tertiary unit), from which one pumping station could pump water to individual farms through a pipe system, or (ii) at the head of individual farms in on-farm storage ponds equipped with small pumping units. The first solution requires the acquisition of land to build the storage reservoirs; this would become easier if land consolidation was carried out. Changes in service by the irrigation authorities or the use of intermediate technologies on the farm, such as gated pipes may require changes in the structures (the interface) between the irrigation distribution system and the individual farms. Various design options could be used depending on the existing design. The farm outlet could be: (i) either a low pressure hydrant that could accommodate both a flexible pipe for surface irrigation or (in the future) a mobile pump for sprinkler or micro-irrigation; (ii) a sump for pumping; or (iii) as above, the inlet structure for a small farm pond. Sufficient flexibility would have to be built into the design to avoid hampering the future use of more efficient irrigation techniques.

For distribution systems in public groundwater schemes with individual wells irrigating about 50 to 100 hectares, an improved design has been adopted in India and Nepal and has proved to be operationally more efficient and less costly. The well water is pumped into an elevated tank, which provides working pressure and is equipped with sensors to automatically regulate the pumped water. A looped, buried system of PVC pipes provided with hydrants distributes the water to individual farms. The Sahara Development Project (Algeria) is the first project in MENA where this system will be introduced. Groundwater schemes in Yemen and elsewhere would also benefit from this design. Where feasible, the introduction of private shallow tubewells is preferable over larger capacity deep public tubewells.

Tailwater return systems can also be used to recycle water and increase project efficiency, although this water is generally of a lower quality. The runoff from the fields, from either one or more farms, would be collected in a storage pond and would be returned--mostly through pumping--for reuse. Guidelines for determining when upgrading would be preferable to rehabilitation are difficult to provide. The decision would depend on local conditions, such as investment costs, anticipated on-farm irrigation technologies, the value of additional crop production, and the value of the water saved by applying improved technologies. ICID is preparing guidelines for irrigation rehabilitation and modernization.

None of the concepts described at the beginning of this section has been considered in the design of several rehabilitation projects. Financing institutions are often presented with a finished, technically sound design that is not optimum and will not meet future needs. Little diagnostic work is completed in order to identify deficiencies in the present system and arrive at criteria for rehabilitation. The Bank-initiated and UNDP-financed study for the rehabilitation and improvement of the "old lands" in Egypt was an exception. The study included detailed water balance studies for upper, middle and tail end reaches of representative canals and their operation characteristics.

**Recommendations.** As part of project preparation for future rehabilitation and improvement projects, more diagnostic work (technical, agronomic and socio-economic) should be carried out to evaluate the existing systems and to determine the need for upgrading. Long-term evolution of cropping patterns, marketing projections for crops, regional water balances and marginal value of water should be considered in determining rehabilitation criteria.

**Designing and Implementing New Systems**

Some of the same design principles used for rehabilitation apply for designing and implementing new systems. Planned operation of the systems and design, and the role of WUAs should be closely linked, depending on local customs and farmers' skill levels. The use of pipe systems is becoming prevalent in new projects because pipe systems are easier to operate, reduce operational losses and provide a more reliable water supply. Moreover, pipe systems can be advantageous if natural pressure exists for use of modern on-farm irrigation technologies and the topography is difficult. Unfortunately, high costs deter their use in many situations. (The average total cost of the main distribution system for SCP is about US$7,000 per hectare, excluding dams, tunnels and on-farm development and US$13,000 per hectare for MIP.)

For higher capacity conveyance facilities, open canals may be cheaper to construct in normal terrain. Any economic comparison between alternative solutions should consider the cost of water delivered at the outlet, and should take into account the conveyance efficiency and the cost to recuperate losses downstream. A combination of open canal systems for the larger capacities and pipe distribution systems for the tail-end systems is likely to provide the most economical solution for large schemes. With advanced canal technology, buffer storage between the two systems may not be a technical requirement. However, buffer storages at strategic locations could reduce the maximum discharges and the sizes of the main conveyor pipes upstream from the storage points and thus could provide a more economical solution. Small storage reservoirs at the tail-ends of the distribution system would be the ideal location for a WUA to receive its water in bulk from the irrigation authority.

The Maghreb countries have adopted modern canal control technologies, such as "dynamic control" (for example, the Rocade canal in the Houss, Morocco). In Egypt modern design is still met with reluctance. Financing institutions should avoid involvement in projects where the main delivery systems may already have been constructed, but may not have been adequately designed. Inadequate designs could lead to serious problems, especially in projects that plan to use modern irrigation technology on the farm.

**Pilot and Demonstration Schemes**

The need for pilot and demonstration schemes was well recognized in the 1960s, but the pressure to finance new schemes has led to the neglect of these schemes. Pilot schemes of 5,000 to 10,000 hectares may be needed to demonstrate and test the viability of advanced canal design technology in a specific socio-economic and cultural environment. Pilots and demonstrations can be helpful for examining design concepts for upgrading schemes because the basic infrastructure is already available. Smaller pilot schemes (50 to 100 hectares) may suffice where only tertiary or quaternary systems need to be tested. Pilot schemes could also make use of groundwater.

*System Operation*

**Integrated System Management**

Only a few Bank-financed irrigation projects in the MENA Region include complicated reservoir systems and diversions. Detailed system operation plans are being prepared for the SCP and involve reservoir operations, conjunctive use of surface and groundwater for irrigation and municipal water, reuse of waste water and groundwater recharge. Interlinked reservoirs and diversions for irrigation and drinking water are being used in Northern Tunisia.

**Recommendations.** To optimize operations, technical models should be linked to economic models. The models would be useful during droughts to give advice, based on crop yield response to water and knowledge of critical growth stages, on setting priorities for irrigation.

**Conjunctive Use of Surface and Groundwater**

Few projects in MENA have been designed specifically to use surface and groundwater. The SCP (Phase I) was reformulated to spread the surface water over a larger area, but part of the deficit was diminished by groundwater. Ground water can also play a significant role in providing a buffer storage during droughts. During project planning, more attention should be paid to the joint use of surface and groundwater in new projects.

**System Operation and Irrigation Scheduling**

System operation and irrigation scheduling vary throughout the Region. In the Maghreb, system operation is adequate; advanced water control structures are being used. Water is delivered to farmers on pre-arranged demand for public gravity irrigation schemes and on demand for sprinkler schemes. But the lack of maintenance has lowered obtainable efficiencies in many cases. In Egypt, farmers receive water on demand within the canal rotation period. However, most projects in Iran and Turkey lack efficient control structures and water measurement devices. Water is normally supplied on rotation. Traditional irrigation schemes built by farmers in North Africa have precise rules for operation; water rights for individual farmers are expressed in specific water doses (main d'eau) and irrigation intervals (tour d'eau). Whether irrigation is scheduled by pre-arranged demand or by rotation, aggregating demands by hand for different points in the distribution system is difficult, and causes difficiencies in operations. Computers and readily available software could facilitate demand aggregation.

**The Role of Water Users Associations**

Water users associations have been established throughout the world to reduce the managerial and financial burdens of operating smaller canal systems and improve the equity and reliability of water distribution. WUAs have been promoted in several Bank-financed projects (SMSI I and II, IMIP). This experience has underlined the importance of having detailed procedures for promoting WUAs, clear incentives for farmers to join WUAs, and agreements on the mutual obligations and responsibilities of the WUAs and Government.

**Recommendations.** The decision to establish a WUA and its organizational structure can be important for designing physical infrastructure, and should be addressed during project preparation. Useful guidelines for establishing WUAs and recommendations for enhancing the performance of irrigation institutions have been developed by Ostrom (1990) under contract with USAID; the eight design principles for crafting irrigation institutions developed under this study are shown in annex C, table C-6. The establishment of WUAs should be designed during project preparation by experienced institutional and social scientists.

### *On-farm Irrigation Systems*

With few exceptions (Israel, Cyprus and Jordan), most on-farm irrigation in the region is conducted by inefficient gravity (surface) irrigation methods. Several constraints prevent small farmers from investing in more sophisticated irrigation technologies that would increase their crop production and save water. First, and most important, the private investment would need to produce higher financial returns for the farmer; in other words, farmers need access to domestic or foreign markets to sell valuable crops. Unfortunately, agricultural marketing systems are often inadequate. Farmers' options for crop diversification and inputs use are often limited because agricultural research and extension programs are inadequate. Other common constraints are (i) the appropriate interface between public irrigation distribution systems and on-farm irrigation systems for large scale irrigation schemes; (ii) well-proven on-farm irrigation technologies suitable for prevailing socio-economic conditions and adaptive research programs to identify technologies; (iii) access to support services for selection, design and initial training in the operation and maintenance of the systems, including advice on irrigation and cultural practices and irrigation scheduling; (iv) land tenure constraints; (v) access to agricultural credit.

**The Introduction of Modern Technology**

The emphasis given in Bank-financed projects to improved irrigation methods on the farm has been mixed. New projects have included the adoption of sprinkler systems (Doukkala II in Morocco, the Vasilikos-Pendaskinos Irrigation Project and SCP in Cyprus, and the Haut Cheliff and MIP in Algeria). Rehabilitation projects have done little to make water use more efficient. The LSI did not include a component to improve on-farm water management. A 500 hectare pilot scheme in the IMIP was intended to experiment with water distribution and alternative technologies; the pilot scheme was scaled down and contained no follow-up action program. However, the proposed LSIIP II will include on-farm demonstrations with improved gravity irrigation methods, including lining quaternary canals, land leveling, and demonstrations with sprinkler and drip systems. The LWCP in Yemen will include demonstrations on 220 one-hectare plots with sprinkler and drip systems. These developments are positive, but much more remains to be done. (Experiences with modern irrigation technologies are presented in box 4-3.)

***Box 4-3: Selected Area Experiences with Modern Irrigation Technologies***

**Morocco.** An Impact Evaluation on the Doukkala Irrigation Projects revealed that field application efficiencies for the Doukkala II project, provided with (mobile) sprinkler equipment on the farm, were only marginally higher than for the gravity systems adopted in the Doukkala I Project (67 percent compared with 58 percent). The performance of the sprinkler systems was low. Equipment maintenance was poor, in part, because it was jointly owned by the users. The sprinkler system designs did not fit ownership patterns; farm sizes had decreased considerably through inheritance. Individual plots had become long and narrow, therefore, irrigation overlapped from sprinklers in adjacent plots. Other sprinkler areas in Morocco have reported problems, such as poor maintenance, occasional removal of flow limiting devices by farmers, pressure regulators and water meters, and lack of spare parts. These problems could be corrected by rearranging the plots, adopting more appropriate sprinkler technology (including part-circle sprinklers), stricter controls, imposing sanctions for vandalism, and better field services for maintenance and repair.

**Tunisia.** Several sprinkler irrigation schemes have been implemented, however, some schemes suffer from low uniformities in water applications. Sprinkler equipment has surpassed its technical and economic life. Often, the equipment is not replaced because farmers perceive the costs to be too high (partly because low value crops are grown) and because farmers have problems with access to agricultural credit. Problems have also been experienced with drip irrigation. For example, uniform specifications were adopted for a 2,000 hectare scheme in Cap Bon, but performance was poor because soil conditions were not uniform. Other examples of deficiencies are the omission of filters, the lack of pressure control and inappropriate capacity in the emitters. These problems could be avoided with quality control during design and installation.

**Egypt.** About 68,000 hectares were under micro-irrigation according to a 1986 ICID survey. The same survey reported that about 20 percent of the systems had been abandoned because of maintenance problems, clogging, insufficient pressures and power failures. Although the "new lands" cover about 25 percent of the total irrigated area, their contribution to total agricultural production is only 7 percent. Many problems have been observed in the "new lands" located east and west of the Nile Delta: poorly planned and designed irrigation systems with insufficient in-system storage and inadequate water control; poorly constructed and maintained booster pumping stations with frequent breakdowns and unreliable power supplies; inadequate quality control in the design and installation of the on-farm equipment; lack of training for inexperienced settlers; and farmers' lack of access to spare parts. In contrast, some excellent working systems can also be found in the "new lands," but most systems are owned by large farmers or companies with good access to water and sufficient resources to procure advice and services directly from the private sector.

### Land Tenure Constraints

Land tenure constraints include incomplete cadastral surveys and documentation, absence of legal regulations for private land transactions and fragmentation of farms through inheritance. This report does not intend to discuss land tenure problems in detail, but the problems must be addresssed so that farmers will be able to invest in more sophisticated, costly irrigation technologies. Land tenure problems in Tunisia have immobilized the land market, and have inhibited the efficient use of land resources (see Tunisia: Small Farmers Potential and Prospects, World Bank, 1991). Moreover, farmers cannot obtain agricultural credit because land titles are unavailable. In Morocco, land consolidation accompanied the implementation of its large-scale irrigation projects, but the subsequent fragmentation of land holdings has led to inefficient on-farm irrigation systems (box 4-3).

**Recommendations.** The resolution of these problems would require improvements in cadastral services and modifications in inheritance laws. Thus more attention must be paid to land tenure problems during project preparation.

### The Need for Adaptive Research

No single system can fulfill the requirements of different physical and cropping systems and different skill levels among farmers--even in one country. Less costly, intermediate technologies will be needed for most farmers because high value crops for export cannot be cultivated everywhere in a country. Although adaptive research is being used to develop inexpensive intermediate technologies, more needs to be done to promote intermediate technologies through national campaigns to conserve water (see box 4-4). Adaptive research, if properly conducted, should consider all relevant aspects of the technical interventions: (i) investment and operation costs (including energy and labor); (ii) the uniformity of water application and application efficiency; (iii) impact on crop yields; (iv) agronomic aspects, such as fertilizer savings; and (v) the financial viability of the system for adoption by small farmers.

**Recommendations.** Adaptive research programs should be promoted to identify suitable irrigation technologies for small farmers, and should take into account all relevant technical, socio-economic and marketing conditions. The programs may be developed in cooperation with IPTRID and should include: (i) an adaptive research period (possibly guided by a panel of multi-disciplinary experts); (ii) testing in farmers' fields; (iii) further promotion of proven systems through demonstrations and other extension efforts.

### Farmer and NGO Participation in Technology Development

If new on-farm irrigation technology is unacceptable to the farmers' community, efforts to introduce the technology will fail--probably for good reason. Formal research and development agencies are not designed and equipped to promote a participatory process for technology development, however, involvement by NGOs and farmers' organizations has great potential. NGOs have successfully conducted on-farm adaptive trials, and farmers and farmers groups have conducted on-farm testing (Coen Reijntjes et al, 1992). The farming community's active involvement is needed during all stages--identification, adaptation, testing, and dissemination. Therefore, during the design stage of adaptive research in irrigation technology and irrigation agronomy, attention should be given to ensuring farmers' involvement.

## International Networking

UNDP has approved a US$3.8 million "Regional Network for the Management of Supplementary Irrigation for Non-Irrigated Agriculture and the Improvement of On-Farm Irrigation Management" (RAB/90/005/A/01/31). The project aims to establish a network between national institutions to cooperate, exchange research information and demonstrate new technologies. Several countries are proposed to participate: Egypt, Algeria, Iraq, Jordan, Morocco, Oman, Sudan, Syria, Tunisia and Yemen.

***Box 4-4: Adaptive Research in Tunisia and Egypt***

Tunisia. Eighty percent of the areas are irrigated by traditional surface irrigation methods, with efficiencies of about 40 to 45 percent. Despite growing water shortages, very little adaptive research has been undertaken to find proven systems that could be used beneficially by the small farmer, and national research institutes are not equipped for this task. Only the former Development Offices (now CRDAs) have undertaken research. Unfortunately, the research has been limited in scope, has focused on narrow technical objectives and the development offices have not shared ideas or information. Recently UNDP approved the "Training and Development for Water Savings in Irrigation Project" (TUN/91/002/A/01/12) to support adaptive research for on-farm irrigation technologies and disseminate the improved technologies to farmers' communities through demonstrations and extension.

Egypt. Intensive irrigation field studies were conducted in the USAID-funded "Egypt Water Use and Management Project" (1977-1984) at three representative sites in the Nile Delta and Valley. Farmers irrigated small flat basins, either by flooding or by using level furrows. For the heavy clay soils (the main soil type), average application efficiencies were about 70 to 75 percent. For the sandy soils on the fringes of the Delta and Valley, average application efficiencies were about 45 percent. However, these efficiencies had high coefficients of variation. The main problems observed with the systems were: (i) high labor requirements; (ii) uneven levels within the basins; (iii) difficulties with farm machinery; and (v) difficult access to the fields. Irrigation trials were conducted with long level basins and long level furrows to improve water management, and included precision land leveling. At two sites the trials were unsuccessful and farmers fared as well or better with conventional systems. Improvements were reported at one site where farms and available flows were somewhat larger, but the reported net water savings were doubtful because drainage water and groundwater recycling was not taken into consideration. The main benefits seemed to come from increased yields from improved water management practices and land savings from a more rational lay-out of the field irrigation systems. Unfortunately, the economic and financial feasibility of the proposed interventions had not been analyzed. Precision land leveling proved to be difficult because cropping was conducted year-round. Alternative meska (water course) improvements were also made: an unlined, low-level meska was transformed and farmers pumped individually into a lined saqia above field-level served by one communal pumping station. However, such a system would have disadvantages: (i) an almost on-demand system would be changed to a rotational system, which could result in serious management problems; (ii) a considerable loss of night storage capacity would occur--a feature that has made the Egyptian system efficient; (iii) difficulties might be expected with maintenance of the pumping stations, which would be owned by groups of farmers. Unfortunately, with the end of the EWUP the adaptive research program for the "old lands" has stopped. For both the "old lands" and the "new lands" continuing research is needed to resolve existing problems and identify the most appropriate technologies for a range of local conditions in order to save water and increase yields.

**Irrigation Scheduling**

In Morocco, the duration and quantity of water supply to an individual farm is based on a request from the farmer to the ditchrider. The farmer is notified at least 24 hours before delivery. The on-farm irrigation schedules probably do not accurately meet the crop water requirements. Water can easily be over or under-supplied because the ditchrider may have some knowledge of crop water requirements, but would not know to account for moisture conditions in the soil. In most Bank-financed projects, extension services are relied upon to provide farmers with all the information needed to irrigate efficiently, but extension services are often poorly equipped. Several methods are available for proper irrigation scheduling; maintaining a balance of the water content of the root zone is probably the most appropriate method for developing countries. With this method, reference fields for major crops may be monitored. More predictable scheduling on the farm could make system operation more efficient. In Morocco, a specific project was prepared to strengthen irrigation research and extension. In Egypt, steps are being taken to set up an Irrigation Advisory Service with assistance from USAID.

**Recommendations.** Detailed proposals should be made during project preparation for irrigation extension to promote better water scheduling practices on the farm. A guide should be prepared for establishing and operating irrigation scheduling service.

***Research in Irrigation Agronomy***

Irrigation technologies cannot evolve successfully without strong research programs to identify remunerative crops for domestic and foreign markets. In addition, sound cultivation and irrigation practices should be formulated for use by the farmers. Crop water requirements should be determined for difference climatic zones with different irrigation practices, critical stages of crop growth, and the response of crop yield to water. If applicable, recommendations for crop water allocations should be developed. Many countries have been involved with research in irrigation agronomy, but the research has been insufficient. A modest effort has been made to provide support for the on-going MIP and CIP in the Algeria Research and Extension Project. An Irrigated Areas Agricultural Project is presently being prepared for Morocco that would provide parallel support for the proposed LSIIP II.

**Recommendations.** Agronomic research for irrigated agriculture should be promoted, either as a component in projects for irrigation infrastructure or through free-standing research and extension projects.

***Promoting the Role of the Private Sector***

Government can play an important role in the identification and demonstration of viable irrigation technologies, especially with technologies suitable for small farmers. After a market for the products has been established, Government could encourage private industry to undertake mass production, possible through an industrial credit or by guaranteeing the sale of its initial production.

**Recommendation**. Governments should be given assistance to establish institutions to exercise quality control on locally manufactured or imported products.

# 5. CONCLUSIONS AND RECOMMENDATIONS

**General.** There is no panacea for improving water use efficiencies, especially in existing projects. Financing institutions should continue to persuade governments to (i) improve their policies and institutions to achieve more efficient O&M; (ii) upgrade their irrigation infrastructure to ensure a more reliable water supply at the farm-turnout to accommodate the demands of modern agriculture; and (iii) promote more advanced on-farm irrigation technologies--improved surface irrigation, sprinkler or micro-irrigation.

**The Irrigation Distribution System.** Modern on-farm irrigation technologies require a reliable water supply at the farm-turnout, and micro-irrigation requires an almost continuous water supply. In many cases, current irrigation infrastructure should be upgraded or modifications should be made to the interface between the main distribution and the on-farm system. Whether to rehabilitate current projects to existing standards only or upgrade them to standards for (future) adoption of improved irrigation technologies on the farm is an issue that has not been sufficiently addressed in rehabilitation projects.

**Modern On-farm Irrigation Technologies.** Of the modern irrigation technologies, micro-irrigation has great potential to conserve water on the farm (30 to 50 percent compared to surface irrigation). The potential yield increases per unit of water are substantial (often two or three-fold). However, the technology's suitability for smallholders depends on the local terrain and the socio-economic environment, farmers' education, demand and market mechanisms for profitable crops to justify on-farm investments in irrigation, farmers' willingness to innovate, access to agricultural credit and agricultural support services (training, extension, after sales services, etc.). None of the advanced technologies are "easy". Micro-irrigation requires high skill levels, although it has been successfully introduced in traditional farming communities in Israel and Jordan (box 3-1). Micro-irrigation should not be promoted on a large scale without testing and adapting it to local conditions. Otherwise, intermediate technologies may be more appropriate.

**Water Savings.** Real water savings--in the riverbasins--in water conservation projects are difficult to predict. Hydrological analysis is needed to examine the possibility of recycling water losses through groundwater pumping and drainage reuse. Since water use efficiency is a relative term, the criterion for evaluating water conservation measures should be economic efficiency.

**The Case Studies for Israel, Cyprus and Jordan.** In Israel, surface irrigation is not practiced; in Cyprus and Jordan, pipes are used for all new distribution systems; in Jordan, open canal systems are being converted to pipe systems. The most important pre-conditions for using modern irrigation technologies on the farm have probably been (i) water shortages and the search for solutions--especially in Israel; and (ii) a strong local or export market for agricultural produce to give farmers sufficient financial incentive to invest in advanced irrigation technologies. In Jordan, land reform, land consolidation, expropriation of water rights and rural development were also key actions undertaken by government in order to modernize agriculture. In Cyprus, land consolidation was an important feature of irrigation development. Moreover, strong farmer support services in irrigation extension (including irrigation scheduling) and agricultural credit (subsidized or partly as grant) is essential, and a strong program for irrigation agronomy research and government control on the quality of manufactured irrigation products is highly recommendable. Special water conservation campaigns can also contribute to quicker adoption of water saving measures. Strong institutions supported by appropriate legislation are required to promote changes and exercise control.

**Water Charges.** Water charges have been used most often to collect funds for O&M. Graduated water charges to improve water use efficiency should be given more attention. The level of water charge may also be linked to the level of service provided by the irrigation authority.

**Water Rights and Legal Framework for Farmer Participation.** The water rights of beneficiaries need to be clearly established during project preparation in order to improve traditional irrigation schemes. The legal framework for farmer participation in O&M and capital cost recovery needs to be in place before project implementation begins.

**Land Tenure Constraints.** More efforts should be made to remove constraints on land ownership, such as the lack of titles and the continuing fragmentation of land through inheritance. These constraints prevent the farmer from investing in new technologies.

**Strengthening Institutions for O&M.** Project components such as establishing MIS systems, preparing O&M manuals and improving financial management need more detailed preparation. If the components are correctly designed, long delays during project implementation will be avoided and commitment can be obtained from the irrigation authorities.

**Need for More Diagnostic Work as the Basis for Rehabilitation.** Project preparation to rehabilitate and improve irrigation schemes should include detailed diagnostic field work to analyze local conditions and determine criteria for upgrading the distribution system. On-farm technologies should be included in the upgrading, and should allow cropping patterns to evolve. The projected cropping patterns should be based on expected future markets for crops and water availability determined by regional water balance studies.

**Need for More Pilot and Demonstration Schemes.** Pilot projects should be used to test new design concepts under local conditions, especially in the tertiary and quaternary systems at the end of the distribution systems in order to measure farmers reactions, assess impact on yields, etc. Rehabilitation projects would benefit greatly from pilot schemes if new on-farm irrigation technologies are introduced that require storage ponds at the head of the tertiary unit, farm ponds on the farm, or low pressure pipe systems within the tertiary units (with or without land consolidation). Pilot projects with improved irrigation technologies should be established in places where (i) water balance studies indicate water shortages or the potential for water shortages; (ii) projects are to be redesigned; and (iii) potential markets exist for the cultivation of remunerative crops, in other words, markets close to main population centers.

**Joint Use of Surface and Groundwater.** Where feasible, attention should be paid to the conjunctive use of surface and groundwater.

**WUA Design.** Procedures for promoting WUAs, identification of incentives for farmers to join WUAs, and proposals on mutual obligations and responsibilities of WUAs and irrigation authorities should be included in project preparation. The WUA design should be linked with the design of the physical infrastructure. WUAs can also play an important role in the accountability of irrigation institutions to farmers.

**Adaptive Research Programs.** Adaptive research programs to identify appropriate on-farm irrigation technologies should be promoted. The selection of technologies should account for all technical, financial, socio-economic and marketing aspects. The programs may be developed in cooperation with IPTRID and should include: (i) an adaptive research period (possibly guided by multi-disciplinary experts); (ii) testing in farmers' fields; and (iii) promotion of proven systems through demonstrations and other extension efforts. Adaptive research should include the whole range of irrigation technologies, including micro-irrigation, unless markets for valuable crops do not exist. Farmers and NGOs should be involved in testing new technologies.

**Irrigation Scheduling.** Projects that promote the introduction of improved irrigation technologies on the farm should be accompanied by detailed proposals for improved irrigation scheduling. Or nationwide irrigation extension projects may be undertaken. A guide should be prepared for establishing and operating an irrigation scheduling service.

**Agronomic Research.** Agronomic research in irrigated agriculture should be promoted in order to identify remunerative crops and to formulate better irrigation practices. Research on crop water requirements under different irrigation practices and water-crop yield functions is recommended.

**Manufacturing and Quality Control.** After appropriate irrigation technologies and demand for materials and products have been identified, governments should promote local manufacturing and should ensure quality control for products and on-farm system design.

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# ANNEX A
# APPROPRIATE IRRIGATION SYSTEMS FOR SMALL HOLDERS

*Improved Surface Irrigation Systems*

Several surface irrigation methods are used--graded border, level border, contour levee, contour ditch, furrow (either graded, level or on the contour), and corrugation irrigation. These methods are often adapted to local conditions and irrigation traditions. The methods often result in low irrigation efficiencies (especially in lighter soils); the notable exception is level basin irrigation on heavy soils in which irrigation efficiencies can reach 80 to 90 percent.

**Improved furrow and border irrigation.** Surface irrigation can be improved by using syphons to distribute the water onto the field or by using gated flexible or rigid tubing, accompanied by precision land leveling and maintenance of the leveled fields. If tubing is used, permanent ditches are not required and the cultivable area increases. The tubing can be attached to risers on buried low pressure pipe systems. With more than one riser along long furrows, the pipe setting could be varied and would provide flexibility because the optimum length of run varies with the stage of crop growth. For example, during germination shorter runs would be better. Efficient furrow irrigation also requires high "run-in" streams for initial wetting, followed by smaller "cut-back" streams. Modern furrow systems thus require high management skills if efficiencies are to be obtained. Recent studies for the proposed LSIIP II in Morocco indicated that land leveling would cost about US$250-400. With gated pipes costing about US$500 per hectare (annex 3, t-3), the on-farm costs to modernize surface irrigation amount to about US$750-900 per hectare--not much less than the investment costs for a mobile sprinkler system.

**Pipe-basin irrigation** was used in Cyprus to irrigate mature orchard trees. The water is conveyed to the basin of each tree by buried main lines and movable secondary aluminum or light galvanised steel pipes that can handle discharges of 30 $m^3$ per hour. The low pressure (1 atm or less) required to operate the system and the low initial investment cost made it very popular among farmers during 1965-75. Reportedly, application efficiencies of 80 percent were achieved.

**Hose-basin irrigation** was used successfully in Cyprus. The system is identical to the pipe-basin system, except that the secondary lines are replaced by plastic hoses 16 to 32 mm in diameter. It was used extensively in small orchards during the 1965-75, especially in areas with low discharge. It offers the same advantages as the pipe-basin system, and it is easier to move the hoses around.

*Sprinkler Irrigation*

**Mobile sprinkler systems** are composed of a buried or portable main line with valve outlets at regular spacings where the laterals can be attached. Typical operating pressures are 3.5 atm, but low pressure nozzles have been developed that operate at 1.0 to 1.8 atm and laterals are suitable for moves of 10-20m (Keller,1981). The following systems are used in Cyprus with operating pressures from 1.5 to 2.5 atm: (i) for orchards: low angle, low capacity (0.5 to 0,10 $m^3$ per hour) sprinklers, placed at 5mx6m or 6mx12m; (ii) for vegetables and vines: medium capacity sprinklers (1.0 to 1.5 $m^3$ per hour), spaced at 6mx12m or 12mx12m; (iii) pastures: medium capacity sprinklers placed again at 6mx12m or 12mx12m.

**Perforated Pipe** systems use rigid pipe with small holes drilled along the top and sides of the pipe. The holes are sized and spaced to obtain a reasonable uniform water distribution. Working pressures are generally 0.3-2.0 atm. The spread ranges from 8 to 15 m and increases as the pressure increases (adapted from Keller, 1981).

**Overlapped hose-fed sprinkler grid** is used to supply small sprinklers that operate at pressures as low as 0.35 to 0.7 atm. These systems can also produce relatively uniform wetting if the sprinklers are moved in a systematic grid pattern with sufficient overlap (adapted from Keller, 1981)

***Micro-Irrigation (Localized Irrigation)***

**The Bas-Rhône system**, developed in France in 1969 (Decroix, 1988), is used mainly for tree crops. The system uses black polyethylene pipe (25 mm) and nozzles with drilled holes (1.2-2.1 mm) covered by splash rings. The size of the holes can be varied with the pressure in the pipe. Operating pressure is about 0.3 to 1 atm. The pipes are laid parallel to the crop rows and with flow rates of 20 to 140 liters per hour short closed furrows are filled. The large nozzle openings (made by a hand-held nipper) only require simple filtering.

**Bubbler irrigation** consists of buried polyethylene corrugated pipe between rows of trees with (for example) 1/4-inch flexible branches emerging from the soil, each irrigating one or two trees. The height of the risers above the field is a function of the pressure in the pipe and is adjusted until the flow rates are uniform. There are no emitters, no flow control devices and no filters (except perhaps a simple screen near the pump). Investment and operating costs are low. The system operates at low pressure (0.1 to 0.2 atm at the beginning of the pipe). There is little danger of clogging because the pipe diameters are large. Because the system is underground, its life expectancy will be longer than that of an above ground tubing system. The reported cost in Yemen is about US$20 per tree.

**Modular drip systems** can be used by small farmers (see box 3-1). The water can be pumped directly from small storage ponds or standard sized barrels could be used for storage and as pressure tanks with pressure provided by hand pumps. In Israel, the latter method was estimated to cost US$260 for a 0.1-hectare plot, US$2650 for a 1.0-hectare plot and US$6,100 for a 6-hectare plot. These low costs were achieved by having one drip line serve six rows, thus substituting labor for capital investment (Eldar, 1987).

# ANNEX B
# WATER CONSERVATION IN ISRAEL, JORDAN AND CYPRUS

### *Background*

**Israel.** Irrigation has developed in three distinct phases (see annex B, chart B-1). During Stage One (1948-65) the main infrastructure was developed, the legislative and administrative frameworks were established and surface irrigation was replaced by sprinkler irrigation. Stage Two (1966-79) focused on increasing water use efficiency through micro-irrigation and the development and use of treated sewage effluents and brackish groundwater. Stage Three (1980-present) has focused on refining irrigation technology, allocation cutbacks for agriculture, decentralizing the structure of the water economy and more widespread use of non-conventional water resources. During these development periods the area under irrigation increased from 30,000 hectares in 1948 to 213,000 hectares in 1990. Water use (metered gross supply to consumers), which amounted to 8,700 $m^3$ per hectare in the early-50s, was only 5,700 $m^3$ per hectare in the late eighties. Production per hectare increased and the yield per unit of water increased from 1 kilograms per $m^3$ to about 2.5 kilograms per $m^3$ (see annex B, charts B-2 and B-3).

In addition to the recognition of water shortages, an important factor in irrigation development in Israel has been the receptiveness of the farmers to innovation because most settlers had no previous agricultural experience. The receptiveness was also linked to the farmers' sense of security, which resulted from strong Government support for the agricultural sector.

**Cyprus.** Water conservation was given top priority after independence in 1960. Programs were initiated to control groundwater extraction, introduce efficient irrigation practices, construct water storage and groundwater recharge facilities, implement small irrigation projects, line irrigation channels, and develop new aquifers. The irrigated area in 1954 was 18,690 hectares, all under inefficient surface irrigation. Total irrigated area in public schemes reached 28,200 hectares in 1990, of which 27,000 hectares were irrigated with modern irrigation technologies.

**Jordan.** During Stage I (1959-69) the East Ghor Canal was constructed, based on a Master Plan developed for the Valley in 1955. By 1969 this 78-kilometer long canal commanded 13,400 hectares by gravity. During Stage II (1973-present) efforts were directed at rehabilitation and further development, including comprehensive social and economic development in rural areas. Pressurized irrigation networks were constructed for new lands and 7,300 hectares of canal systems were converted into pipe networks. The total irrigated area in the Jordan Valley is 27,700 hectares, of which 26 percent are supplied from open canals, and 74 percent from pipe systems. Until the mid-70s surface irrigation methods were used on the farm, but 60 percent of the farm land is now under drip irrigation. These developments resulted in increased average yields for vegetables from 8.3 tons per hectare in 1973 to 18.2 tons per hectare in 1986; the yields for fruits increased from 7.1 tons per hectare to 16.0 tons per hectare.

*Institutions*

**Israel.** One of the principal elements facilitating attainment of the development objectives was the early establishment of the Water Commission (WC) and the enactment of a comprehensive code of water laws during 1955-1959. The executor of these laws is the Water Commissioner, who is appointed by the Minister of Agriculture and armed with an extensive array of legal powers granting him discretion on all matters concerning the allocation of water, control of water use, planning of new schemes and their operation, imposition of sanctions, etc. Important roles have also been played by (i) the Irrigation and Soil Field Service, established in the mid-fifties under the authority of the Water Commission and assigned to deal exclusively with extension in irrigation; (ii) the Israel Center of Water Works Equipment (ICWE) established in 1965, also responsible to the Water Commission and responsible for the development and application of water use efficiency devices and to draw up specifications and standards for irrigation equipment together with the Standards Institution of Israel; (iii) the Israel Water Works Association, an association of agricultural settlements and cooperatives and regional water supply associations, and which has as objective to enhance the technical qualifications and know-how of those responsible for O&M of the water supply and irrigation systems.

**Cyprus.** The ultimate body with responsibility for water resources management policy is the Council of Ministers. The two most important ministries involved in policy making are (i) the Ministry of Agriculture and Natural Resources (MANR), concerned with water resources development works; and (ii) the Ministry of the Interior, concerned with legal aspects of water resources planning, development and management. On the execution and administrative levels the most important departments and agents with respect to irrigation development are (i) the Department of Water Development Works (WDD) of the MANR, which plans, designs, constructs and maintains the works and also delivers water to municipalities, villages, irrigation groups, etc.; (ii) the Department of Agriculture (DA) of MANR; (iii) the Land Consolidation Department of MANR; and (iv) the District Officers of MOI, who exercise power as chairmen of District Water Boards, Project Water Committees, Irrigation Divisions, etc. Government is presently considering to unite the two chain of commands (one through MANR and one through MOI) into a semi-autonomous water authority.

**Jordan.** The East Ghor Canal Authority was established in 1960 with full responsibility for irrigation development in the Valley but was amalgamated into a new government institution, the Natural Resources Authority in 1966. Stage II development was entrusted to another institution set up for that purpose and with wide ranging powers, the Jordan Valley Commission. This commission was transformed into the Jordan Valley Authority in 1977. Today the JVA is part of the Ministry of Water and Irrigation that was created in 1988 and is fully responsible for irrigation development and O&M in the Valley.

*The Irrigation Infrastructure*

At an early stage Israel has planned a fully integrated water supply grid that now covers most parts of the country, its main artery being the National Water Carrier, which transfers water from the relatively water-rich north to the arid south. Initial development of settlement schemes was mostly from groundwater resources, so that when the national grid was completed they could be immediately connected, resulting in a rapid utilization of the major irrigation infrastructure and an efficient conjunctive use system of surface and groundwater. Only surface irrigation existed in 1948 which was first replaced by sprinkler irrigation and became the predominant method in the early 1950's. Beginning in the mid-sixties micro-irrigation (drip and spray) systems were developed and introduced on a gradually increasing scale; they cover presently some 170,000 hectares or 80 percent of the irrigated area, the balance still being under sprinkler irrigation.

**Cyprus.** Since independence Cyprus has implemented a number of irrigation schemes of which the most ambitious one, the Southern Conveyor Project (SCP) is still under construction. This multi-purpose project includes river basin transfer works, two storage reservoirs, a main water conveyor, a pressurized irrigation network for 13,460 hectares and facilities for M&I water supply. Under this project irrigation water is supplied from the main pipe network to night storage reservoirs commanding about 400 hectares. From these reservoirs water is delivered to hydrants with one to four outlets. Each outlet is provided with filter, flow-limiting device, flow meter and pressure regulator. Farm sizes are small in Cyprus (on average less than one hectare) and fragmented. Farm plots are therefore grouped together in sub-units of 2.5 hectares (with a maximum of three plots per sub-unit) and each outlet of a hydrant may serve three sub-units (7.5 hectares). Clearly the experience in Cyprus has been that the replacement of open channels by pipelines considerably increased overall system efficiency and the reliability of the water supply.

**Jordan.** Since 1973 the JVA has adopted pipe networks for the conveyance and distribution of irrigation water for the purpose of (i) making use of the natural topography to create almost free gravity pressures at the farm-turnout; (ii) increasing the conveyance efficiency; and (iii) reducing the environmental hazards of irrigation water that had become polluted. The remaining 7,300 hectares of open canal networks are scheduled to be transformed in pipe networks by 1995.

***Special Actions undertaken by Government***

**Israel.** A first water master plan for the water sector was prepared in 1951, which has since been updated several times. The 1960 update revealed that the total renewable water resources were some 28 percent lower than first estimated. This sounded an alarm and motivated the WC to initiate a number of programs to increase water use efficiency, including (i) the monitoring, measurement and documentation of water related activities in four settlement villages over a three year period, which indicated substantial waste caused by human error and equipment failures; (ii) the development of water saving devices, such as volumetric valves and pressure regulators and the production of enough prototypes for use in a long-term observation study; (iii) the use of the four model villages as focal points for demonstration and dissemination of improved practices (the WC also convinced a manufacturer that a market existed for the equipment and assisted in establishing the plant by providing financial guarantees); (iv) the launching in the early seventies of a country-wide, four year long campaign aimed at the dissemination of information on more water efficient systems and devices through field trials and demonstrations and financial support for the purchase and installation of the new devices (it was estimated that this water use efficiency campaign resulted in about 10 percent water savings, mostly from improved sprinkler irrigation); (v) a nationwide salinity survey, aimed at determining the effect of relatively high salinity water on crops and soils, the results of which were applied to the development of a policy and plans for the supply of water of different qualities for different crops and different areas.

**Cyprus.** The MANR introduced a Water Use Improvement Project in 1965 with the aim to raise farm irrigation efficiencies by 10 to 25 percent and increase yields by 5%. Under this program the government provided (i) free technical assistance by the Water Use Section of the DA for on-farm irrigation systems design (pipe and hose-basin systems); and (ii) subsidized credits for system installation. In addition, irrigation schedules were prepared by the staff of the Water Use Section and the farmers were advised on the proper use of the new technologies. The project was reportedly successful. Other special measures taken by Cyprus included the passing of (i) the Water Development and Distribution Law (1954) and the Water Supply and Special Measures Law (1964). The first law provides for the declaration of certain regions into "Development Areas" for the conservation and better use of water resources and whereby all private water rights and works are transferred to a Water Development Committee. Some provisions of the Special Measures Law are (i) the prohibition of wastage of water; (ii) the periodic revision of permits for water utilization, the extent of land and types of crops to be irrigated and the systems of irrigation to be used; and (iii) the requirement for a water meter at each well for the measurement and control of extraction. Nevertheless the control over groundwater pumping proved to be practically impossible in areas where farmers had no access to other water resources and new wells could practically be drilled overnight.

**Jordan.** A primary feature of the Jordan Valley development was the enactment of a law for land distribution in 1960, enabling the expropriation of lands and water rights within the project areas and a revised parcelation in accordance with an efficient irrigation system lay-out. The farm size was set at 3 to 4 hectares depending on the soil classification. The law also stipulated that the farm unit would be physically indivisible although it could have joint ownership. In parallel to irrigation development substantial investments were made in the rural areas in economic and social infrastructure during 1973-1990 mainly to stem migration from rural areas to cities and to make the Valley attractive for living. This development included the construction of roads, agricultural support infrastructure (grading, packing and marketing centers, tomato processing plants; etc.), schools, health centers, housing, domestic water supply and electricity, telecommunication networks etc., and must have significantly contributed to the agricultural transformation that took place in the Valley.

***Demand Management***

**Israel.** In view of its scarce water resources, Israel choose to rely heavily on demand management. This policy consisted of a comprehensive package of legislative and administrative measures in order to strictly regulate water use through a licensing and allocation system. The primary tools used to discourage inefficient water use are metering, pricing and allocation. All water use is metered, water users are licensed by the Government and the license must be renewed annually. Failure to use water in a manner consistent with the license can lead to its forfeiture. Each license prescribes the quantity of water that can be withdrawn from any source, including groundwater and sewage effluents. Water allocation is based on established water norms by crop and ecological region, which are constantly being reduced because of water scarcity on the one hand and agro-technical advances on the other hand. This has compelled the agricultural sector to invest heavily in improved irrigation technologies and to strive for higher yields with less water.

Water rates, which are set by Government, are uniform throughout the country. In 1974 a system of graduated water prices was introduced, whereby a higher price is being paid for part of the consumption within the limits of the allocation. The 1991 water charges were as follows: (i) up to 70 percent of the water allocation: US$0.15 per $m^3$; (ii) for 70 to 100 percent of the allocation: 67 percent extra per $m^3$; (iii) for 101 to 130 percent of the allocation: 94 percent extra per $m^3$; (iv) any quantity over and above 130 percent of the allocation: 220 percent extra per $m^3$. It has been estimated that when first introduced this system resulted in water sales that were 10 percent below the forecast, while prior to its introduction actual consumption exceeded the allocation. Present water charges cover about 50 percent of O&M costs.

**Cyprus**. As stated above, all irrigation water supplied in the public irrigation systems is metered, as well as all groundwater extractions; permissible amounts to be extracted from groundwater aquifers are determined seasonally with the help of groundwater models. Water is charged for on a volumetric basis. Under the SCP the water is delivered in bulk to the Irrigation Divisions in control of the areas commanded by the night storage reservoirs. Upon request of the farmers water meters are presently also being installed at the turnouts of individual farmers--at their request--to facilitate the split-up of the water bill. Water rates in Cyprus vary between traditional schemes and modern systems and take into account the farmers' ability to pay.

**Jordan**. Although the pipe networks have been designed on a demand basis and meters have been installed at the farm-turnout, rationing of water had to be resorted to in recent years when a serious drought persisted. Water was supplied four hours per day three times per week which forced farmers to build small storage reservoirs to store their share and use it on a continuous basis for their drip systems. This arrangement eliminated of course the advantages of the pressurized system and entailed considerable extra expenses to the farmers but is certainly a good technology for existing traditional systems. The cost of water in the Jordan Valley is about 58 fils (US$0.09) out of which 40 fils is capital cost and 18 fils O&M cost. Present water charges are only 6 fils (US$0.01). However, due to the high opportunity cost of irrigation water, these low charges have not been a constraint in its efficient use.

### *System Operation, Irrigation Scheduling and Irrigation Extension*

**Israel's** fully integrated national water supply grid provides for flexibility in water transfer and regional exchanges of water between sources with high and low salt concentrations. A country wide management system has been developed for minimizing losses and for optimal utilization of both surface water and groundwater. Water is supplied to consumers on demand. The ISFS advises farmers on irrigation practices (when and how to irrigate and with how much water) and prepares detailed irrigation schedules for the settlement schemes; these were initially prepared manually on the basis of auger tests and laboratory determinations of soil moisture. Subsequently more advanced methods were introduced, using inter alia, a wide network of Class A evaporation pans and tensiometers to determine crop-water deficits. The use of tensiometers reduced water application to the field in many cases by 30-40%, while yields also improved. The preparation of irrigation schedules is now computerized; the schedules are up-dated monthly.

**Cyprus**. In the modern irrigation systems water supply is mostly on demand, except in some very water short areas like Kokkinokhoria at the tail end of the SCP where the water supply is on rotation because the allocated amount of project water is only sufficient to irrigate about half of the area; however this is complemented with controlled amounts of groundwater.

Extension services are provided by the District Agricultural Offices, which in addition to beat officers have specialists in irrigation water use on their staff to advise the farmers on the type of on-farm system to use and on irrigation scheduling. Irrigation scheduling may be based on either of the following two methods: (i) irrigation is scheduled at a time when soil moisture has been depleted up to a certain predetermined level, measured by tensiometers or estimated in relation to evaporation pan readings; or (ii) irrigation is scheduled based on a fixed interval between irrigations. The Water Use Section of the DA plays a primary role in collecting information on soil characteristics. The work of educating and training the farmers has included: (i) personal contacts between farmers and irrigation specialists; (ii) demonstrations on irrigated plots in all districts; (iii) short courses and lectures; and (iv) excursions and visits. In addition publicity campaigns have been held to promote improved irrigation systems and schedules, including use of radio and television, film shows, articles, technical leaflets and posters.

**Jordan**. The pipe networks are designed to operate on demand although in recent years they have been supplied with water on rotation caused by the drought; the remaining open canal networks supply water on rotation. On-farm water management is the responsibility of the farmers. Advice on irrigation practices has been provided by both the extension service and the suppliers of irrigation equipment, but in Jordan one should mostly credit the advisory services of the private sector with the rapid adoption of the modern irrigation technologies.

***Technology Development, Transfer and Research***

**Israel**. The main developments that have led to a drastic reduction in water use after adoption of pressurized irrigation in the mid-sixties are:

- for irrigation technologies (i) an emphasis on irrigation with sprinklers during the night when there is little wind and evaporation; (ii) the need for correct sprinkler spacings and uniform pressures to obtain high water distribution uniformities; (iii) the importance of regular maintenance and follow-up of system performance; (iv) development and installation of volumetric valves which shut off after delivery of a set quantity of water rather than on a time basis, thus eliminating the influence of pressure variations; (vi) the use of part-circle sprinklers (without these water losses on small plots were about 30 percent due to irrigation of areas beyond the plot boundaries); (vii) the introduction of sequentially automated valves and central computerized command systems; (viii) the wide-scale shift to low volume irrigation, in particular drip irrigation, which also promoted the widespread use of fertigation, chemigation and herbigation; (ix) the formulation of irrigation equipment standards by ICWE.

- for agronomic research and agro-technologies (i) research trials on optimum crop water applications and irrigation and agro-technical practices for all major irrigated crops, which also formed the basis for the legally enforced crop water allocations and enabled further reductions in water allocations; (ii) the cultivation of vegetable crops, small fruits, dwarf fruit trees and flower crops in greenhouses under micro-irrigation and fertigation; (iii) introduction of other agro-technical practices, including (but not limited to): adjustment of crop planting dates, greenhouse production of seedlings, increased nitrogen application for certain crops to compensate for reduced water applications, and stricter weeding practices.

The experience has also been that it was easier to teach unskilled farmers to manage sprinkler or drip irrigation than to teach them the intricacies of efficient surface irrigation.

**Cyprus.** As an intermediate technology, pipe-basin systems and hose basin systems became popular for orchards during the 1965-1975 period. Also the first mobile sprinkler systems were first introduced in 1965 and are still popular for orchards, vegetables, vines and pastures. The first drip irrigation system was imported from Israel in 1970 and drip systems are now widely used for vegetable growing. Mini sprinklers have become popular as permanent installations for irrigating orchards and potato fields. Research on water use is carried out by the Agricultural Research Institute; its work focusses on comparing irrigation methods and practices and crop response to water quality and amounts of water applied for major crops grown.

**Jordan.** Drip irrigation was first introduced to Jordan by the private sector in 1975. American and Australian technicians were brought in to train Jordanian technicians and farmers on the use and maintenance of the systems. Despite the initial high cost (US$3,600 per hectare) these systems were rapidly adopted by the farmers as they greatly alleviated the problems caused by chronic water shortages and were ideal for the protected agriculture (plastic greenhouses) that had been introduced to the Valley in the early 1970s. Also credit was extended by the suppliers and commercial banks for the purchase of the drip systems. Moreover, the high costs were no constraints because of the booming exports of agricultural produce to the Gulf states. The average pay-back period to the farmer was 2-3 years. This development took place despite a ban on agricultural credit from parastatal institutions for their procurement because of fear of failure with this, in Jordan, yet untested system. Unfortunately, the JVA had procured sprinkler equipment for some 9,300 hectares, which was delivered in 1978; because the drip systems were popular, very little equipment was used in the Valley, mainly for irrigating cereals, alfalfa and other field crops. Micro-sprinklers were introduced in the early 1980s to irrigate fruit trees, primarily citrus. Bubbler irrigation has been introduced recently and is finding a favorable response from owners of old orchards that have been irrigated by basin irrigation.

Only recently have Jordanian researchers started work to determine optimal crop water requirements (so far these were only based on experiences outside Jordan). Initial results showed that for certain crops yields were substantially higher with less water, which demonstrates the importance of agronomic research.

### *Role of the Private Sector*

**Israel.** A transition was made from surface irrigation systems to, first, imported sprinkler irrigation technology and then gradually to new locally developed and locally manufactured sprinkler and micro-irrigation systems. This was achieved through a strong, innovative irrigation equipment industry, closely related to the farmers' community. Market prices of new water saving devices were often subsidized by government to promote their adoption.

**Cyprus.** At first modern irrigation equipment was imported but as these systems became popular among the farmers, various local industries were set up copying this equipment. Although initially locally produced materials and equipment were of low quality, quality improved with time and irrigation products are now being manufactured to international standards.

**Jordan.** Most of the credit for the rapid development of drip irrigation in Jordan should go to the private sector, partly Jordanian and partly foreign, that also conducted initial demonstrations in the Jordan Valley in cooperation with the farmers. By 1980 the market for drip systems had expanded to a size that justified the local manufacturing of plastic drip lines. Presently there are six factories in Jordan that produce drip irrigation supplies under license. As a result the price for drip irrigation has drastically fallen and the cost for a drip system is now reportedly only about US$1,000 per hectare (including sand filters, but excluding pumps). The suppliers provided installation and maintenance services at the beginning but the farmers learned quickly to install and maintain the systems at lower cost.

### *Quality Control*

**Israel.** The quality of irrigation equipment has been improved through the adoption of a certification system, which is implemented by the Standards Institution of Israel (SII) in conformity with the directives of the International Organization for Standardization (IOS). Preparation of irrigation equipment standards are being prepared by SII in cooperation with the ICWE. These specifications are replaced by ISO standards when issued and adopted by Israel. SII has established quality assurance procedures and manuals for plants coming under its supervision and audits are carried out; products manufactured under such procedures bear the Standards Mark of the SII.

**Cyprus and Jordan.** In Cyprus quality control on the manufacturing of irrigation equipment and materials is exercised by the Cyprus Standards Organization of the Ministry of Commerce and Industry and in Jordan by the Department of Specifications of the Ministry of Trade and Industry. It appears that in Cyprus strict quality control can not yet be exercised on all products due to lack of testing facilities.

### *Land Tenure and Land Consolidation*

**Israel.** Land tenure problems have been minimal, despite the relatively small parcels, for reason that some 90 percent of the land is state property.

**Cyprus**. Because of small and fragmented holdings, land consolidation has, wherever possible, been an integral part of the implementation of irrigation projects. This was accompanied by, inter alia, the elimination of some defects in the land tenure system, increase in the average size of the holdings through some land expropriation and allocation of state land and the construction of new roads. Because of the more rational layout of the irrigation networks as a result of land consolidation, the costs of the construction works were reduced. At the other hand, land consolidation proved to be a difficult and slow process.

**Jordan**. Comprehensive legislation was enacted to enable the redistribution of land and reparcelation for efficient irrigation layouts.

*Agricultural Credit*

**Israel**. During the four year long campaign on water conservation, long-term loans were granted to farmer settlements, as well as grants, for the installation of water saving irrigation systems. Subsequently the terms of the loans became gradually less attractive until they were phased out at the beginning of the eighties. Approval of the loans was subject to approval of the plans by joint regional and central committees, staffed by the Water Commission and extension personnel.

**Cyprus**. The provision of agricultural credit has been considered of fundamental importance for on-farm development. Local cooperative societies are well established in Cyprus and have a high standard of organization and administration. The provision of credit is combined with the marketing of agricultural produce at the local level, which proves a useful system for ensuring prompt repayment of loans. Under the Water Use Improvement Project, incentives were offered to farmers to invest in improved irrigation technologies in the form of 15 percent subsidy and the balance 85 percent as loan at 4.5 percent interest; these terms have subsequently become less favorable.

**Jordan**. The suppliers of the drip systems also extended credit. Collaterals were often worked out between the purchaser, the supplier and the agricultural marketing agent of the purchaser, the collateral generally being the produce, especially where the supplier also provided marketing services. Industrial credits for the manufacturers of irrigation equipment and materials were advanced by the parastatal Industrial Development Bank and by commercial banks.

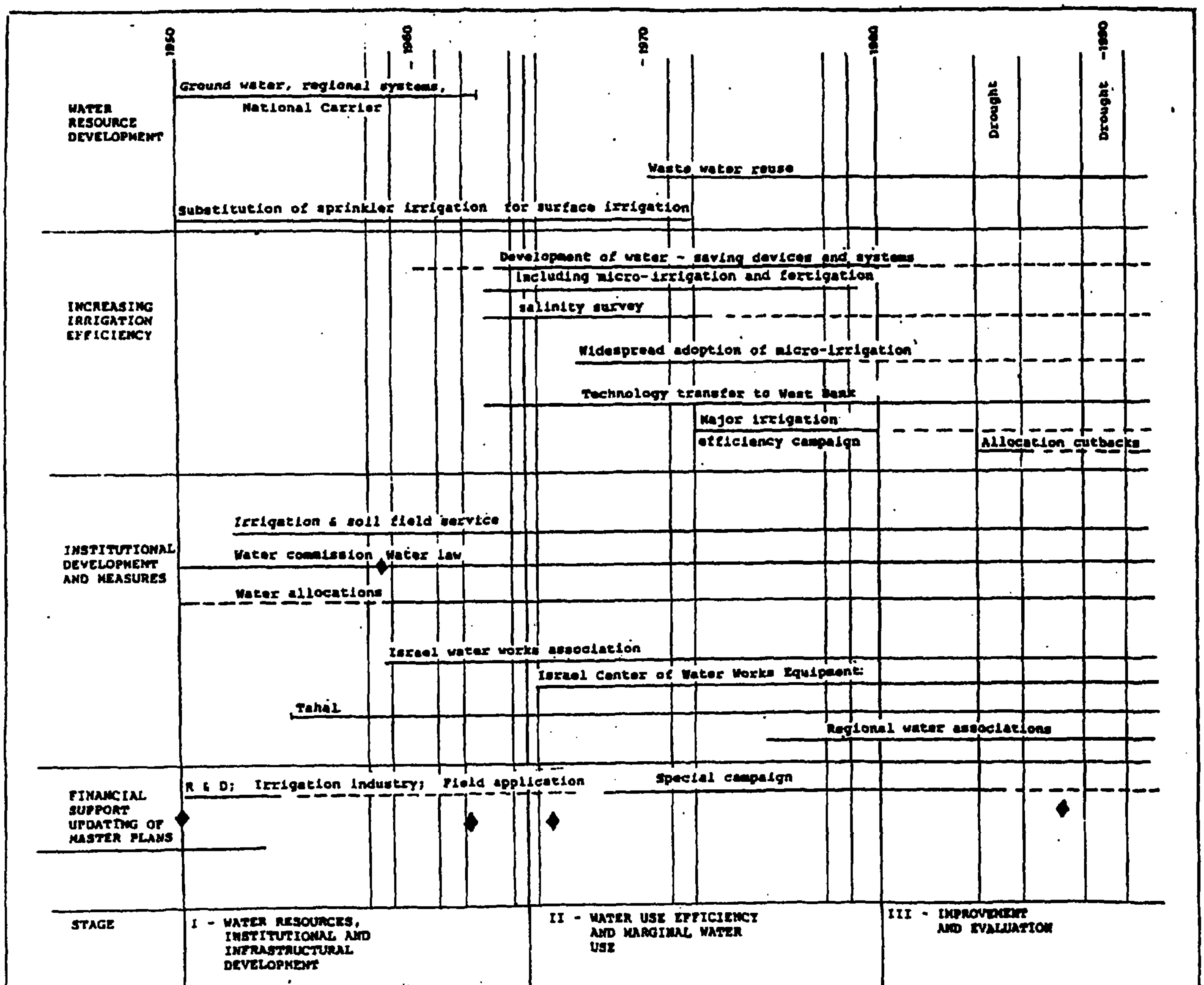
*Water Users Associations*

**Israel**. Most of the irrigation water is supplied in bulk to collective settlements (kibbutzim) and cooperative settlements (moshavim) on the basis of yearly allocations set by the Water Commission. In addition, there are regional associations, most of which have been set up after 1977 and many of them are still in the process of being established. They developed principally due to the dissatisfaction of the farmers with the centralized role of the water authorities and their desire to take a more active part in the management of their water, the construction of new projects and deciding on water allocations within their own region. This points towards a process of decentralization of the water system that was originally set up as a strictly centralized system.

**Cyprus.** In accordance with the Irrigations Associations Law (1949) a minimum of seven land owners who should also be the owners of water can form an Irrigation Association for the purpose of constructing and maintaining irrigation works. The District Officer is the chairman of the Association. The Irrigation Division Law (1938) provides for the establishment of Irrigation Divisions (IDs) for the purpose of constructing, managing and maintaining irrigation works and calculating the water charges owned by the members. IDs have been set up for the 400 hectare areas commanded by night storage reservoirs in the SCP. The IDs are run by five member committees selected by the members and which are responsible for water distribution. The committees are chaired by the DO. Each committee employs a full-time accountant to manage its financial affairs.

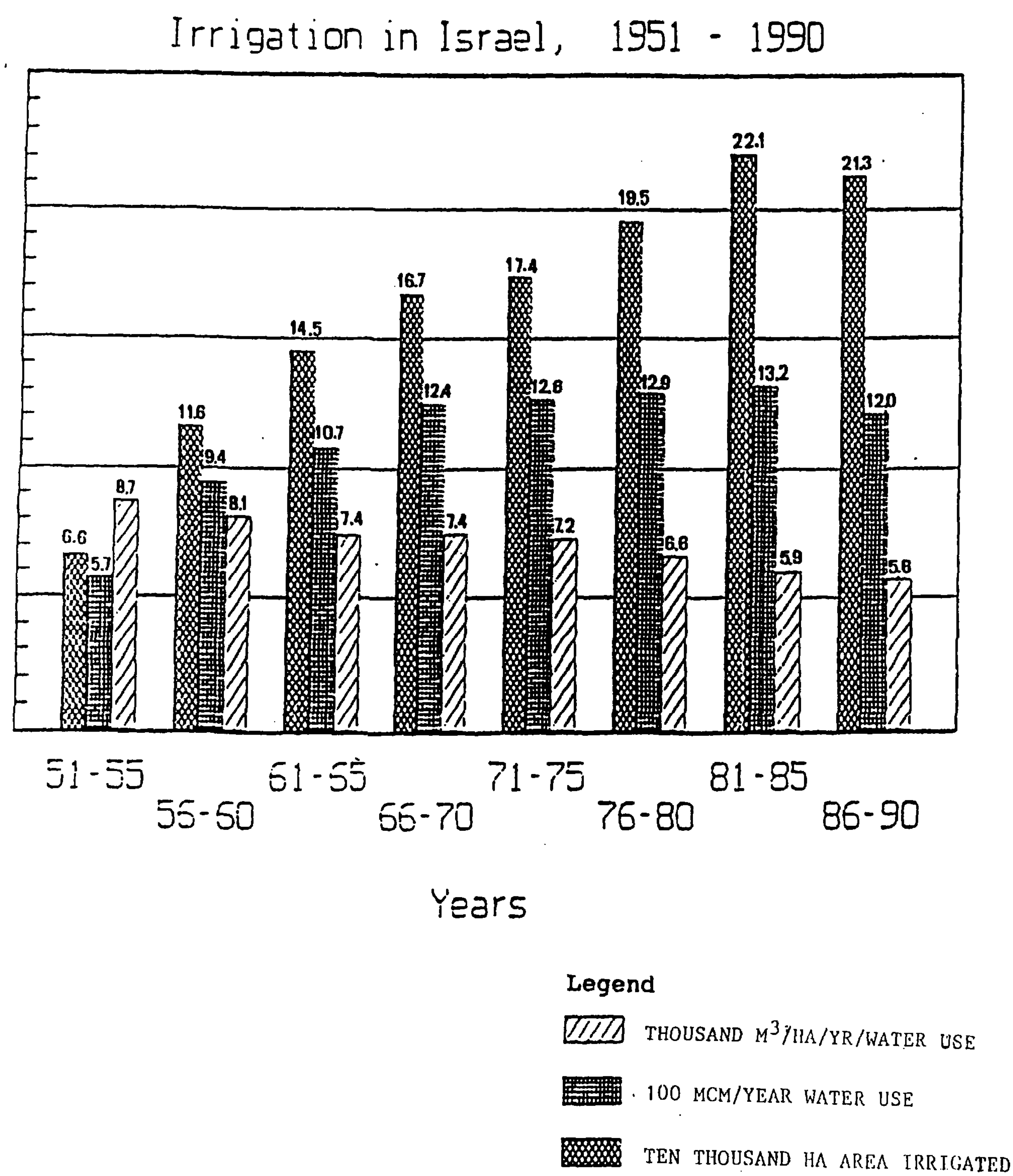
**Jordan.** A Farmers' Association was created by legislation in 1974 for the purpose of procuring farm inputs, farm machinery, agricultural services and marketing. It was not involved in water management and overall its achievements have been marginal.

**Annex B**
**Chart B-1**



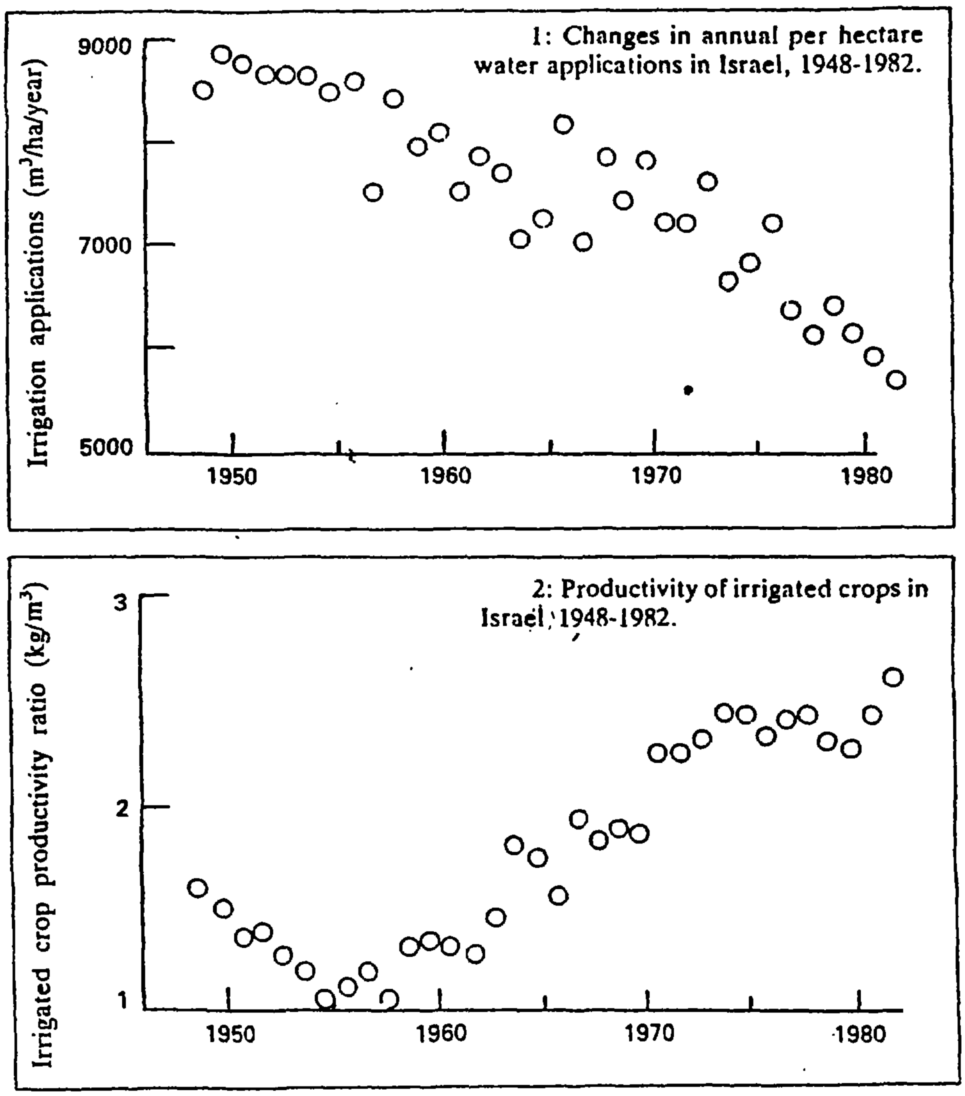

ISRAEL: DEVELOPMENT STAGES IN INCREASING WATER USE EFFICIENCY

**Annex B**
**Chart B-2**



**Annex B**
**Chart B-3**

***ISRAEL -- Water Application and Productivity***
***1948-1982***

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*Source:* H. Bielorai, Irrigation Research in the Institute of Soils and Water of the Volcanic Center -- Goals and Achievements.

# ANNEX C
# ADDITIONAL TABLES

***Table C-1: Comparison of Irrigation Methods and Factors that Affect Irrigation, Power, and Operating Efficiency***

| ITEM | IRRIGATION METHOD | | | | | |
|---|---|---|---|---|---|---|
| | | Sloping furrow | Sprinkler | | | |
| | Level furrow | w/ return flow | Linear move | Center Pivot | Hand Move | Drip |
| Dirt in water | No effect | No effect | Sand separator and/or filter needed. Extra system pressure necessary= 3-10 psi | | | Extremely sensitive Filtration + chemical inject. needed |
| Maximum slope | Level | up to 3% | 4% | 15% | 15% | Anything farmable |
| Min. economical field size, hectare | No minimum | 4 | 100 | 50 | 1 | 2 |
| Field shape | Any | Any | Long and Rectangular | Circular or modified circle | Any, but major edge effects on odd shapes | Any |
| Energy for install. and materials | Medium | Mod. low | Mod. high | Medium | Mod. high | Mod. high |
| Annual pumping $ | None-V. low | Low | Medium | Mod. high | High | Mod. high |
| Technical expertise needed by farmer | Medium | Medium | Very high | High | Medium | Extremely high |
| Relative # of moving or complex parts (1=few, 10=many) | 1 | 2 | 6 | 5 | 3 | 10 |
| High salt water | Special bed shapes required, highest sensitivity during germination and seedling stages | | Toxicity and leaf burn after plant has leaves. Good for germination | | More serious problems than linear move or pivots | Best, but soil needs leaching by other means every five years |
| Non-uniform soils | Sensitive | | Non-sensitive | | | |
| Inflexible water delivery system | Moderately tolerant | | Very sensitive | Sensitive | Moderately tolerant | Sensitive |
| Minimum SMD, cm. | 4-7 | 2.5-7 | 0.3 | 0.3 | 2.5 | 0.3 |
| Fertigation ease | Good | Good | Excellent | | Good | Excellent |
| Potential IE w/ Xlnt. mgmt. & design | 88 | 88 | 90 | 85 | 75 | 88 |
| Irrig. Effic. with excellent design and average mgmt. | 65 | 70 | 70 | 65 | 60 | 65 |

Source: Adapted from Charles M. Burt, "Trends Toward Efficient Low Energy Irrigation." Paper presented at "Aqua 83," Acapulco, Mexico, 1983 (San Luis Obispo, CA: Department of Agricultural Engineering, California Polytechnic State University, 1983).

*Table C-2: On-Farm Irrigation System Costs, Israel*

| *Crop* <br> *Irrigation System* | *Cost* <br> *(US$ per hectare)* |
|---|---|
| *Truck Crops* | |
| Hand-move sprinkler laterals | 1,400 |
| Drip-solid set | 3,000 |
| Mini-sprinklers - solid set | 3,100 |
| Solid set sprinkler laterals | 5,700 |
| *Field Crops* | |
| Hand-move sprinkler laterals | 1,000 |
| End-tow laterals | 1,600 |
| Mechanical move laterals | 1,600 |
| Drip - seasonally solid | 2,500 |
| Drip - seasonally solid - thin wall | 1,300 |
| *Orchards* | |
| Hand-move sprinkler laterals | 1,600 |
| Sprinklers on plastic drag lines | 2,000 |
| Overtree sprinklers - solid set | 3,200 |
| Drip - solid set | 1,500 |
| Micro-sprinklers - solid set | 2,200 |
| *Grapevines* | |
| Drip | 2,200 |

*Source:* Melamed, David. 1988. Technological Developments: The Israeli Experience, World Bank Technical Paper Number 94

*Table C-3: Improved Surface Irrigation*[a]

| | Investment costs in US$ per hectare | | | |
|---|---|---|---|---|
| *Materials Used* | *Syphons* | *Flexible PVC pipe* | *Rigid PVC pipe with adjustable openings* | *Buried PVC pipe with Risers* |
| Area equipped (hectares) | 50 | 70 | 195 | 120 |
| Cost Range (US$1ha) | | | | |
| - average | | 415 | 585 | 800 |
| - minimum | 17 | 385 | 500 | 565 |
| - maximum | | 450 | 665 | 1035 |
| Average life (in years) | 5 | 5 | 5 | 15 |

*Note:*
a. Excludes costs for land leveling.
*Source:* CEMAGREF (France, 1990)

## *Table C-4: Drip Irrigation: Examples of Yield Increases and Water Savings with Drip Irrigation as Compared to Furrow/Sprinkler Irrigation*

| | | | *Yields* | | *Water Use Efficiency/Savings on the farm* |
|---|---|---|---|---|---|
| ***Reference*** | ***Country*** | ***Crop*** | ***F/S*** | ***Drip*** | ***Drip*** |
| Bui (1965) | Hawaii (USA) | Sugar cane | 29.3 t/ha<br>(F) | +22% (cane)<br>+26% sugar<br>(35.7 t/ha) | $e_a$=80%<br>(savings:56%) |
| Pyle (1985) | Hawaii (USA) | Sugar cane | (F)<br>(S) | +22%<br>+35% | (savings:33%)<br>(savings:15%) |
| Fangmeier (1985) | Arizona (USA) | Cotton | 5.1 t/ha<br>(F)<br>0.283 kg/m$^3$<br>(F) | <br><br>0.547 kg/m$^3$ | <br><br>▲$e_o$=93% |
| Fereres (1985) | Spain | Cotton | 2.5 t/ha<br>(capsules) | 4.0-5.7 t/ha | |
| Lopez (1985) | Canaries | Bananas | 1.74 kg/m$^3$<br>(F)<br>2.53 kg/m$^3$<br>(S) | (3.64 kg/m$^3$)<br><br>(3.49 kg/m$^3$) | ▲$e_o$=109%<br><br>▲$e_c$=38% |
| Hall (1985) | USA | Tomatoes | 65 t/ha<br>(F) | 82.5 t/ha | (savings: 35%) |
| Or (1985) | Israel<br>(Jordan Valley) | Tomatoes<br>Cucumbers<br>Onions<br>Pepper | 15 t/ha<br>5<br>15<br>10 | 60 t/ha<br>24<br>35<br>15 | (savings: 50%) |
| Eldar (1987) | Israel[a]<br>(Jordan Valley) | Eggplant | 20 | 70 | (savings: 50%) |
| Sivanappan (1985) | India | Coconuts | 30-40<br>nuts/tree | 60-70<br>nuts/tree | (savings: 60%) |
| Klein (1983) | Israel | Avocado | (S) | | (savings: 50%) |

F = Furrow irrigation
S = Sprinkler irrigation
$e_a$ = On-farm application efficiency
▲$e_c$ = Increase in conversion efficiency

*Note:*

a. Eldar describes same project as Or (1985) but also reports 600% increase in use of fertilizer and pesticides.

*Source:* Decroix (1989), *La Micro-Irrigation dans le Monde*.

## *Table C-5: Economic, Social, and Ecological Advantages and Disadvantages of Different Irrigation Methods*

| Items to be considered | Surface / furrow irrigation by | | Sprinkler irrigation | | | | Drip irrigation, microjet, automated |
|---|---|---|---|---|---|---|---|
| | earthen canals | lined canals / canalettes or low pressure buried pipes | with mobile network for on-field distribution | | with fixed network for on-field distribution | | |
| | | | on schedule | on free demand | on free demand | on schedule, automated | |
| *a. Water consumption* | | | | | | | |
| 1. Total volume per ha/yr | 7 | 6 | 4 | 5 | 3 | 2 | 1 |
| 2. Effective discharge liter/s/ha | 7 | 6 | 3 | 5 | 4 | 2 | 1 |
| 3. Water consumption per ton of produce | 7 | 6 | 4 | 5 | 3 | 2 | 1 |
| *b. Investment costs per hectare* | | | | | | | |
| 1. Main reservoir | 7 | 6 | 4 | 5 | 3 | 2 | 1 |
| 2. Water transport, main canals, etc. | 6 | 5 | 3 | 4 | 4 | 2 | 1 |
| 3. Pumping stations; discharge/pressure | 5/1 | 4/1 | 2/3 | 3/3 | 3/3 | 2/3 | 1/2 |
| 4. Distribution network (sec. + tert.) | 1 | 2-3 | 3 | 5 | 5 | 4 | 4 |
| 5. Leveling / on-field distribution works | 2 | 2 | 1 | 1 | 3 | 3 | 4 |
| 6. Total investment costs | 4 | 3 | 1 | 4 | 5 | 2 | 1 |
| *c. Social factors* | | | | | | | |
| 1. Quantity of labor needed | 6 | 4 | 5 | 5 | 2 | 1 | 3 |
| 2. Physical effort of workers | 3 | 3 | 4 | 4 | 1 | 1 | 2 |
| 3. Techn. education of staff / workers / farmers | 2 | 1 | 3 | 3 | 4 | 5 | 6 |
| 4. Irrigation at night | 4 | 4 | 3 | 2 | 2 | 1 | 1 |
| *d. Operation / maintenance costs* | | | | | | | |
| 1. Energy consumption, if any | 2 | 1 | 4 | 5 | 5 | 4 | 3 |
| 2. Maintenance: distribution network | 4 | 3 | 1 | 1 | 1 | 2 | 2 |
| 3. Maintenance: leveling, field distribution | 6 | 5 | 3 | 3 | 1 | 2 | 4 |
| *e. Time element* | | | | | | | |
| 1. Construction time | 5 | 6 | 1 | 2 | 3 | 3 | 4 |
| 2. Adaptation time | 3 | 3 | 3 | 4 | 2 | 1 | 1 |
| 3. Lifetime (technical) | 1 | 2 | 4 | 4 | 3 | 3 | 5 |
| *f. Land use* | | | | | | | |
| 1. Flexibility after installation | 2 | 2 | 1 | 1 | 3 | 3 | 4 |
| 2. Suitable for cereals | no | no | yes | yes | 0 | 0 | no |
| 3. Suitable for maize | yes | yes | yes | yes | 0 | 0 | 0 |
| 4. Suitable for forage, pasture | no | no | yes | yes | yes | yes | no |
| 5. Suitable for potatoes, sugar beet, cotton | yes | yes | yes | yes | 0 | 0 | 0 |
| 6. Suitable for vegetables | yes | yes | yes | yes | yes | yes | yes |
| 7. Suitable for fruit trees | yes | yes | yes | yes | yes | yes | yes |
| 8. Yield per ha | 5 | 4 | 3 | 3 | 3 | 2 | 1 |
| *g. Ecological factors* | | | | | | | |
| 1. Risk of salination, drainage needs | 4 | 3 | 2 | 2 | 2 | 2 | 1 |
| 2. Risk of erosion | 4 | 4 | 2 | 3 | 3 | 2 | 1 |

* The numbers in each column are ordinals and give the rank, not the magnitude of the different irrigation systems for each item, 1 being the most economic (lowest cost or highest gross product). Indentical numbers mean that here is no significant difference between systems from this particular point of view. "0" means "possible" under certain conditions.

Source: H. Bergmann (1984) Economic Considerations in Selecting Irrigation Systems.

***Table C-6: Design Principles for Irrigation Institutions***

I. **Clearly Defined Boundaries**
The boundaries of the service area and the individuals or households with rights to use water from an irrigation system are clearly defined.

II. **Proportional Equivalence Between Benefits and Costs**
Rules specifying the amount of water that an irrigator is allocated are related to local conditions and to rules requiring labor, materials, and/or money inputs.

III. **Collective-Choice Arrangements**
Most individuals affected by operational rules are included in the group which can modify these rules.

IV. **Monitoring**
Monitors, who actively audit physical conditions and irrigator behavior, are accountable to the users and/or the users themselves.

V. **Graduated Sanctions**
Users who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other users, from officials accountable to these users, or from both.

VI. **Conflict Resolution Mechanisms**
Users and their officials have rapid access to low-cost, local arenas to resolve conflict between users or between users and officials.

VII. **Minimal Recognition of Rights to Organize**
The rights of users to devise their own institutions are not challenged by external governmental authorities.

VIII. **Nested Enterprises**
Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

*Source:* Ostrom, Elinor. 1990. Crafting Irrigation Institutions; Social and Policy Analysis, Indiana University.

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