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Case studies on water conservation in the Mediterranean region

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CASE STUDIES ON WATER CONSERVATION

IN THE MEDITERRANEAN REGION

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Preface

Water is a finite resource. It is fast becoming a scarce commodity. Competition among agriculture, industry and cities for limited water supplies is already constraining development efforts in many countries. Among the 21 countries that have been declared water-scarce, 12 are in the Near East region and many of them are Mediterranean countries.

Despite water shortages, misuse of water is widespread. In the Mediterranean region, agriculture is considered to be the sector where the largest volume of water can be saved. Agriculture accounts for some 80 percent of total demand and large amounts of water are poorly used.

Mediterranean countries share many common features in terms of climate, water and land resources and development issues. These include arid and semi-arid climate, limited water resources, agricultural development limited by water availability and high economic and social value of water.

Development of public irrigation in the region, mostly initiated after the Second World War, accelerated in the 1960s. The irrigated area in the region has increased from about 7 million hectares between 1960 and 1980 to the present 11.8 million hectares. Mediterranean countries benefited from technological progress in hydraulics, construction and automation techniques and water application at farm level.

During the past three years, IPTRID paid special attention to the water problems in the Mediterranean region. It launched a regional research and development programme aimed at conserving water use in agriculture, focusing on scheme and on-farm levels. IPTRID studies have revealed that many countries in the region have gained good knowledge, at local level, of efficient measures and processes to reduce water demand. Advanced techniques of canal regulation make it possible to supply water to farmers on demand, but, poor implementation and management have seriously limited expected water savings and increased productivity.

The objective of this publication is to document a number of success stories in water conservation in the Mediterranean region and disseminate this experience widely to other parts of the world. Case studies from five countries were analysed in terms of successes and limiting factors, reported water savings, crop yield increase and efficiency of water use.

It is hoped that this publication will stimulate irrigation and drainage researchers and practitioners to re-think the issue of water saving in agriculture, identify gaps in knowledge and formulate and implement research projects and pilot demonstrations to fill the knowledge gap.

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Contents

Acronyms

CRDA	Commissariat Régional au Développement Agricole, Tunisia
DSI	Devlet Su Isleri (state water works), Turkey
FAO	Food and Agriculture Organization of the United Nations
GDRS	General Directorate of Rural Services, Turkey
GNP	Gross National Product
IAS	Irrigation Advisory Services
ICARDA	International Centre for Agricultural Research in the Dry Areas
IIP	Irrigation Improvement Programme, Egypt
INAT	Institut National Agronomique de Tunisie
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
JVA	Jordan Valley Authority
MENR	Ministry of Energy and Natural Resources, Turkey
MRT	Management of Resources in Tadla project, Morocco
NPK	Nitrogen, Phosphorus and Potassium (fertilizers)
O&M	Operation and Maintenance
ORMVA	Office Régional de Mise en Valeur Agricole, Morocco
PIM	Participatory Irrigation Management
UN	United Nations
UNEP	United Nations Environment Programme
USAID	US Agency for International Development
WUA	Water Users' Association

Summary

In the Mediterranean region, agriculture is considered to be the sector where the largest volume of water can be saved. It accounts for some 80 percent of total demand and large amounts of water are poorly used. Countries have obviously developed good knowledge at local level of efficient measures and processes to implement reductions in water demand. The idea of the present project is to gather a number of success stories and disseminate this Mediterranean experience to other parts of the world.

Mediterranean countries share a common situation in terms of water and land resources. This includes arid and semi-arid climate, poor water or a tendency to water shortages, land development limited by water availability and high economic and social value of water. Irrigated agriculture accounts for the greatest water use – some 85 percent of the total – and has a major role in agricultural production, marketing and export. There are related social considerations, too, such as rural development as opposed to migration to urban areas, degradation of water quality in the environment and the impact of climate change.

Development of public irrigation in the region, mostly initiated after the Second World War, accelerated in the 1960s. The irrigated area in the region has increased from about 7 million ha between 1960 and 1980 to the present 11.8 million ha. Mediterranean countries benefited from technological progress in hydraulics, construction and automation techniques and water application at farm level. Advanced techniques of canal regulation should make it possible to supply farmers' demand for water, a prerequisite for achieving maximum agricultural productivity and meeting crop requirements. Poor implementation and management, however, have seriously limited expected productivity.

There are several areas of intervention for the future. These include:

- policies for water and food supply: water policy reforms, irrigation management transfer, increasing the role of virtual water and creation of a regional free-trade area;
- food production capacity: horizontal capacity through extension of irrigated areas based on mobilization of new resources or savings from existing irrigated areas;
- vertical growth: water productivity increases and improvements in water management and resources, making existing resources sustainable, limiting exploitation of fossil aquifers;
- creation of new resources: surface and underground storage and use of non-conventional resources such as brackish and waste water.

Case studies in five countries were analysed in terms of successes and limiting factors, reported water savings, crop yield increase and efficiency[1] of water use.

In Jordan, the case study concerned farms in the Jordan valley using drip irrigation. It showed that the use of tensiometers with drip irrigation saved 20-50 percent of water and increased cucumber and tomato crop yields by 15-20 percent, resulting in an increase of water use efficiency of 44-140 percent. The existing rigid irrigation situation does not currently allow the spread of these techniques unless farmers build their own reservoirs.

[1] Water-use efficiency = crop production (and its monetary value) per m^3 of water.

The Morocco study was located in the Tadla region. The Public Irrigation Agency (ORMVA), in partnership with private companies, promoted laser-levelled basin irrigation, resulting in water savings of 20 percent, cereal crop yield increases of 30 percent and an increase of water use efficiency of 62 percent. This technique is not applicable on all lands and the present land consolidation model may be inappropriate for optimum water application and distribution in service areas.

In middle Egypt, the case study of Beni Ibeid command area showed that modernized lined mesqa (tertiary canals) and management transfer to water-users' associations (WUAs) have both been successful, mainly because farmers were informally organized before modernization. Cereal and cotton crop increases of 10 percent were reported, resulting in an estimated increase of water use efficiency of 10 percent. Improvement of the main system to solve problems of night storage is more complex than expected, however.

A case study was conducted in the Antalya region of Turkey on a system recently transferred to WUAs and modernized using drip, sprinkler and California systems. This combined system generated water savings of 34 percent, resulting in an estimated 51 percent increase in water use efficiency. Further progress might be limited by the ability of many WUAs to modernize their system and improve performance.

In Tunisia**,** public irrigation agencies (CRDAs) and WUAs are managing drip, sprinkler and modernized surface irrigation. Public water-saving programmes and incentives resulted in estimated savings of 25 percent and a 33 percent efficiency increase in water use. Stronger financial incentives through water pricing and strengthening farm water-saving techniques should improve the results.

Lessons learned from these success stories can be summarized as follows:

- localized irrigation is not a miracle technology. Excellent as well as poor results were obtained from these technologies and their adoption really depends on the ability of farmers to finance and operate them and the type of crop production;
- modernized surface irrigation can be a water-saving technique comparable with more costly drip or sprinkler irrigation. It is more easily adopted by farmers, since it is closer to traditional practices;
- an environment that enables water conservation is necessary for successful water conservation and improved water use efficiency. It includes public incentives, irrigation management transfer to users and involvement of the private sector to relate crop marketing to water savings.

Sustainability of water management depends on measures that complement each other. A substantial loss in water productivity results from poor irrigation water provision in surface irrigation systems. Rigid delivery of water at long intervals (Jordan, Egypt and Turkey) and/or a land consolidation model incompatible with liberal agriculture policies (Morocco) preclude the adoption of water-saving techniques and the change from staple food to high-value, water-sensitive crops.

Water conservation: a priority in the Mediterranean Region

Situation and regional characteristics

This section is limited to the 11 countries of the Mediterranean basin in the Middle East and North Africa: Morocco, Algeria, Tunisia, Libya, Egypt, Jordan, Israel, Lebanon, Syria, Turkey and Cyprus. These countries are widely different in terms of physical setting, water resources, food situation and development of irrigation.

Water, land and energy resources

The 1995 population of the 11 countries was about 230 million people (see Table 1). The United Nations (UN) projection for 2025 shows an increase of around 75 percent. Population density at national level has little meaning in these countries, given the high proportion of desert and mountains. In many cases, population is dense in the very small parts of the territories, such as coastal areas, that are fertile and well connected to transport facilities. For example, the population of Egypt is highly concentrated in the arable lands of the Nile valley and its delta – about 3 percent of the country area. Much the same is true of Libya and Algeria. Most countries are experiencing negative or low growth of the rural population, with the exception of Syria and Egypt, which have about 2 percent growth per year. In all the countries, the growth of urban populations is significant. It is expected that in 2025 the urban population of all countries in the region will be greater than the rural population.

Most of these countries have an arid or semi-arid climate. They are generally water poor and prone to water shortages. For instance, dry year precipitation with a ten-year frequency can be as little as one third of the average. Fresh water resources vary from 220 m^3 per capita in Jordan and 330 m^3 per capita in Palestine to about 2 000 m^3 per capita for Turkey and Syria. Although the latter two countries are better endowed, Turkey contains regions of severe shortage and Syria is highly dependent on transboundary water. Libya and Egypt are rainless countries for practical purposes, with the exception of a narrow coastal belt; Cairo has an annual 30 mm of rain. By contrast, the Black Sea region of Turkey receives more than 2 000 mm. Rainfall varies greatly both temporally and spatially within the region, from an average of 643 mm in Turkey to 207 mm in Tunisia and less than 100 mm in Egypt. Variations can be extremely high in a single country: in Tunisia, rainfall varies from 100 mm in the south to more than 1 500 mm in the north. The availability of fresh water per capita is steadily decreasing as population grows and water resources development reaches a ceiling in many countries, either for technical or economic reasons. Exceptions are Turkey and Morocco.

Land resources are not in themselves a limiting factor but the water available to develop the land is limited. In rural areas, land fragmentation resulting from rapid population increase is a major concern for the future viability of farming systems. The average size of land holdings has dropped to 1.5 feddan (0.6 ha) in Egypt. Land ownership and random urban expansion are other constraints in developing profitable agriculture. Water and cultivable land are unevenly distributed throughout the region:

- Tunisia, Israel, Jordan and Egypt are facing immediate water stress and adopting water demand management policies;
- Morocco and Turkey are not currently experiencing water stress, except in local areas.

Table 1: Demographic and water resources indicators of the Mediterranean countries

Country	Population		GNP	Fresh water
	million	density/ km^2	US$ per cap.	m^3 per cap.
Algeria	30	13	1 550	485
Cyprus	1	80	11 960	1 213
Egypt	62	63	1 400	949
Israel	6	296	16 180	184
Jordan	5	53	1 500	198
Lebanon	4	418	3 700	1 140
Libya	5	3	n/a	111
Morocco	28	447	1 200	1080
Syria	16	185	970	2 926
Tunisia	9	164	2 100	439
Turkey	64	775	2 900	3 213

Sources[1]: World Development Report 2000/2001, *Attacking poverty*. World Bank and FAOSTAT.

[1] The same sources are used for all tables.

There is a common understanding that water is of high value in the region. This value is felt in economic terms and even more importantly in social terms. Access to safe water is considered to be fundamental to life.

The region as a whole is rich in oil but distribution is very uneven. Non-renewable energy should be included with resources such as water and human resources as main components in the development of strong regional cooperation, which is desired by many. The potential for solar energy is high and evenly distributed. The cost of solar energy use is projected to decline dramatically, which would in turn benefit water processing systems such as desalinization and local pressurized irrigation. Wind energy might be a viable alternative for power production in some areas.

In the regional context of very low runoff from precipitation, there are countries where water supply is highly dependent on precipitation and upstream use. There are four major international rivers in the region – the Nile, Euphrates, Tigris and Jordan – which supply a great deal of irrigation development and for which sustainable and equitable development must be found through international cooperation. Deep Saharan aquifers are shared among Algeria, Tunisia, Libya and Egypt; these too require international cooperation, since they are finite resources and their exploitation will be limited. Most of the countries in the region have reached or are close to the safe level of water abstraction in 70-80 percent of their main river basins. This is the case in the Souss, Oum-er Rbia and Tensift river basins in Morocco. Two rivers are fully regulated and their waters fully used: the Nile at Aswan and the upper tributaries of the Jordan by Lake Tiberias. Horizontal expansion of irrigation and development of conventional water resources are therefore limited in the 11 countries. The only important exception is Turkey, which has developed only 20 percent of its water resources. Improving productivity of already mobilized resources is therefore unavoidable.

To complement this existing but scarce supply, non conventional water sources, water transfers as well as non-renewable resources, are already in use in the region. Wastewater is now a very important source of water in the Jordan river basin. An annual volume of about 50 million m^3 of sewerage effluents from the conurbation of Amman is reused for irrigation in the Jordan valley after primary treatment. Desalinization is also an important source of water in Israel, which is entering an agreement with Turkey for importing fresh water by sea in tankers. Libya depends solely on the exploitation of the immensely rich aquifers located about 800 km south of the arable lands in the coastal belt.

Table 2: Annual freshwater withdrawals

Country	m^3 billions	% of total resources	% for agriculture
Algeria	4.5	31.5	60
Cyprus	0.2	23.4	74
Egypt	55.1	94.5	86
Israel	1.7	155.5	64
Jordan	1.0	51.1	75
Lebanon	1.3	26.9	68
Libya	4.6	767.0	87
Morocco	11.1	36.8	92
Syria	14.4	32.2	94
Tunisia	2.8	69.0	86
Turkey	35.5	17.4	73

Table 2 presents main indicators of freshwater withdrawals.

Food production and agriculture

The average per capita energy intake in the region is 3 070 Kcal, 56 percent supplied by cereals, 16 percent by animal products and 28 percent by products such as oil, sugar, vegetables and fish. Despite an important and steady increase in grain production of 2.7 percent per year in recent decades, countries have not been able to meet demand and have increasingly relied on food imports to balance supplies of staple foods. In 1995, the region relied on the international market to meet 33 percent of the consumption of cereals. Cereal imports increased sharply in 1973-74, reaching a plateau in 1984 where it stabilized for about ten years. Figures for 1996 and 1997, however, reflect another sharp increase: grain imports increased by another 40 percent in 1997. This reliance on food imports makes the region a significant user of virtual water. The average virtual water requirement for grain per capita is 100 m^3/year. Given a static average energy intake and no change in the balance of cereal, animal and other foodstuffs, requirements for cereals in 2025 will increase by 75 percent. It is likely, therefore, that the dependency of the Middle East and North Africa on the international market will increase. Projections for imports of grain for 2025 are about 90 million tons if the vertical increase of productivity is maintained at the current pace and 110 million tons under the assumption that the average growth of yield is limited to 1 percent per year. Both scenarios take the net horizontal extension to be zero. Complete food self-sufficiency is neither feasible nor desirable in most of the countries. Imports of food, especially cereals, are increasing.

The pattern of water use is similar in all countries of the region: irrigated agriculture takes the major share of water: from an estimated 72 percent in Turkey and Israel and 74 percent in Jordan, to 86 percent in Morocco and Tunisia and 87 percent in Egypt. Major variations reflect:

- the contribution of agriculture to the economy;
- the percentage of people employed in agriculture;
- the percentage of rural population.

In Egypt and Morocco, more than 50 percent of the population is rural, compared with less than 30 percent in Jordan. Almost 40 percent of the labour force in Morocco and Turkey are in the agricultural sector, but only 3 percent in Israel.

Irrigation plays a major role in agricultural production. The almost 100 percent growth of irrigated areas from 1960 to 1998 has boosted agricultural production. It is estimated that 11.8 million ha of arable land were under irrigation in 1998. The contribution of irrigated areas to food production is very important because of its high productivity. Irrigated cereal yields reached 5.5 tons/ha in Egypt; non–irrigated cereals elsewhere yielded only 1.5 tons/ha. Irrigation has contributed significantly to the increase of agricultural production and to the economy. The role of irrigated agriculture is likely to decrease in relative terms, however, as it is expected that other sectors will develop more rapidly. It still employs a high percentage of the active population but in Israel the urban population and industrial and service activities are replacing the agricultural sector.

Policies relating to the allocation of water and other resources for development must take account of the opportunities and constraints of the economy, the social and environmental situation and technology. Some important economic considerations are:

- the efficiency of the marketing system for agricultural products;
- the financial impact on farmers of adopting modern technology;
- risks linked to investment in cash crops and export-oriented products (high quality products, protectionism);
- the future of non-viable farming systems;
- dependence on subsidized inputs.

Social considerations are:

- migration from rural to urban areas;
- low wages;
- lack of social security.

Technical considerations include:

- low economic efficiency when dealing with production inputs;
- access to technology and its application;
- transfer of knowledge;
- capacity building.

Given the major importance if irrigation in the area, its specifically regional characteristics need to be understood more thoroughly when considering the above constraints and opportunities.

Irrigation

Irrigation development

Irrigation has been practised since the earliest times all over the Mediterranean basin. Some ancient works are still in use and remnants of old irrigation systems abound in Egypt, Tunisia and Turkey. Most of the areas irrigated before the mid-1950s were developed by individuals or local communities. In Turkey, for example, 915 000 ha were privately irrigated but only 40 000 ha were developed by the government. About half of the area irrigated in Tunisia was in private hands. The case of Egypt is unique: about 2.6 million ha were irrigable in the Nile valley through a vast construction programme of barrages and canals developed since 1826 on initiatives of the rulers of Egypt. Development of irrigation by governments in the other ten countries was mainly initiated after the Second World War, accelerating in the 1960s as countries became independent. This late development, compared to some of the developing countries in southern Asia, where government-managed irrigation started in the 1860s, has given an advantage to the Mediterranean countries, which have benefited from technological progress in hydraulic, construction and automation techniques, and improved water application at farm level.

The total area irrigated in the region increased from about 6.0 to 8.0 million ha between 1960 and 1980 and now is reaching 11.8 million ha. Turkey and Egypt together represent over 63 percent of the present development. Table 3 shows the evolution of equipped surfaces from 1960 to the present in the 11 countries.

Table 3: Irrigated surfaces equipped per country since 1960 (1 000 ha)

Country	1961	1980	1998
Algeria	229	280	560
Cyprus	30	30	40
Egypt	2 568	2 445	3 300
Israel	136	203	199
Jordan	31	37	75
Lebanon	41	86	120
Libya	120	225	470
Morocco	875	1 217	1 291
Syria	558	539	1 213
Tunisia	100	243	380
Turkey	1 310	2 700	4 200
TOTAL	**6 009**	**8 005**	**11 848**

There is limited data on the proportion of irrigated lands developed and managed by the private sector, communities and governments in the 11 countries. It is estimated that about a quarter of irrigated lands in Turkey – 1 million ha – were developed by the private sector. In Jordan, the percentage is about 52 percent, or 36 000 ha, and in Tunisia about 56 percent, or 210 000 ha. The highest percentage is in Algeria, where 435 000 out of a total of 672 000 ha have been developed by individual owners. Table 4 presents some estimates of the percentage of private irrigation, derived from FAO/Aquastat information. It is likely that most privately developed irrigated lands depend on groundwater. There is, unfortunately, very little documentation on the performance of private irrigation in most countries. It can only be assumed that such irrigation is more efficient and productive than public systems because of pumping costs and flexibility in water use. The conclusion might be that there is not much scope for improving productivity in private irrigation in the region and consequently that significant increases in land and water productivity may be more likely in countries where there is a large proportion of public irrigation.

Government irrigation systems

The rivers supplying major government-built irrigation systems are in general regulated by large reservoirs on a seasonal or annual basis. The very low silt content in released water favours the adoption of modern regulation techniques for the canal systems. The highly silted waters in southern Asia and northern China have been a serious constraint to system modernization. Most primary canals were lined with concrete, some by canal-lining machinery. In North Africa and Turkey, secondary and tertiary canals consist of precast elevated canaletti, or flumes, which provide high flow efficiency compared to unlined or badly lined distribution systems in large alluvial plains.

Modern hydromechanical techniques and, more recently, sophisticated automatic remote monitoring and control through telemetry and simulation modelling have been adopted for water flow and level control. For example, the Canal du Haouz in Morocco and the King Abdullah Canal in Jordan are automatically controlled in real time through dynamic regulation. The Nile valley system is monitored by telemetry. The canaletti distribution systems in North Africa were designed for simple and efficient operation through the use of basic, robust concrete structures and equipment such as duckbill weirs, flow limiters and modular distributers. By contrast, the main systems in Turkey, built to different design standards, are manually operated.

Pressurized systems have been adopted in some countries, either to reduce water losses or because

Table 4: Irrigation indicators for the 11 countries (Source: FAO/Aquastat, 1998)

Country	Irrigated land % cropland	% Irrigated/ equipped	% Sprinkler irrigation	% Drip irrigation	% Private irrigation[3]
Algeria	7	82	9	n/a	65
Cyprus	29	83	5	90	47
Egypt	100	100	3	3	n/a
Israel	46	100	0	100	n/a
Jordan	20	n/a	9	60	52
Lebanon	36	n/a	24	15	n/a
Libya	11	51	n/a	n/a	30-40
Morocco	13	n/a	9	0.4	15
Syria	21	n/a	3	0.2	66
Tunisia	8	91	15	2	56
Turkey	15	74	6	0	25

[3] No precise figure on private irrigation is usually available. Figures presented here were derived from FAO/Aquastat country profiles, which usually refer to smallholdings or small and medium irrigation.

of soil characteristics unsuitable for gravity irrigation. In Israel, the entire water system pumped from Lake Tiberias is in pressurized pipelines. The gravity irrigation system in the Jordan valley was converted to pressurized pipelines in the mid 1970s. Some large-scale projects in Morocco were designed for sprinkler irrigation, in the southwestern Doukkala project because of shallow soils and in the Massa project because of sandy soils. The water transfer system in Cyprus is also under pipeline for micro-irrigation application.

The advanced canal-regulation techniques adopted in the region should make it possible to deliver water according to farmers' needs, a prerequisite to achieving the highest level of agricultural productivity and meeting specific crop requirements. In Turkey, where the systems are manually controlled, water is delivered on prearranged demand. In Egypt, farmers are free to pump from the tertiary canals at any time when the secondary systems, worked on a rotation basis, are operative. However, the recent shift from animal power to diesel pumps has created inequalities in water allocation in the absence of regulation on extractions, a situation which the Government of Egypt is now trying to correct. In Morocco, water is delivered according to a schedule determined by the managing agencies. The modern long-furrow surface irrigation method is widely used by Turkish farmers, but in North Africa that method, which was part of the original design, has not been widely adopted. Lack of maintenance of levelled land and the quaternary canals has forced most farmers to adopt the traditional small-basin technique, called "robta" in North Africa.

It is estimated that pressurized irrigation is practised over 15 percent of the region, compared to about 8 percent worldwide, including developed countries. As shown in Table 4, this average figure hides important variations, from 3 percent sprinkler irrigation in Syria to more than 90 percent drip irrigation in Cyprus and Israel.

Environmental issues

The degradation of water quality is a growing concern in the region. There are several causes:

- increasing intensity of inputs in agriculture;
- increases in untreated pollution from urban and industrial areas;
- salinity and uncertain longterm effects of using brackish water for irrigation;
- degradation of land by salinization and waterlogging.

Even the recycling of water, which alleviates water scarcity by improving global efficiency, at the same time generates an increase in chemical loads. In the coastal aquifers of Israel, the amount of chlorides and other solutes is rising. Based on past trends, it is forecast that 25 percent of available groundwater will have a chloride content of more than 250 mg/litre by the year 2025. This clearly illustrates that a limiting factor in improving water efficiency in terms of quantity is the resulting decline in water quality.

There is concern about the impact of climate change, considered as a global temperature increase of 1°C in the next 50 years, on precipitation, climatic demand and crop evapotranspiration. Expected effects are increases in climate variability and the severity of extreme climatic events. Simulations on the Mediterranean region have been conducted using the UK Hadley Centre model. They show a decrease of rainfall of about 20-40 percent during dry seasons and 0-20 percent in rainy seasons, based on the assumption of a 1°C increase of global temperature in 50 years. These predictions obviously rely on various other assumptions and therefore contain many uncertainties, but the trend towards a global change is already apparent. Decreases in dry-season rainfall and a rise in temperature of 0.2°C have been observed in the last two decades. Global climate change should therefore be considered by policy makers in future scenarios. For example, there is concern that a decrease in rainfall will lead to the decline of some rain-fed agriculture. This may have limited consequences on the food production balance, given the relatively low productivity of rain-fed areas, but a social threat can be perceived in the sense that migration to already overpopulated urban areas and increases in unemployment may be accelerated.

Areas of future intervention

Policies for water and food supply

The history of water development, which is driven by political, economic and social forces, differs in each country. In Morocco, for example, policy objectives evolved from 1963 onwards are now focused on an integrated approach to irrigation, taking account of rural development.

While many countries have already reached the technical or economic limits of exploitable water resources, further development is under way in Turkey and Morocco. Expansion of irrigation systems is currently being carried out in Egypt on the basis of improved efficiency derived from reallocation of water saved elsewhere in the country, including the Nile basin. Part of the policy in Egypt is to modify the cropping pattern and favour crops that are less water-dependent. There are, for example, plans to move progressively from sugar cane to sugar beet. In the long term, decreases in water availability in agriculture might be expected in countries where water is drawn mainly from non-renewable groundwater.

All countries expect the agricultural share of the total water budget to decrease. As population growth is high, however, food requirements are increasing. The balance between dryland farming and irrigated land is expected to be maintained in Israel and improved in Tunisia and Morocco. In Tunisia, irrigated agriculture could be abandoned in some areas because of non-viable and uneconomic farming systems.

Countries are in different stages of water-policy reform. There is, however, a noticeable general trend in transferring responsibility for the operation to local agents, while strengthening the role of the state in regulating water resource quantity and quality and acting as a watchdog and safety system in case of major crisis. There is a clear shift in most of the countries towards water-demand management, whilst water resources are further developed.

- **Egypt**. There is emphasis on the move from a supply-oriented approach to an integrated approach, with the objective of investing in rural development: optimizing use of available resources, implementing groundwater development strategies, reusing drainage and sewage water and developing surface-water and other sources such as desalination and harvesting of rainfall. Demand management requires improved water-use efficiency.
- **Jordan**. Priority is being given to maintaining or possibly increasing crop production, while progressively reallocating water to other sectors. This implies careful planning of mid- and long-term use of water resources; treated wastewater will constitute an increasing part of agricultural water supply.
- **Morocco**. The main strategies are further to extend irrigation, improve field efficiency and trends for use at catchment level and improve cropping patterns.
- **Tunisia**. Key objectives are to have integrated development that will encourage people to stay in rural areas and to enhance rural development. This implies improvement in the domestic water service, which is less than 70 percent in rural areas, sustainable and equitable exploitation of resources and protection against pollution.
- **Turkey**. Further development of water resources and irrigation and institutional reform are the main objectives. The goal for water development is to reach all economically irrigable land, which is estimated to be 8.5 million ha; the gross irrigated area was 4.5 million ha in 1995. The multiple objectives of institutional reforms undertaken in Turkey in the 1990s were geared to creating an economically sustainable agricultural sector. They included eliminating direct support and input subsidies to existing farming systems except for basic crops, developing private enterprise in irrigated areas, increasing operation and maintenance cost recovery and increasing the responsibilities of local development agents.

The concept of virtual water already exists in the region. The region became short of water in the 1970s and started importing virtual water in the form of food. Reliance on virtual water implies both need in a water-scarce region and confidence that the international market will continue to provide. The concept of virtual water should not be limited to grain: there are higher water-demanding products that must be accounted for. For example, a closer look at virtual water for a country like Jordan reveals that wheat for staple food is only one fifth of the imported virtual water. Rough estimates for Jordan's virtual water are 70 million m^3 exported in the form of fruits and vegetables, while 70 million m^3 are imported as wheat, another 70 million m^3 as animal feed and 140 million m^3 as meat. The interesting point in this example is that there is a balance in virtual water for exported fruits and vegetables and imported staple food, which should give room for safety in case of a major food crisis. The concept of virtual water is important for decision-makers, but it has little meaning for farmers and may even give rise to the old belief that everybody has the right of access to and use of water. Farmers are more sensitive to jobs and money: at local level, the assessment of virtual water in money terms is considered to be more pertinent.

There is a willingness to create a free-trade area in the Mediterranean. This might generate positive results but there are concerns about negative social impacts. Cooperation on food security amongst the Mediterranean countries and other regions is crucial for sustainable development. Pressure on water resources, for example, can be reduced if countries can rely on an external market for cash crops needing low water input and at the same time import staple foods at regulated prices.

Food-production capacity

Food-production capacity is examined in two main directions: the horizontal capacity for production and the vertical capacity for productivity.

- **Horizontal capacity**. The main limiting factor in the region is water, not land. The horizontal capacity or extension is hence mainly constrained by the availability of water. Expansion or reduction of the irrigated area is highly dependent on the possibility of maintaining existing water resources, of developing new resources, including non-conventional water, and of generating water savings in existing processes. Horizontal irrigation increase, the development of water and extension of irrigated areas, is continuing in Egypt, Morocco and Turkey. Given the non-sustainability of some irrigated systems based on fossil water, however, a long-term horizontal decline cannot be excluded.
- **Vertical growth**. Vertical growth is more likely to be the main driving force for increasing food production capacity in future decades. Average cropping intensity (crops/year/ha) is slightly above 100 percent, except in Egypt, where it reaches 165 percent. There is scope to increase cropping intensity, provided that more water is available. Again, water is the limiting factor. Methods of improving water productivity, measured in kg/m^3, have been tested in the region by the International Centre for Agricultural Research in the Dry Areas (ICARDA) and others. Supplementary irrigation, for example, shows a high return to water. Applied on cereals at critical development stages, it yields marginal productivity of water from 1.5 to 2.5 kg of grain per m^3 of water. This technique has progressed beyond pilot studies and in Tunisia there are already 50 000 ha of rainfed areas that benefit from supplementary irrigation.

It is expected that crops will also experience major improvements. Biotechnology, including genetic engineering and crop breeding, can help in crop development. For marginal land, drought-tolerant crops can be developed that require less water and reduced inputs of chemicals and fertilizers, that are adapted to brackish and saline water and are more resistant to disease – and hence more productive. Organizations such as ICARDA are involved in crop breeding to develop these characteristics in new varieties.

Water is still used with low efficiency at field level in some countries. Nonetheless, local irrigation performance can improve rapidly in Israel and Jordan with the implementation of new techniques and in Turkey, Tunisia and Morocco through participation by user associations and farmers. This can lead to an overall increase of water efficiency in a basin where recycling is not dominant. Improvements in efficiency at field level are technically possible through sprinkler irrigation, drip irrigation and modernized surface irrigation. The choice is site specific and investment to develop and disseminate these modern techniques must be well adapted. Subsurface drip irrigation is often cited as the most efficient technique for water distribution but it must be borne in mind that surface irrigation is by far the most common technique in use in the region. For the countries concerned, it is estimated that surface irrigation covers 85 percent of the irrigated area. There is little chance that all these areas will be converted to pressurized techniques; it is likely that surface irrigation will still be dominant in 2025. Large investment in modern management and surface irrigation techniques, including levelling and distribution at field level, is therefore crucial.

Better water management implies technical improvement (as discussed above) but also institutional change and better participation of water users.

Water resources

Competition in the Mediterranean basin between water resources, which are scarce and fragile, and water use is already intense and will increase in the 21st century, aggravating the shortage problem. This situation could disadvantage development in the future, particularly agricultural food production. Long-term management of water resources and water demand is required, involving changes of resources and uses and implementation of sustainable development. This should improve the ratio of water used and its contribution to development in each economic sector.

New surface-water developments are taking place, but at the same time there are concerns about the sustainability of existing resources. Some resources, such as confined Saharan groundwater, are non-renewable and the main question is whether exploitation can continue for 50 years or more. Other surface resources are threatened by the inevitable decline of storage capacity resulting from heavy sedimentation. This is particularly the case in North Africa, where current loss of live storage reservoir resources ranges from 1 percent to 2.5 percent per year in Tunisia and 2 percent in Morocco. This phenomenon may be further exacerbated if global climate change leads to more extreme and violent weather events causing increased erosion in the watershed. The rapid decline of reservoir capacity generates huge economic problems: for example, what is the return of a dam that silts up in about 50 years? It creates resource problems, too: since manageable sites have already been equipped, what will be the alternative at some time in the 21st century once the dams are silted up? There are ways to increase storage capacity by the recharging of subsurface and groundwater reservoirs. Techniques for efficient rainfall harvesting, concentrating the water in the root zone, are well known and have been used in the region sometimes for centuries; designers, managers and decision-makers should give attention to them. In Tunisia, flood-harvesting techniques involving diverting floodwater to nearby fertile lands and storing the water in the root zone have been used successfully for centuries. It is recognized that there is a knowledge deficit regarding recharging groundwater. Better knowledge of the spatial distribution of recharge characteristics should lead to improved groundwater management in terms of both quantity and quality.

The need to improve efficiency, productivity and returns from water is recognized and has been discussed in previous sections. What needs to be stressed here is the need to raise management efficiency levels, which calls for an effective institutional framework and reliable information systems about withdrawal, water use and recharging of groundwater. In a situation where the quality of water has become a concern, new ways of managing the resources have to be implemented.

The proportion of unconventional resources, especially brackish water, should be increased and water should be dedicated to sectors of higher economic, social and environmental returns, using independent energy sources such as solar energy. It has been estimated that 70 percent of agricultural water reallocated to urban uses could be reused for agriculture after treatment. There are various unconventional ways of increasing water supply, such as rainfall and flood harvesting and the artificial increase of rainfall. These should be considered for immediate intervention when the marginal return is extremely high, for example when drought threatens a harvest, and not for supplying an entire season, which is not economically viable.

"Wet" or "dry" water saving: real or paper savings

If a water conservation technique simply reduces the amount of drainage water from a particular use and this drainage water is beneficially used downstream, there would be only a "dry" water saving. But if the drainage water flows directly into a salt sink, "wet" water would be saved. By definition, all usable drainage water in closed water basins is already being beneficially used, so water-efficiency measures that merely reduce drainage water create only "dry" water savings. In open systems, on the other hand, usable drainage water is being lost to salt sinks. Reducing this loss by reducing drainage water will result in "wet" water savings, a real gain in efficiency.

In sum, real global gains in water efficiency through reduced drainage losses depend on whether the water basin is open or closed. This is only one source of efficiency gain, however. Whether in closed or open water basins, real efficiency gains can be achieved by:

- increasing output per unit of evaporated water;
- reducing water losses to sinks;
- reducing water pollution;
- reallocating water from low-value to high-value uses.

D.Seckler. 1996. *The new era of water resources management: from "dry" to "wet" water savings*. IWM

Potential water savings in the region

The increasing attention given to the management of water resources during the last decade has encouraged new thinking about evaluation of water consumption and water balance. Some experts have recommended abandoning the conventional term "irrigation efficiency". Given that irrigated agriculture consumes over 80 percent of the world's developed water supplies and that the low efficiency of surface irrigation systems, 40 percent and less, that account for 85 percent of the irrigated area, the potential for saving would be tremendous. The scope for improving water-use efficiency[2] is much lower than commonly assumed when basin efficiency is the measure of evaluation. To avoid confusion about potential savings, a new definition of effective irrigation efficiency has been proposed which incorporates recycling and pollution effects.

The concept of "wet" and "dry" savings used in the USA (see previous box) is very important for river-basin systems where the drainage water from irrigation is recycled from groundwater or surface drains. The extraction of groundwater in the alluvial plain of the Indus river is estimated at 43 billion m^3. Most of this volume is the annual recharge from the surface system. Drainage losses to highly saline aquifers, creating waterlogging and salinization, are real losses. In the Nile valley, drainage water is safely recycled several times, while in the delta, north of Cairo, recycling is less and less acceptable, even for agricultural uses, because of increased pollution.

Traditional irrigation systems built by local communities in high mountain valleys, for example in the Atlas mountains in Morocco, are generally inefficient. Although water losses are replenished by other systems downstream, measures to improve the efficiency of these systems would not significantly improve basin efficiency. A similar situation has been observed in large irrigation plains at Tadla and Gharb in Morocco, where canal leakage and tailend losses feed a water table that remains high with an acceptable quality and contributes to plant water consumption up to 1-1.5 mm per day during summer. (Reported by Vidal, 1990, on sugar cane in Gharb).

In lower areas, however, such as southern Tunisia, where drainage water is lost to the sea or to saline evaporation sinks, water-saving measures are essential for the water-scarce countries in the region. The rapidly increasing use of groundwater observed in irrigation systems in the alluvial plains of Asia – the Indus, Ganges, Yellow River and Brahmaputra – is not taking place in the Mediterranean region. The reasons are both social and physical: higher farmer confidence in the reliability and adequacy of water delivery from surface systems and less favorable hydro-geological characteristics of aquifers.

A substantial loss of water productivity results from poor water supply in surface irrigation systems. Unreliable delivery may cause substantially reduced yields. Rigid delivery of water at long intervals precludes the adoption of water-saving techniques and the change from staple food to high-value, water-sensitive crops.

[2] Water use efficiency = crop production and by extension its monetary value per m^3 of water derived (Oweis *et al.*, 1999).

Case study summaries

> **Single initiatives are unlikely to produce the required results; sustainability of water management depends on carefully selected measures that complement each other.** (J.Langford)
>
> **Economics instruments do not work in isolation but only as a part of an overall water-resources management system** (J. Briscoe)
>
> MENA/MED Water Initiative, Proceedings of the First Regional Seminar On Water Policy Reforms

Case studies on water conservation initiatives in five countries of the region are discussed here. Two, in Jordan and Morocco, refer to isolated physical changes, the adoption of drip irrigation with tensiometric scheduling and laser-levelled basins. The Egypt study relates to an initiative that recognizes the relation between improvements at the levels of delivery systems and farms. The fourth case discusses institutional reform in Turkey consisting of the transfer of management to WUAs. The last case discusses the comprehensive water reform programme in Tunisia. The pilot experiences in these five countries are summarized in this chapter, and discussed in annexes. This chapter presents some historical background information on the development of irrigation infrastructure in each of these countries required for discussing the constraints to the full-scale implementation of isolated initiatives. Table 5 presents the main relevant features of the five countries considered.

Jordan: irrigation optimization in the Jordan valley

This case study is detailed in Annex 1.

Jordan is one of the Mediterranean countries with the scarcest water resources – less than 300 m^3 per capita. Annual water extraction exceeds the renewable water resources. It is estimated that agriculture consumes about 75 percent of the available resources. About 18 percent of the cropped area benefits from irrigation, mostly in the northern region and in the Jordan valley. About half of the irrigated area, 39 000 ha, is supplied by government-owned and managed irrigation systems, mostly in the Jordan valley; the other half is privately owned and operated by farmers depending mostly on groundwater. Irrigated agriculture in the Jordan valley is an important sector of the Jordanian economy, contributing up to 80 percent of agricultural production. Fruit trees account for about 30 percent of the land, vegetables 60 percent and the rest about 10 percent. Irrigation in the Jordan valley is managed by an irrigation agency, the Jordan Valley Authority (JVA), which is responsible for other economic and social activities in the valley.

The water-saving tests

This chapter and Annex 1 describe the results of a pilot programme undertaken with French assistance in the Jordan valley to demonstrate the benefits that can be obtained from water-saving techniques at farm level. The first test consists of comparison of the performance of two farms cultivating tomatoes and cucumbers in greenhouses. Both farms use drip

Table 5: Main water features of the five countries of the case studies

Country	GNP dollars per capita	Fresh water resources: m^3 per capita	Withdrawal: % of total resources	Irrigated / equipped: %	Sprinkler irrigation: %	Drip irrigation: %
Egypt	1 400	949	94.5	100	3	3
Jordan	1 500	198	51.1	n/a[1]	9	60
Morocco	1 200	1 080	36.8	n/a	9	0.4
Tunisia	2 100	439	69.0	91	15	2
Turkey	2 900	3 213	17.4	74	6	0

[1] Data not available

Figure 1: Tensiometer reading on a citrus farm in the Jordan valley *[Alain Vidal]*

irrigation supplied from their own settling basins, supplied in turn on a rotational basis from the JVA-managed pipe system. Only one of the farms uses tensiometers to determine irrigation scheduling. The tests showed that the water consumption for cucumbers decreases by about 20 percent and for tomatoes by about 50 percent when tensiometer scheduling is used. Cucumber production increased by about 15 percent and tomato production by about 20 percent. The application of fertilizers was 30 percent higher for nitrogen (N) and potassium (K) and 80 percent for phosphorus (P). The use of tensiometers nearly doubled productivity per unit of water.

A second test consists in the change of a citrus farm from traditional surface irrigation to micro-irrigation associated with tensiometric scheduling (see Figure 1). This test failed because the drip system was not adapted to the root development of a 40-year-old orchard irrigated by basin irrigation.

Discussion

The potential increase in water productivity and farm income resulting from the adoption of water-saving techniques should have encouraged many farmers in the Jordan valley to adopt these techniques. This section examines the constraints on their wide application in the Jordan valley. Farmers in the highlands do not usually use irrigation scheduling techniques, with the notable exception of some orchards in Showbak, near Petra. Jordanian farmers have a high level of education and are well informed about modern irrigation techniques used in developed countries and on the other bank of the Jordan river.

Over time, the JVA has converted most existing open-channel distribution networks irrigating about 20 000 ha in the mid 1970s into pressurized networks and has adopted the same pipe design for the new 10 000 ha lands developed since then. The JVA has modernized the 110 km main canal diverting water from the Yarmouk river, a tributary of the Jordan. In addition, sophisticated Supervisory Control and Data Acquisition (SCADA) systems for water-resource management and water-use scheduling, monitoring and accounting purposes in the Jordan valley have been installed.

The objective of that conversion was that farmers would adopt sprinkler irrigation. Very few farmers purchased the mobile sprinkler equipment procured by the JVA. As of 1997, about 53 percent of farmers have adopted micro-irrigation, including a significant proportion of open pipe irrigation, a transitional technique between surface and drip irrigation. Two out of three citrus farms are still under surface irrigation. A very rapid increase in the adoption of plasticulture, green houses and small tunnels, took place in the early 1980s. For vegetables, it is estimated that plasticulture now covers about 800 ha out of 16 860 ha in the Jordan valley.

Despite the infrastructure modernization programme in the Jordan valley, the method of water delivery to farmers by rotation has not been changed by the JVA. Water is still distributed to users under a rigid and cumbersome process that includes the calculation of water requirements for each crop on each farm and for each rotation. The JVA also enforces a water-quota system based on location in the valley and the type of crop. This method of water distribution, suited to surface irrigation, is inappropriate to micro-irrigation, which requires small quantities of water, frequent application and variable frequency. It is not possible for the farmers to achieve the substantial benefits in water savings and crop yields that are expected from modern pressurized irrigation. For this reason, a large number of farmers have built small farm reservoirs to be used for storage of the volumes of water released from the JVA system four times a week for desilting purposes.

The main reason why the JVA does not convert to continuous irrigation is the risk that farmers would exceed their seasonal quota. Water rates charged to the farmers have been increased many times during the last decades but are still far below the level required to have an impact on water consumption and too low to cover JVA operation and maintenance costs. Farmers believe that they can minimize the problem of rigid rotation by applying excess water when it is available. Even the farmers who have adopted modern micro-irrigation techniques irrigate by excess because of the uncertainties of water delivery resulting from limited resources. The result of over-irrigation is underground leaching of water and fertilizers and increased pollution of the aquifers.

Maintaining rigid policies while encouraging adoption of water-saving application techniques is the JVA's challenge, conflicting with its declared agenda of optimization of water use. About half the farmers use low-flow, frequent application techniques and the other half use surface application, which requires large flows over short periods. This dual system is not compatible with a pipe distribution system designed for conventional sprinklers. Some flow limiters installed on farm outlets have been removed to increase the flow to between 9 and 12 litres. Engineering studies have shown that the existing system cannot be operated properly on demand because of the excessive capacities of the farm outlets.

A pilot project of 400 ha served by a single secondary pipeline has been carried out to test the full conversion of the irrigated area from the present dual distribution to micro-irrigation. Detailed engineering studies indicate that modifications to pumps and pipelines may be required to remove the constraints of the present system.

Conclusions

Pilot tests in the Jordan valley with bilateral assistance from France and the USA have confirmed that vegetable farmers could reduce water application through micro-irrigation and tensiometric scheduling and increase crop yields. Another test has cast doubts on the suitability of drip irrigation for old citrus farms. The rigid allocation system imposed by the government agency and the low level of water charges conflict with the adoption of water-saving techniques in the Jordan valley.

Morocco: improvement of on-farm irrigation by laser levelling and basin irrigation in Tadla

This case study is detailed in Annex 2.

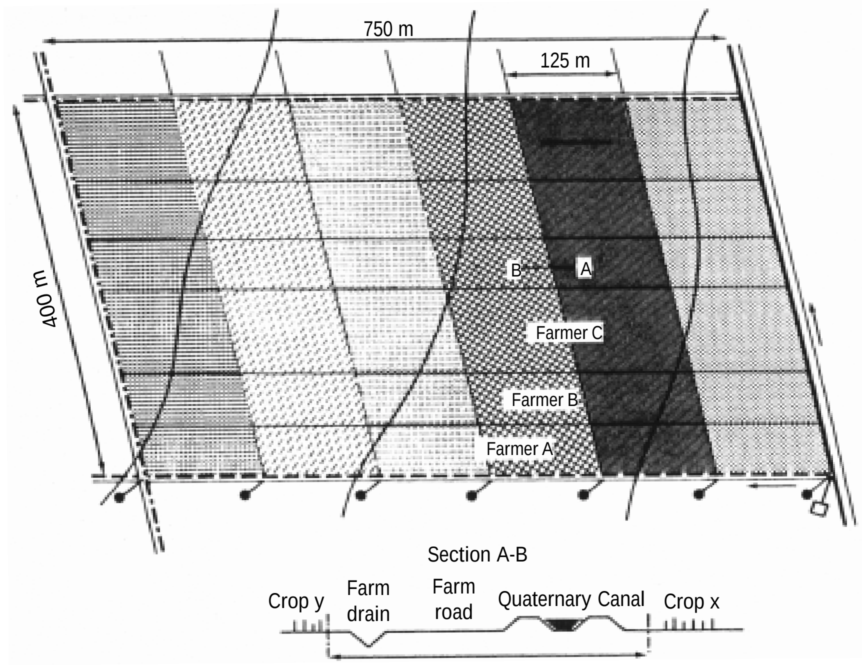
Morocco is relatively well endowed with water resources compared to the other North African countries. Renewable water resources per capita are two and three times higher than in Algeria and Tunisia, but they are not well distributed in space and time. According to studies by the International Water Management Institute, Morocco will be in the category of countries with severe water scarcity by 2025. Increasing water competition, urban and tourism needs and pollution will reduce the percentage of water extraction used by agriculture from the current 92 percent.

Traditional irrigation has been practised in Morocco since ancient times. Development of modern irrigation started in the 1930s but accelerated after independence. Of the 1.2 million ha under irrigation, 55 percent, or 672 000 ha, are government managed, 30 percent are owned and managed by local communities and 15 percent, mostly using groundwater, are privately owned.

Morocco is well known for its very modern public irrigation infrastructure. Operation of the main systems is controlled either by automatic hydraulic devices or by sophisticated remote control, such as the Canal de Rocade near Marrakech. Secondary and tertiary canals consist of prefabricated canaletti, or aqueducts, with sophisticated flow and water-level control through simple but efficient hydraulic structures. Although it benefits from one of the most advanced systems in the world, irrigation in Morocco is not superior in terms of agricultural production per unit of land and water. This paper first examines the effect of water distribution procedures and on-farm development on water use before discussing the conversion to basin irrigation in the Tadla project.

In the earlier stages of modern irrigation in Morocco, from the 1930s to 1950s, only the main and secondary irrigation canals were build, with the expectation that farmers would build tertiary canals to serve their plots. This approach was used in many developing countries worldwide but was, inevitably, found inadequate. Farmers either did not built their own systems or, if they did, they could not adopt efficient irrigation practices because of the

Figure 2: Schematic layout (Trame B) of a service unit of about 30 ha



constraints imposed by the random layout of farm boundaries. In the period following the Second World War, land consolidation was not considered feasible in Morocco because of social constraints and anticipated strong opposition by farmers. It was later decided that land consolidation was a prerequisite to development of modern irrigation. A land consolidation pilot project was implemented in the early 1950s in the Doukkala region. In 1962, a law stipulated that land consolidation should be carried out before installation of irrigation infrastructure.

Soon after independence in 1956, the Moroccan Government decided to take responsibility for on-farm development and provide firm control of farming activities by imposing cropping patterns combining industrial and staple crops and mandatory activities. This somewhat authoritarian agricultural strategy has had a considerable impact on the selection of a model for land consolidation, which has been in effect countrywide since 1962.

After a ten-year period of tests with different approaches to land consolidation, a model known as Trame rationnelle, or Trame B, emerged in 1962, which took into consideration engineering and agricultural aspects. That approach is a product of the creation of the Office National des Irrigations, which merged the responsibilities of relevant divisions from the Ministry of Agriculture and the Ministry of Public Works.

The specific characteristics of Trame B are given in Figure 2.

- Typical dimensions of irrigation units are about 400 m by 700 m, or approximately 30 ha. Each unit is served by a tertiary canal or pipeline running along its longest side.
- Depending on the size of the unit, there are four to six regularly spaced permanent quaternary canals of between 100 m and 200 m in length. Quaternary canals are associated with a farm road and a farm drain. The design provides that each area of about 5 ha served by a quaternary canal will be mono-cropped.
- Individual farms are strips of land parallel to the tertiary canal and across the quaternary canals.
- Quaternary canals are collectively owned by the farmers of the unit, who are responsible for its maintenance.
- The areas delineated by quaternary canals are levelled, with gentle slopes for furrow or border irrigation.

A village example from the Doukkala region illustrates the impact of land consolidation on land tenure in that region of very small landholdings. The number of farm lots was reduced from 406 to 80 and the average size of farm plots increased from 0.43 ha to 2.26 ha.

This model, with farm perimeters running across crop strips, makes possible the application of modern design criteria for surface irrigation determined by

Figure 3: Laser-levelled basin irrigation in Tadla region *[H. Bartali]*

soil permeability and slope. It permits the use of modern mechanized farming practices across 5 ha plots, including application of irrigation water. In sum, it allows the development of modern agriculture in a context of very small farm holdings. The anticipated success of this official model was based on the expectation of strict discipline among farmers in respecting government-imposed cropping patterns and organization of work within a crop strip – land preparation, harvesting and application of inputs, including irrigation – to obtain full benefit.

This was not the case. Farmers progressively deviated from the imposed crop pattern, particularly for the non-industrial crops. The most serious deviation from the original design was, however, in on-farm water management.

Irrigation was designed to be organized by crop and not by farm. The unit stream flow of 30 litres/sec allocated to each block is transferred from one farmer's section of the crop under irrigation to the adjacent one before passing to the next crop strip. The actual method of irrigation scheduling in Morocco is not well documented. It is known, however, that it is not carried out as designed. In some regions, rotational irrigation is organized by farms, not by crop. The result is that the same farmer has to use several collective quaternary canals during the allocated time, which is wasteful of water. Some farmers have built individual quaternary canals to avoid that inconvenience. The original land levelling was badly degraded and in most cases never restored. As a result of the above, farmers returned to the centuries-old irrigation method of small basins, in use in all countries of the Mediterranean region and known as "robta" in Morocco. The present field efficiency is far below the design value of 60 percent, which, combined with a system efficiency of 75-80 percent, should achieve an overall efficiency of nearly 50 percent.

The pilot test: laser-levelled basin irrigation

This chapter and Annex 2,describe the on-farm activities of a project being implemented in the Tadla region with the assistance of the US Agency for International Development (USAID) to improve the management of resources. The goal is to foster the long-term competitiveness of irrigated agriculture in Morocco and to protect the quality of its environment. The immediate objectives of the project are:

- irrigation water saving through improvement of the irrigation system and on-farm water application;
- reduction of pollution through rational use of farm inputs;
- active involvement of farmers;
- transfer of technologies applied in the Tadla region to other large-scale projects in Morocco.

To improve on-farm irrigation, laser-levelled irrigation was introduced on a number of farms(see Figure 3). This technique has been widely used for field crops in the USA and for rice cultivation worldwide. It is particularly well adapted to flat terrain and heavy soils. Demonstrations on some farms showed substantial benefits in water saving of 20 percent and crop increases of 30 percent. Other farm inputs were improved by 10 percent and there were labour savings of 50 percent. Uniformity of irrigation is about 90 percent.

Discussion

The description of the case study does not, unfortunately, provide enough information on the conditions under which basin irrigation was tested in the Tadla – farm size, natural ground slope, size of basins, location of the basins in the land consolidation layout and changes, if any, made to irrigation scheduling.

Basin irrigation is the simplest in principle of all surface irrigation methods. The key is to design the size of the basins to flood the entire area in a reasonable time, so that the depth of water is applied with a high degree of uniformity over the entire basin. Optimal sizes therefore vary with soil types and stream flows. Very large basins served by flows of up to 150 litres/sec are used in the USA. That method is not appropriate for crops that are sensitive to wet soil conditions around the stems or for crops on soils that crust badly when flooded. A disadvantage of basin irrigation is the interference of levees with the movement of cultivation and harvesting equipment.

Conclusions

There is no doubt that laser-levelled basins can improve water management under certain conditions, as demonstrated by the tests in Tadla and experience in other countries. There is large scope for its application in the flat lands irrigated in the lower Sebou river basin in Gharb. Its application may be limited in regions with shallow soils, such as Zemamra, and by economic considerations in areas with moderate to high slope, for example Beni Moussa in the Tadla.

A countrywide review of the suitability of the Trame B land consolidation model used in Morocco in the context of the changing conditions is desirable. The government agriculture strategy is being progressively liberalized. The need to modify farm layouts in the 30 ha units should be examined. This was successfully accomplished in the Loukkos project by application of the old Trame A model tested in the 1950s. The introduction of mobile equipment and meters in areas irrigated by pressurized systems and the privatization of the quaternary canals made possible by this new model were widely acclaimed by farmers.

Egypt: improvement of surface irrigation systems in the Nile valley

This case study is detailed in Annex 3.

Egypt has the largest population in the Middle East, but over 99 percent of the population is concentrated in the Nile river valley and delta on less than 4 percent of the country. Egypt has a unique situation in terms of land and water resources: over 99 percent of the cultivated lands are irrigated. The Nile, the only river in Egypt, draws the greater part of its water from Ethiopia and other central African countries. The entitlement of Egypt from this international external source is 55.5 billion m^3, which is fully regulated by the Aswan High Dam. Based on detailed surveys, groundwater resources have been evaluated in the New Valley and Upper Egypt at a total annual safe yield of about 5 billion m^3. The per capita share of the agricultural area in Egypt, 0.07 ha in 1980, is the lowest in the world.

Extensive studies have shown that the efficiency of the Nile water system downstream of the Aswan dam is very high because of the extensive reuse of drainage water. Over 90 percent is used if minimum flow releases to the sea are not considered as losses but as environment requirements. Egypt has no alternative but to improve the productivity of its scarce land and water resources. Most crop yields in Egypt are higher than world average yields, however, which limits the potential increase of agricultural production.

Irrigation has been practised throughout the Nile valley from the earliest times. The present system of barrages and canals was built between the 1860s and 1930s and later expanded to serve the needs of new lands in the valley and newly reclaimed lands on both sides of the Nile delta. A unique feature of Egyptian irrigation is that water in most secondary and tertiary canals is below ground level. Farmers used to lift water from the tertiary canals, the “mesqas”, through animal-driven pumps, the “sakias”.

Irrigation is mostly carried out during daytime. The relatively low flow of individual pumps ensures an equitable distribution of water between head-end and tail-end users and, in contrast with gravity systems, avoids over-watering cultivated lands. This situation has changed drastically since the 1970s with the rapid replacement of traditional pumps by individually owned diesel or electric pumps, which created large inequalities of water extraction along mesqas and created socio-economic inequities between head-end and tail-end farmers. Tail-end farmers responded by looking for other sources of

Figure 4: Modernized lined mesqa in the Nile delta *[A. Vidal]*

water, mainly by pumping from the drain system, an appropriate alternative in the valley upstream of Cairo but not in the delta, where drain water is highly polluted.

The Ministry of Public Works and Water Resources is responsible for the management of the main irrigation system of barrages, main and branch canals and farmers are collectively responsible for the mesqas, serving 12-40 ha. The branch canals are operated in rotation, depending on the prevailing cropping pattern – for example, four days on and three days off. Farmers are free to pump water at any time when their branch canals are on.

The Egyptian government was aware of the declining performance of the Nile system in terms of inequity of water distribution, decreasing quality of water used and manipulation of the system by farmers. One view was that the farmers were using water more efficiently if they had to lift it instead of irrigating by gravity. Imposed rotation among branch canals was seen as an additional management tool to limit over-irrigation.

The irrigation improvement programme (IIP)

The IIP, initiated in the late 1970s, recognized the close dependency between irrigation water delivery and on-farm water management. The technical improvement package includes interventions at two levels of the irrigation system: branch and tertiary canals. At tertiary level, the concept is to move the lifting points from the heads of field ditches to the head of the mesqa. Farmers stop using their own pumps and become dependent on one communal source to abstract water from the branch canal. At branch level, the concept is conversion from on/off rotation to the application of continuous flow. An additional objective of the programme was to address excessive spillage of water from canals and mesqas to the drainage system that resulted from limited hours of operation of uncontrolled individual pumps, mostly during daytime. This new concept requires a relatively high level of organization among farmers, who need to manage communal pumping stations, organize irrigation turns and set their own financial and maintenance rules. The organization of WUAs is therefore a prerequisite for technical innovations to become effective. A pilot project was implemented with support of USAID in the 1980s. A full-scale project started in 1995 for improvement of 100 000 ha in the Nile delta is being implemented with support from the World Bank.

The IIP pilot project

This chapter and Annex 3 present the first IIP pilot project implemented in the Nile valley with support from USAID in the Beni-Ibeid command area (2 000 ha). This is located in Middle Egypt and served by the main Serry canal.

Low-level mesqas were replaced by either elevated concrete-lined (see Figure 4) or buried low-pressure pipelines, at the choice of user associations, with a single lifting point. The branch canal was equipped with automatic downstream control gates to facilitate continuous flow.

A farmer survey confirms that delivery has been improved in terms of quantity from 33 percent to 82 percent as well as in terms of reliability. The number of farmers irrigating at night has decreased from 62 to 6 percent. About 80 percent of farmers now depend on the common pumps; individual pumps are being sold, which is an indication of farmers’ confidence in the project. However, 20 percent of farmers are still using their private pumps. Although their reasons are not reported in the case of Beni-Ibeid, surveys conducted on other IIP schemes show that the most common reasons are the reluctance of farmers who own their pumps to pay maintenance costs of IIP pumps and poor farmers' inability to meet the high cost of IIP pumps. The time required for each irrigation has been reduced by 50 percent and pumping costs have been reduced by 35 percent. A survey of the farmers using the first mesqas to be improved under the project confirms their satisfaction with the improved system in terms of saved time and labour and reduced operating costs.

The conclusion of the Annex is a matter of concern: "Compared to other command areas where IIP has been implemented, Beni-Ibeid command area appears as a success. IIP has been very well accepted and adopted by most farmers, who have observed positive impacts on their day-to-day operation and farm income. At main canals, however, the main canal has also been improved, except in periods where connections with the upstream main canal was disturbed by inappropriate operation. This supports the idea that improvement programmes should not be limited to isolated command areas but should be conducted on an integrated basis from main canals down to mesqa level". The ongoing project provides a telemetry system for monitoring and remote control of the regulating structures of the main feeder canals.

Discussion

The basic emphasis of the pilot project was development and improvement of mesqas and organization of user associations. Less attention was given to improvement of the delivery system, as confirmed by field observations that:

- during the period of low water requirements, the water level in the Serry main canal was below the design level automatically controlled by the main gate of the Beni-Ibeid canal, making it impossible to divert flows during peak hours, which caused deficits that affected upstream mesqas;
- farmers altered the balance of the automatic gates by using heavy weights.

The major technical challenge for upgrading the Nile irrigation system is the issue of night storage. The main system is operated in a continuous mode with bi-monthly adjustments to meet climatic and crop changes while little or no irrigation is carried out at night. Appropriate structures were built at the tail of branch and tertiary canals to spill excess water at night into the drainage system. This mode of operation is acceptable in Upper and Middle Egypt, where the drains flow back to the Nile upstream of the next barrage, but not in the Nile delta, where water in the drains is of lower quality or not suitable for irrigation.

Under the current project, the hydraulic design of branch canals is now based on a variable-flow hydraulic simulation model to determine future operating conditions and storage capacities to meet night storage requirements. Further consideration was given to flow control at the head of branch canals. With simple downstream control of branch canals, most variations in demand are passed upstream to the main feeder canal. Since the volume created by downstream control is limited, additional storage has to be mobilized above or below the normal flow lines. Various alternative solutions are under consideration to control flows at the heads of branch canals. As no system has been completed, however, the project concept has not yet been fully proven.

This project illustrates the difficulty of improving the performance of an existing irrigation system. This is particularly true when the improvement calls for a change in the mode of operation and organization. A simple solution to enable flexible irrigation at farm level – including day irrigation only – with a delivery system operated in continuous mode is the creation of farm reservoirs. That solution is not accepted in Egypt because of the scarcity of cultivated land.

The case study does not provide any statistically significant information on water saving and crop-yield increase. The very large capacities of the pumps may encourage farmers to continue to over-irrigate as in the past.

The nominal design discharge under the project provides for pumps delivering over 3 litres/ha with a minimum of two pumps for reasons of security. Total pump capacity comfortably exceeds the capacities of the branch and feeder canals. This is a further justification for the creation of federations of WUAs to coordinate the operation of mesqa pumps at peak hours, such as early morning in summer.

Figure 5: Irrigated cotton field in southeast Anatolia *[A. Vidal]*

Conclusions

It was clear from the outset of the project that changes in institutional arrangements and infrastructure at all levels of the system was required. However, slow and painstaking implementation indicates that “the devil is in the details”.

TURKEY: WATER SAVINGS IN RELATION TO PARTICIPATORY IRRIGATION MANAGEMENT

This case study is detailed in Annex 4.

Turkey has the most favourable water situation of the region. Average annual precipitation is highest in the Black Sea region – 2 400 mm – and exceeds 800 mm in some coastal areas. In the remaining 70 percent of the country, precipitation averages less than 500 mm, which is still enough for winter cultivation in some areas. The annual runoff of 187 billion m^3 exceeds the accumulated runoff of the other countries. It is estimated that nearly 45 percent of the annual runoff – 86 billion m^3 – can be mobilized for water use. The runoff coefficient of 36 percent is the highest in the region, about three times the value for North African countries. It was estimated in the early 1980s that only one fourth of mobilized resources were actually used. The government focus is on further development of water resources and sustainability of already developed infrastructures.

The gross irrigation potential in Turkey is estimated at 8.5 million ha, of which 93 percent is surface water potential. By the mid 1990s, about half of the irrigation potential had been developed and 70 percent of the potential groundwater had been exploited. In the early 1950s, most of the irrigated area – 874 000 ha or 95 percent of the total – was developed by the private sector. The role of the government has increased dramatically since then. Of the 4.2 million ha irrigated in 1995, 3.2 million ha are surface irrigation areas, of which 2.4 million ha have been developed by the government (see Figure 5).

Transfer of irrigation systems to users started gradually in the early 1950s. Encouraged by the experience of Mexico and by World Bank financial support, in 1993 Turkey began an accelerated programme of transferring management of responsibilities for large irrigation systems. The main motives driving this transfer programme were concern about the ability of the Devlet Su Isleri (DSI), the state water works, to operate and maintain the large irrigation systems for which it was responsible and the heavy financial burden on the government. In 1993, it was estimated that there was an 83 percent shortfall between operation and maintenance (O&M) allocations to DSI and collected tariffs. In three years, DSI succeeded in transferring about 1 million ha to local government units or to irrigation associations and has now completed the transfer of the nearly 1.5 million ha it has developed.

The transfer programme

Four provinces – Antalya, Adana, Konya and Izmir – were selected for the pilot programme of accelerated transfer, largely because officials and farmers in these provinces were more receptive. Transfer was supported with enhanced internal training, including seminars and workshops. Friendly rivalry among regions in promoting

Table 6: Results obtained from DSI Antalya Regional Directorate after irrigation management transfer

Results by the end of 1998	Regular irrigation in 1993		Transferred irrigation in 1998		Increase in efficiency: %
Water saving	16 109	m^3/ha	10 684	m^3/ha	34
Energy saving	1 502	kWh/ha	1 030	kWh/ha	31
Area with high water table	8 892	ha (20%)	6 683	ha (15%)	5
Salinization: area improved	38 692	ha (89%)	39 610	(91%)	2
Increase in collection rate		71%		95%	24

successful transfer contributed positively to the process.

As a pilot case, the Antalya Regional Directorate of the DSI carried out a comparative study that showed that transfer of O&M services to WUAs had a significant and quantifiable positive impact on water savings and O&M, from both technical and financial points of view. Positive results included:

- an increased sense of responsibility;
- more reliable and equitable water supply;
- improved irrigation efficiency with modern techniques such as drip irrigation, sprinkler and California systems;
- a collection rate increase from 42 to 80 percent;
- savings in energy costs of approximately 25 percent.

Results are summarized in Table 6. The results of WUA monitoring proved that the transfer process was successful but DSI opinion was that there was insufficient time for post-evaluation at each of the transferred facilities. In particular, legal and technical skills in WUAs need to be consolidated.

Discussion and conclusions

Some outcomes of the transfer programme were expected soon after completion. Most remarkable was the dramatic increase of cost recovery from a low average nationally of 40 percent to over 70 percent. A less expected benefit of the programme was the significant reduction in water and energy use and consequent reduction in salinity and waterlogging in the pilot area. This reduction does not necessarily result from the implementation of modern application techniques, which should have yielded a lower rate of water use. A possible explanation is that excessive use before transfer – 16 000 m^3/ha – was decreased by better management. In Uzbekistan, for example, it was possible to reduce water use from 16 000 m^3/ha to 12 000 m^3/ha simply by improved management and without any improvement or transfer.

Experiences in other countries show a dramatic increase in collection rates for water bills and significant progress in maintenance activities. The effects of transfer programmes on crop yields and water use, however, are generally slow to materialize. A possible scenario is that WUAs should undertake modernization of their irrigation infrastructure to improve service to members, through greater flexibility in water delivery based on pre-arranged demand, and to increase farm income through a reduction of operation and maintenance costs. Modernization by users is an ongoing process in industrialized countries, such as California or France. It is expected that the same process will take place soon in the systems recently transferred to large associations in Turkey and Mexico. To be sustainable, however, transfer still needs to be consolidated in Turkey by substantial legal reforms to define and strengthen WUA responsibilities and procedures.

TUNISIA: INTEGRATED WATER MANAGEMENT IN A CONTEXT OF SCARCE WATER RESOURCES

This case study is detailed in Annex 5.

Rainfall in Tunisia is irregular: there are long dry periods and precipitation varies from between 500 mm to 1 000 mm in the north to an average 150 mm in the south. Dry periods lasting several weeks often occur during one season or can last over several consecutive seasons. The present water management strategy in Tunisia is the result of thirty years of water resources evaluation and mobilization and socio-economic development priorities for which water is essential. The present objectives of irrigation in Tunisia are to extend the irrigable surface by fostering adoption of water-saving techniques for irrigation – use of marginal waters and reuse of treated wastewater – and to implement corresponding measures for agricultural and irrigation system development. The recent review of the water sector emphasized the need to strengthen demand management in order to preserve and improve the use of declining and random water resources.

The case study

Tunisia has developed expertise in the fields of water resources mobilization and integrated management in a context of aridity, water scarcity and social and economic constraints. This expertise has been supported from the outset by a national strategy, strong political commitment and increasing user awareness. The water sector has developed as a result of water-saving programmes, training, promulgation of laws governing regulation and development of information and decision support tools and extension techniques.

Prominent features of this expertise were:

- mobilization of surface and groundwater, implementation of a network of water sources to allow water transfer and provide permanent water security and development of integrated management of surface and groundwater;
- implementation of a regularly updated water database and decision support tools to limit the impacts on urban supply and agriculture of the three-year drought of the early 1990s;
- initiation of water saving programmes at network and field levels following a government-sponsored survey of individual water consumption and subsidization of 40 percent to 60 percent of equipment; these programmes resulted in water savings of around 25 percent and increases of cropping intensities to more than 1.0;
- use of pricing as a parameter of water-demand and water-saving management;
- creation of and assistance to WUAs running water-management and hydraulic infrastructure in irrigation schemes, with a corresponding increase in awareness of water scarcity and need for rational use;
- protection of the environment through allocation of water to protected sites;
- increase of potential resources for irrigation of fodder crops by promoting reuse of treated wastewater from treatment plants draining the main cities.

Discussion

In Tunisia, irrigation differs from most regions in the world because water resources are almost entirely tapped and brackish water is used at salt concentrations of up to 4-6 gm/litre higher than standard irrigation practices. Tunisia has therefore acquired considerable experience in using low-quality water, which explains why the use of treated waste water is relatively developed in Tunisian irrigation programmes.

The following points should be taken into consideration when Tunisia promotes a policy of water savings in irrigation:

- Tunisia is characterized by a climatic pattern in which average annual rainfall decreases from north to south. On average, farmers do not need much irrigation water in the northern part of the country, which is why existing schemes are underutilized except in drought periods. More attention should be given to irrigation strategies that will limit waste and investments in irrigation in the north.
- Water salinity is increasing from north to south. Water transfers from the north to central areas of Tunisia increase water availability and decrease water salinity in irrigation transfer schemes.
- Water savings in surface irrigation should be more aggressively promoted, since irrigation in Tunisia often aims to improve cereals such as wheat that are traditionally cultivated in small plots, for which sprinkler irrigation is unsuitable (see Figure 6). Research being carried out on water savings in surface irrigation, especially in supplementary irrigation of wheat, should be strengthened.
- With regard to equipment, the Tunisian water-saving programme has not focused sufficiently on software such as farmer training in optimum use of the equipment. Research shows that the introduction of drip irrigation does not save much water in Tunisia, although it increases yields. Use of brackish or salty water, for example, of which there is not much experience in the world, leads to the clogging of equipment.
- The results from Tunisian water-saving programmes have not been sufficiently evaluated in the field. Such results would be valuable in the development of Tunisian water policies.

Figure 6: Traditional surface irrigation near Kairouan, Tunisia *[A. Vidal]*

Conclusions

Tunisia is at a crossroads because its development cannot be based solely on the mobilization of new water resources or on water transfers from the north to the drier south. Any integrated water management must now address water demand. Technical measures such as the introduction of new irrigation technologies or equipment are not sufficient. Financial measures such as pricing water at its real cost are necessary but politically more difficult to implement. Finally, the involvement of water users is a key element of a successful integrated water-management strategy.

Tunisia has embarked on a new irrigation policy, which gradually shifts water-management responsibilities and costs to WUAs. A comparable irrigation policy using surface water has been adopted in Turkey and other parts of the world. One of the special features of the Tunisia policy, however, is the creation of associations of underground-water users that will improve management of the water requirements of all irrigators using a shallow aquifer. The Tunisia Water Sector Investment Programme, PISEAU, which is financed with the assistance of international and bilateral agencies, has made new underground-water development contingent on the setting up of such organizations. Experience will show whether such WUAs can manage aquifers in a sustainable manner. A success would be a model for other countries facing depletion of aquifers resulting from overuse.

Lessons learned

The following table summarizes the main characteristics and successes of each case study. Three criteria are used to assess improvements in irrigation:

- reported water savings, based on the volumes distributed from tertiary canals or pipes;
- reported crop yield increases, relating to the main crops cultivated in the study area (in brackets);
- resulting increases in water-use efficiency, representing the change in yield per m^3 of water applied: "more crop per drop"[1].

The main success factors and constraints relating to large-scale application of technological innovations are indicated in Table 7.

These success stories show significant and sometimes surprising improvements in water-use efficiency, or "more crop per drop", even in cases where only one figure, water saving or crop yield increase for example, is reported. In the latter case the missing data have been taken as zero, which is probably not the case. For Turkey, Egypt and Tunisia, therefore, the values for derived increases in water-use efficiency are probably minimal and additional field measurements would be necessary to arrive at more precise figures.

On the other hand, these results should be considered carefully: in cases where water savings only were reported, it is not obvious that crop production increased, especially when existing over-irrigation was reduced to regular irrigation simply by better management, for example in Turkey. When crop-production increases are reported (except for Jordan), it is not stated whether the initial situation was at regular crop yields or low crop yields. A 10-30 percent increase does not have the same meaning

Table 7: Summary of outputs from the five case studies

Country	Jordan	Morocco	Egypt	Turkey	Tunisia
Location of case study	Jordan Valley	Tadla	Middle Egypt	Antalya	Whole country
Type of irrigation	Drip	Laser-levelled basin irrigation	Modernized lined mesqa	Drip, sprinkler and California system	Drip, sprinkler and modernized surface irrigation
Irrigation management	National irrigation agency (JVA)	Public irrigation agency (ORMVA)	WUAs	WUAs	Public irrigation agency (CRDA) and WUAs
Main success factor	Use of tensiometers with drip irrigation	Shift to modernized basin irrigation	Farmers organized before modernization	Irrigation management transfer to WUAs	Public water-saving programmes and incentives
Main constraints for application of technology	Rigid irrigation supply inappropriate to micro-irrigation	Not applicable on all lands; land consolidation model may be inappropriate	Absence of continuous flow and of night storage at canal level	Ability of WUAs to modernize their systems and improve performance	Incentives and capacity of farmers to adopt water saving measures
Reported water savings	20-50%	20%	-	34%	25%
Reported crop yield increase	15-20% (cucumber, tomato)	30% (cereals)	10% (cereals, cotton)	-	-
Resulting increase of water-use efficiency[2]	44-140%	62%	10%	51%	33%

[1] Unreported water savings or crop yield increases are taken as 0 percent.

[2] Yield per m^3 of water applied.

and does not require the same effort in terms of irrigation management when crop yields are at a regional average or 50 percent below. Increases in water-use efficiencies may therefore hide very different situations, all of which ultimately contribute to water conservation.

From these case studies, several lessons may be learned and several false ideas may be rejected.

Localized irrigation is not a miracle technology

Localized irrigation techniques are not the only ones that save water, though there is widespread opinion to the contrary. Water losses with sprinklers or drip equipment are equivalent to those of surface irrigation when the techniques are not properly applied, for example because farmers are unfamiliar with them or maintenance is inadequate.

Case studies in Jordan showed that inadequate application of drip irrigation leads to failure. They showed, too, that existing drip irrigation can be improved to the point where water consumption decreases by 20 to 50 percent, while cucumber and tomato production increases by 15 to 20 percent, increasing water-use efficiency by 44 percent (cucumber) and 140 percent (tomato).

Surface irrigation can be a water-saving technique

When technologies are mastered, field efficiencies can reach 80 percent, whatever the technique. Examples of such field efficiencies achieved with surface irrigation exist in California (Wilson *et al.*, 1998), Morocco (case study on Tadla) and Egypt (Clemmens *et al.*, 1998) when laser levelling is regularly applied.

The choice of suitable techniques should rely on careful analysis of constraints and cost-benefits. Modern local irrigation is best suited to horticulture products with high added value, while modernized surface irrigation is suitable for large-scale production, with low rehabilitation costs and equipment that uses less energy than sprinklers.

An environment that enables water conservation is necessary

Measures such as irrigation management transfer must also be accounted for. The case studies of Egypt and Turkey showed that irrigation management transfer, involving WUAs and adequate technology transfer, yielded important water savings and improved recovery of operating and maintenance costs, leading to enhanced sustainability. The Egypt case study emphasizes the need to build on existing farmer organizations when modernizing irrigation systems, especially when farmers are reluctant to introduce new technologies. A similar observation was made by Vermillion *et al*. (1999).

The case study of Tunisia displayed another type of enabling environment, with public water-saving programmes and strong incentives for farmers to modernize their irrigation systems. Even greater success could be achieved by enhancing farmer capacity and increasing participation in WUAs.

In the example of Morocco, a local laser-levelling company joined a public irrigation agency to modernize traditional irrigation on a commercial basis. This creates a new dimension in water conservation programmes. The link with agricultural product markets would probably be the best incentive for farmers to invest in modernized, affordable equipment and technologies. As an executive of the Jordanian Ministry of Water and Irrigation put it, the commonly accepted “more crop per drop” is evolving towards “more income per drop”, which can be a strong incentive for water conservation.

Sustainability depends on complementary measures

Analysis of the case studies shows that, even if successful locally, water conservation measures are unlikely to be successful on a larger scale if other conditions are not met.

The advanced canal-regulation techniques adopted in the region should enable water deliveries in response to farmer requirements, essential for the achievement of the highest level of agricultural productivity and for meeting precise crop requirements. A substantial loss in water productivity, however, results from the poor quality of water supply in surface irrigation systems. Unreliable delivery may cause substantially reduced yields. Rigid delivery of water at long intervals, as in Jordan, Egypt and Turkey, or a land consolidation model incompatible with liberal agriculture policies, as in Morocco, preclude the adoption of water-saving application techniques and the change from staple food to high-value, water-sensitive crops. The solution adopted by some Jordanian farmers –

building small reservoirs to circumvent rigid and unreliable water delivery and create flexible water availability at farm level – shows the way. It is not applicable everywhere, however, especially in Egypt, where every single cultivable hectare is cultivated and cannot be converted into a storage basin.

Currently, the move from rotational water allocation to flexible, farmer-oriented irrigation is one of the challenges of irrigation-water management in the region, if water conservation technologies are to be successfully applied. A possible scenario that would support the spread of improved irrigation technologies and management would be for WUAs and private initiatives to take the lead in modernizing distribution systems and implementing an appropriate land consolidation model.

Conclusions

In the Mediterranean region, agriculture is considered to be the sector where the largest volume of water can be saved. It accounts for some 80 percent of total demand and large amounts of water are poorly used. Countries have obviously developed good knowledge at local level of efficient measures and processes to implement reductions in water demand. The idea of the present project is to gather a number of success stories and disseminate this Mediterranean experience to other parts of the world.

The activity described here focused particularly on approaches, effects and constraints and the opportunity to include water conservation in water strategies. Case studies on water-conservation initiatives carried out in five countries of the region were documented and analysed. The studies in Jordan and Morocco refer to isolated physical changes: adoption of drip irrigation with tensiometric scheduling and creation of laser-levelled basins. The Egypt study relates to an initiative that recognizes the relationship between improvements in delivery systems and farm systems. The fourth case discusses institutional reform in Turkey: transfer of management to WUAs. The last case discusses the comprehensive water reform programme in Tunisia.

These success stories were analysed in terms of their main successes, limiting factors, reported water savings and crop-yield increases and increases in water-use efficiency:

- The Jordan case study concerned farms in the Jordan valley using drip irrigation. It showed that the use of tensiometers with drip irrigation saved 20-50 percent of water, increasing cucumber and tomato crop yields by 15-20 percent and bringing about an increase of water-use efficiency of 44-140 percent. The existing rigid irrigation supply, however, does not allow the spread of these techniques, unless farmers build their own reservoirs.
- In Morocco, the case study was located in the Tadla region. ORMVA, in partnership with private companies, promoted laser-levelled basin irrigation, resulting in water savings of 20 percent, cereal crop-yield increases of 30 percent and an increase of water-use efficiency of 62 percent. This technique is not applicable on all land types and the present land consolidation model may be inappropriate for improved water application and distribution.
- In middle Egypt, the case study of Beni Ibeid command area showed that both modernized lined tertiary canals, or “mesqa”, and management transfer to WUAs have been successful, mainly because farmers were informally organized before modernization. Cotton and cereal crop-yield increases of 10 percent were reported, resulting in an estimated improvement in water-use efficiency of 10 percent. Improvement of the main system to resolve the issue of night storage is more complex than expected, however.
- In the Antalya region of Turkey, a case study was conducted on a modernized system recently transferred to WUAs that uses drip, sprinkler and California systems. This combined system enabled water savings of 34 percent, resulting in an estimated improvement in water-use efficiency of 51 percent. Further progress might be limited by the ability of numerous WUAs to modernize their system and improve performance.
- In Tunisia**,** CRDAs and WUAs are managing drip, sprinkler and modernized surface irrigation. Public water-saving programmes and incentives resulted in estimated water savings of 25 percent and an improvement in water-use efficiency of 33 percent. Enhancement of farmers’ ability to implement water-saving techniques and stronger financial incentives through water pricing should improve the results.

Lessons learned from these success stories can be summarized as follows:

- Localized irrigation is not a miracle technology. Excellent as well as poor results were obtained from these technologies. Whether or not they will be adopted depends on the capacity of farmers to finance and operate them and on the type of crop production.
- Modernized surface irrigation can be a water-saving technique comparable to the more costly

drip or sprinkler irrigation. It is more easily adopted by farmers because it is closer to traditional practices.

- An environment that enables water conservation – public incentives, irrigation management transfer to users and involvement of the private sector to relate product marketing to water savings – is necessary for the achievement of water savings and improvements in water-use efficiency.
- Sustainability of water management depends on complementary measures. Substantial losses in water productivity result from poor water supply in surface irrigation systems. Inflexible delivery of water at long intervals, as in Jordan, Egypt and Turkey, or a land consolidation model incompatible with liberal agriculture policies, as in Morocco, precludes adoption of water-saving application techniques and moves from staple-food crops to high-value, water-sensitive crops.

A possible scenario that would support the spread of improved irrigation technologies and management would be for WUAs and private initiatives to take the lead in modernizing distribution systems and implementing appropriate land-consolidation models.

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Annex 1
Jordan case study: irrigation optimization in the Jordan Valley

Jordan is a country of scarce water resources. The two main irrigation water sources for the intensive farming in the Jordan valley are the Yarmouk river and the King Talal Reservoir. In addition, Jordan is characterized by semi-arid conditions with varied amounts and distribution of rainfall. Rainfall ranges between 50 mm in the desert region to about 600 mm in the eastern mountains adjacent to the Jordan valley. Total rainfall in Jordan is estimated at 8.5 billion m^3, of which about 85 percent is lost to evaporation; the remainder flows into wadis and partially infiltrates into deep aquifers. The population of Jordan was 4.6 million in 1999, with an average growth rate of 3.6 percent. About 78 percent of the population are located in urban areas concentrated in four governorates: Amman, Irbid, Zarqa and Balqa.

Agriculture in Jordan uses more of the available water resources than the industrial and private sectors. It consumes 70-75 percent of the available water resources in the country. The total irrigated area in the Jordan valley covers approximately 30 000 ha. Even small savings over this vast area are thus of great value and can be diverted into domestic or agricultural use by expanding the irrigated area. Appreciation of the value of saving irrigation water and using it efficiently motivated the government, through the JVA, to convert open-channel distribution networks to pressurized pipe systems. This conversion prompted farmers to change to technologically advanced drip and microspray irrigation systems rather than retain traditional surface irrigation and flood methods. The JVA did not, however, change the rigidly scheduled rotation method to a flexible schedule of on-demand supply. The rigid schedule allocates water two or three times a week for a certain number of hours; farmers are obliged to receive the entire supply during the delivery time. This will ultimately increase water losses through evaporation and deep percolation, which results in loss of most of the fertilizers. Flexible scheduling, on the other hand, would satisfy the needs of advanced drip and microspray systems and keep water available for farmers even during high-frequency periods and daily during peak times. Consequently, the farmers are still not benefiting from these changes to achieve the expected savings from the technologically advanced pressurized irrigation method.

The improvements and activities carried out at off-farm level (from the water source to the farm gate) allowed both JVA and the French Embassy in Amman to implement a pilot program for achieving the desired water savings and to get benefit from all changes in the water-delivery pattern. In the pilot farms, water will be scheduled based on frequent tensiometric sensor readings.

The need for a stronger water demand management strategy emerges from the crucial need to reduce or stop over-irrigation although many on-farm systems are pressurized and application efficiencies are higher.

Conservation of irrigation water means that wastage of water is minimized and beneficial use of water is maximized.

Hence, in order to increase the efficiency of using irrigation water and decrease losses at farm level, farmers must be involved in making decisions regarding water delivery and use. To enable efficient use of irrigation water, the JVA must deliver required quantities of water to farmers on demand. Thefts of irrigation water result from perceived shortages in water deliveries and inappropriate delivery schedules. To eliminate these problems, attempts were made to implement irrigation water delivery by prearranged demand, with pilot programmes in the northern and central directorates. These pilot programmes were intended to give the JVA an understanding of how to meet farmers' requirements and offer information to assist expansion of the programme throughout the Jordan valley.

This report presents two cases related to water conservation. They were set up as pilot programmes so that lessons learned can be used by Jordan valley farmers, who can gain benefit and experience from these models and be encouraged to adopt the water saving technologies.

THE PILOT PROGRAMMES

Goals and objectives

The aim of the pilot programmes is to help the JVA and farmers in experimental farms to collaborate on water saving by using tensiometers. To achieve this, farmers in the target area should be informed of this programme and its benefits through seminars, demonstrations and training of farmers in irrigation management. This will require changing the current water-delivery rotation to an on-demand system in order to increase irrigation efficiency and achieve water savings.

The objective to be achieved is savings, compared to traditional irrigation methods, in the cost of irrigation water used related to production quantity and quality.

JD/m³ or kg/m³

THE COMPONENTS OF THE PILOT PROGRAMME

Experiments

Field experimentation involves supplying the pilot area with tensiometers or watermarks and changing the water-delivery pattern to a flexible system. For purposes of diversification of the experiments, other elements should be included, such as study of the design and maintenance of irrigation networks.

The aim is ultimately to achieve sustainability of the system. Overall responsibilities must lie with the Irrigation Advisory Services (IAS) which can transfer the concepts and results of these programmes to other areas in Jordan.

Training

The JVA has recently created an IAS to be responsible for irrigation extension throughout the Jordan valley. Training the staff of this unit is of fundamental importance, because they will bear responsibility for implementing similar studies, collecting and processing data and disseminating it to those concerned in their area. The staff is responsible for training farmers to be trainers in their turn, and for giving guidance on the implementation of what they have learned on their own farms.

The importance of such pilot programmes is evident from the fact that a number of farmers still practise surface or flood irrigation, some of them in the pilot area. The programme thus constitutes a good example from which thay can learn these ideas and implement them. The pilot network should be equipped to handle the new pattern of water delivery and raise irrigation efficiency.

THE CASE STUDIES

Adasiyeh – pilot network and site

The pilot area is in Adasiyeh (northern JVA). The pilot network is composed of 131 farms constituting a total area of 4 000 donum[1]. The JVA has implemented the change in the delivery system from open channels to pressurized pipes and most of the farmers have adopted the high-technology drip system. The JVA should, in addition, implement a flexible delivery pattern. To this end, the JVA should train the staff in charge of managing the hydraulic equipment.

One farmer was chosen, because of his technical skills, to implement the tensiometric scheduling associated with micro-irrigation, but unfortunately the results were disappointing. Although this first case study cannot be counted a success, useful lessons may be learned.

The reasons for failure may be found in the age of the citrus trees, which are over 40 years old. At that age, they have huge root systems distributed vertically and horizontally that overlap in the ground between the trees. Hitherto, irrigation has always been the flood or basin system. Micro-irrigation was implemented in the pilot study, watering a certain area using tensiometers and watermarks. This ultimately affected the trees, since part of the root zone receives a smaller quantity of water because of pressure loss in the pipe network. The net result was that the trees suffered a shortage of water and the farmer stopped scheduling water based on tensiometers and watermarks, returning to traditional methods of applying water in order to save his farm. Full preparation of the system is required in order to follow this programme and get results.

[1]One donum = 0.1 ha

Abu-Ghannam and Al Barghouthi

The following experiment was carried out on tomatoes and cucumber at Abu-Ghannam and Al Barghouthi farms in 1996-97. The objective of this experiment was to show that tensiometric irrigation scheduling, in this case only applied on Abu-Ghannam farm, is suitable for intensive crop production systems of the Jordan valley and that it achieves remarkable water savings and improves crop quality and yield.

Description of the two farms

Well-educated Jordanian farmers own the farms, which are classified as large-scale farming activities. The fact that the farms are real, not experimental, is noteworthy.

Abu-Ghannam

The area of the farm is 60 donum, including 40 donum of greenhouses comprising 51 greenhouses of 540 m^2 and 11 multispans of 1 053 m^2. Water is delivered four times a week – two deliveries of 260 m^3 and two of 520 m^3 a weekly water allocation of 1 560 m^3. A 9 litres/sec flow regulator is used. The capacity of the farm pool is 1 000 m^3. The farmer puts the water directly into the pool for use in cases of emergency. The pool is used as a settling basin to clear the water of suspended solids and debris before it is used in the drip system. Fertigation is carried out at each irrigation. The system is operated by the farm manager or a trained labourer opening and closing the valves. The planting date for tomatoes was 23-25 October 1996 and for cucumbers 24-27 November 1996. Weekly water allocation allowed for 5.7 mm per day. The first irrigation of the tomatoes was on 1 December 1996 and for cucumbers 10 December 1996. This farm was the one monitored with tensiometers.

Al Barghouthi

The farm is composed of 64 greenhouses of 540 m^2 each over an area of 31 donum. Thirty-two of them were planted with cucumbers, 19 with tomatoes, 7 with eggplant and 6 with peas. Irrigation scheduling on this farm followed traditional patterns. The dripper discharge was 4 litres/sec. This farm was chosen as the reference without tensiometers.

Experimentation

The tensiomers on Abu-Ghannam were placed at representative points between the plants and the drippers. Decisions as to whether to irrigate or not were based on the tensiometer readings.

Five watermark sensors were used in each of the tomato greenhouses and the cucumber greenhouses. Sensors were installed 30 cm below the ridge of the trapezoidal bed, which was 15-20 cm high, in order to monitor the water situation in the wetted areas. Readings were taken every two days. Tension readings taken before irrigation would never exceed 30 cbar. As crops develop, the water requirement normally increases.

Results analysis for tomatoes

Irrigation

At Abu-Ghannam, irrigation was 50 percent less than that applied at Al Barghouthi (see Figure 1.1). Irrigation frequency was lower – 28 irrigations instead of 38 during the case study period – and the daily amount was smaller – 4-6 mm instead of 6-12 mm. Agronomic results show that good production levels can be reached while achieving remarkable water savings.

Fertilization

Application of fertilizer was excessive on both farms (see Table 1.1). This is evident at Abu-Ghannam farm, where nitrogen (N) application was 356 kg/ha/year and phosphorus (P) application amounted to 340 kg/ha/year. Applications of potassium (K) ran at 550 units/ha/year at Abu-Ghannam and 722 kg/ha/year at Al Barghouthi.

Table 1.1: Amount of NPK fertilizer used on tomatoes at Abu-Ghannam and Al Barghouthi

Quantity for 1 000 m^2	N	P	K
Abu-Ghannam	35.6	34.0	55.0
Al Barghouthi	25.7	18.0	72.2

Almost 50 percent of these quantities of mineral fertilizer are lost during the annual leaching, which also leaches the products of mineralization of manure.

Figure 1.1: Comparison of curves of cumulated irrigation for tomatoes Al Barghouthi and Abu-Ghannam for 01/01 to 30/04/97

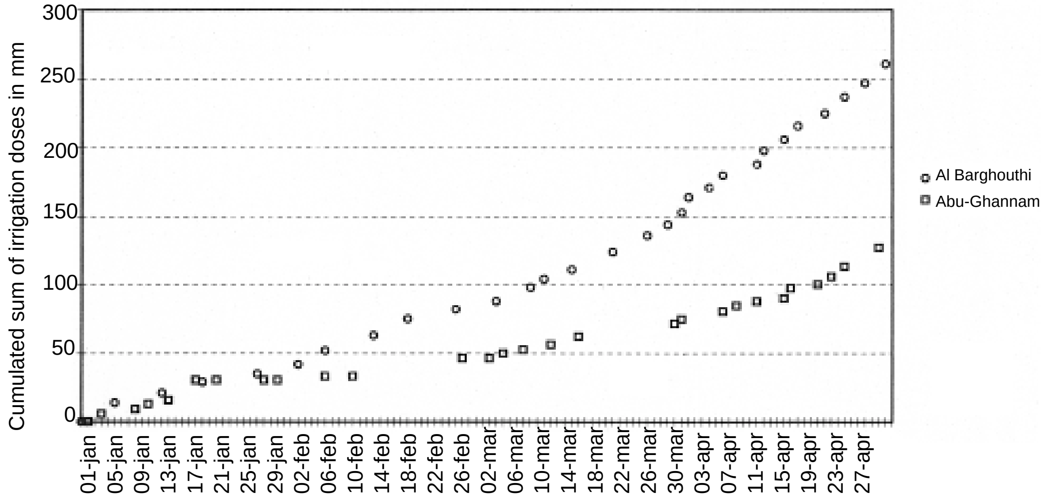


Figure 1.2: Tomatoes: irrigation in mm and production in tonnes/ha at Al Barghouthi and Abu-Ghannam

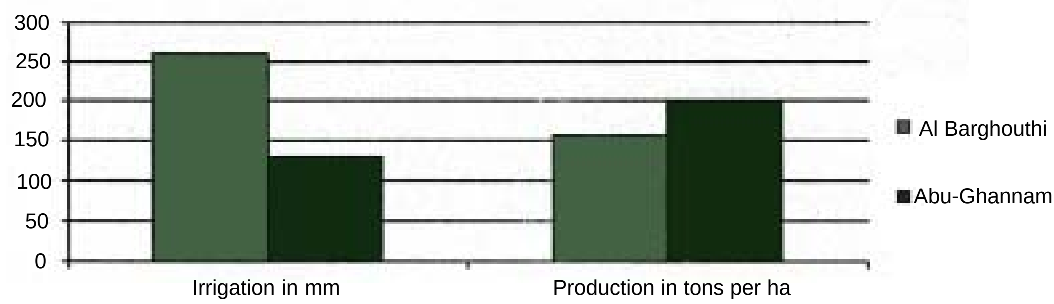


Figure 1.3: Comparison of curves of cumulated irrigation for cucumber Al Barghouthi and Abu-Ghannam for 01/01 to 30/04/97

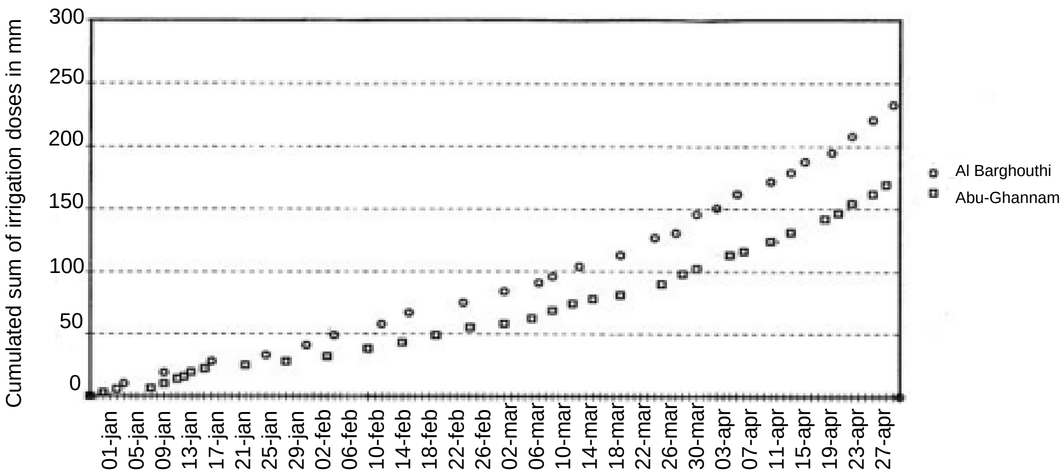
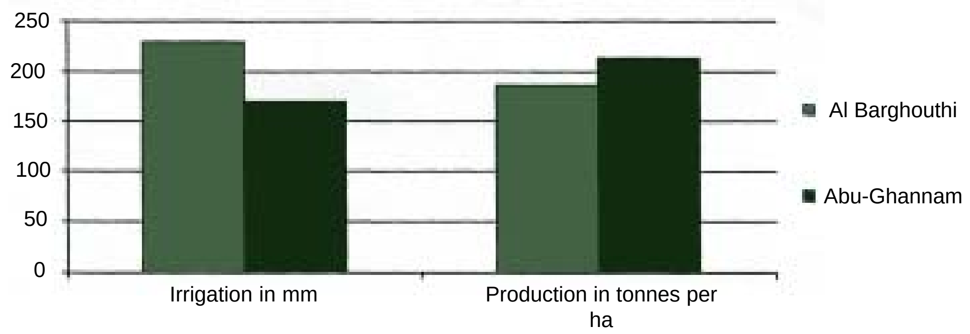


Figure 1.4: Cucumber: irrigation in mm and production in tons/ha at Al Barghouthi and Abu-Ghannam



Production

Tomato production in Abu-Ghannam farm was 3.2 kg/m², approximately 20 percent more than Al Bargouthi (see Figure 1.2).

Results analysis for cucumber

Irrigation

Figure 1.3 shows that total water application at Al Barghouthi exceeds that at Abu-Ghannam by 20 percent.

Fertilization

Both farms use excessive quantities of fertilizers (see Table 1.2). Most of it is lost through leaching.

Table 1.2: Amount of NPK fertilizer used for cucumber at Abu-Ghannam and Al Barghouthi

Quantity for 1 000 m²	N	P	K
Abu-Ghannam	36.4	20.2	20.6
Al Barghouthi	34	22.1	23.1

Production

Cucumber production on Abu-Ghannam farm was 21.3 kg/ m²; Al Barghouthi farm produced 18.7 kg/ m², 15 percent more than Abu-Ghannam (see Figure 1.4).

Conclusion

Irrigation water consumption decreased at Abu-Ghannam by 20 percent for cucumbers and 50 percent for tomatoes. At the same time, production rose by almost 15 percent for cucumbers and 20.5 percent for tomatoes.

Table 1.3 shows the efficiency of water use per crop on each farm.

Table 1.3: Water use efficiencies for tomato and cucumber at Abu-Ghannam and Al Barghouthi

Water use efficiency (kg/m³)	Tomato	Cucumber
Abu-Ghannam (tensiometers)	148.0	125.3
Al Barghouthi (no tensiometers)	67.4	83.0

Annex 2
Morocco case study: improvement of on-farm irrigation by laser levelling and basin irrigation in Tadla[1]

Water in Morocco is, more than in many other countries, an essential and ever scarcer resource that must be carefully managed. Development of irrigated areas is currently following a new approach. The evolution of the irrigated agriculture sector towards more productive, competitive and environmentally friendly methods is part of the national strategy for water resources development in Morocco.

In this perspective, the Ministry of Agriculture and USAID have undertaken a project entitled Management of Resources in Tadla. The project is implemented by the American company Chemonics International and the Office Régional de Mise en Valeur Agricole du Tadla (the Regional office for the agricultural development of Tadla). The global budget of this 5-year project (1993-99) was about US$14 million, of which 75 percent was USAID support.

The goal of MRT was to foster the longterm competitiveness of irrigated agriculture in Morocco and to protect the quality of its environment through more efficient management and use of water resources. The irrigation scheme at Tadla was selected as a pilot area. The objectives of the project were:

- water savings through improvement of irrigation system management and on-farm water application;
- reduction of pollution through rationalized management of fertilizers and pesticides;
- active involvement of water users through user associations;
- further extension of technologies applied at Tadla to other ORMVAs.

To achieve the first objective, MRT set up a management information system including a package of technologies and tools for irrigation water management. The case study is limited to on-farm water application.

The Tadla irrigation scheme

Main features

The Tadla scheme covers a crop area of about 300 000 ha, of which 117 500 ha are irrigated and classified as follows:

- large scale irrigation: 97 700 ha;
- small scale irrigation: 5 000 ha;
- pumped irrigation: 12 000 ha;
- pivot irrigation: 2 800 ha.

The rest of the area is rainfed agriculture (137 500 ha), forest (17 000 ha) and rangeland (28 000 ha).

Water resources

The Tadla plain is crossed by Oued Oum Er-R'bia, one of the most important rivers of the country, which splits the plain into two hydraulically independent regions: Beni Moussa on the left bank and Beni Amir on the right. The average annual flow of Oum Er-R'bia is 37.4 m^3/sec, with a maximum of 1 700 m^3/sec and a minimum of 7.6 m^3/sec. Its most important tributary is Oued El Abid, with an average annual flow of 32 m^3/sec, with a maximum of 77 m^3/sec and a minimum of 10 m^3/sec.

The Beni Amir sub-scheme is irrigated by water tapped directly from Oum Er-R'bia through a facility built at Kasba Tadla in 1929. The Beni Moussa sub-scheme is irrigated from the large storage dam at Bin El Ouidane, on the Oued El Abid, which has a capacity of 1 500 million m^3 and a usable storage capacity of 1 100 million m^3.

Groundwater resources consist of two aquifers: the watertable and a turonian deeper aquifer. Available volume is 440 million m^3; the volume used is 132 million m^3.

[1] Boubker Essafi, Director, International Irrigation Centre, Rabat

Climate

The climate is arid to semi-arid, with a dry season from April to October and a wet season from November to March. Mean annual rainfall is 350 mm. Mean annual temperature is 17°C, with an average maximum of 39°C in August and an average minimum of 3.5°C in January.

Improvement of on-farm irrigation by laser-levelling and basin irrigation

Moving from robta irrigation to laser-levelled basin irrigation

In the Tadla region of Morocco, robta irrigation is used on 97 percent of the irrigated surface. This ancient technique consists of making by hand in each irrigated field small basins of several m^2, which are filled with water by gravity one after the other. It is still in use because field levelling has been degraded by inappropriate soil practices such as use of disk ploughs and lack of maintenance of levelling. Compared with design criteria of the irrigation scheme, this results in:

- low efficiency: 50 percent instead of the 70 percent envisaged in the system design;
- longer irrigation times: 12-15 hours instead of the 8 initially planned;
- land loss of 10 percent resulting from the large number of small channels and basin borders that prevent mechanization;
- low crop yields resulting from irregular irrigation.

Laser-levelled basin irrigation has therefore been introduced to several farmers to overcome these difficulties for field and row crops. Basins are laser levelled so that terrain slope is zero and full water allocations can be delivered to farms.

Associated cropping techniques and irrigation practices

Once fields have been laser levelled in the first year and prepared, suitable soil practices such as ploughing and cover cropping must be maintained, with surfacing, or rough levelling, every four years. Irrigation is from the seguia, or field canal, fed from the quaternary canal. Each basin is irrigated individually, using the entire farm water allocation, through a breach made in the seguia, irrigation being stopped when 90 percent of the field surface is flooded. This technique, which minimizes levelling costs, is most suitable for flat terrain, thick low-infiltration soils and low-rainfall areas. Smaller basins should be designed for row crops to reduce erosion.

Results and discussion

Demonstrations on some farms showed:

- 20 percent water savings;
- 30 percent crop-yield increases;
- 90 percent uniformity of water distribution;
- 10 percent savings on inputs;
- 50 percent savings on manpower costs;
- reduced environmental impact resulting from decreased fertilizer losses.

The success of basin irrigation depends, of course, on the technology adopted and farmers' understanding. Once designed, the system allows more uniform water application, resulting in higher crop production per m^3. Another advantage is that rainfall is more efficiently captured by the basin and there is no erosion by rain. Finally, the manpower required for field irrigation is less than for traditional irrigation.

Conclusions and perspectives

Adoption of laser-levelled basin irrigation is continuing in the Tadla irrigation system with some success as well as real improvements in irrigation outputs. It is noticeable that this improved irrigation technology uses the same principle as traditional robta irrigation: basins are simply larger, flatter and better prepared, allowing mechanized cropping and using less manpower. This largely explains the success of this new technology, since it modernizes a traditional technique rather than changing to a completely different method.

In response to increased demand among farmers the Tadla ORMVA has encouraged the creation of two private companies owned by ex-ORMVA technicians, providing them with laser-levelling equipment and a contract for laser levelling 1 200 ha/year. This programme should result in overall water savings of 3 million m^3 in the first year.

Annex 3
Egypt case study: improvement of surface irrigation systems in the Nile valley

Irrigation in Egypt

Egypt's existence depends on the river Nile, the largest renewable source of fresh water in northern Africa. It is virtually the only source of water for agriculture, industrial and domestic use in this extremely arid country and is a major fishery along its entire length. The agricultural sector is the largest water consumer, using about 85 percent of Egypt's surface water resources at present. A network of about 30 000 km of irrigation canals and 17 500 km of drainage channels serves the estimated 7.4 million feddans[1] of irrigated land in Egypt, which constitute only 3 percent of the total land area.

Until recent times, agricultural production in Egypt was sustained by the annual flooding of the Nile. Construction of the Aswan High Dam, however, allowed perennial watering of crops and intensification of agriculture along the Nile valley and across the delta. The need for drainage soon became evident with rising watertables and increased soil salinity. Surface drainage by open main and branch drains has been under construction since the early 1900s, with investigations into covered drains starting in the 1930s. In 1965, a programme was launched to provide 5 million feddans with tile drains and by 1984, 2.2 million feddans were completed. The current coverage is about 1.76 million ha, or 4.35 million feddans.

The delta is known for intensive agriculture and livestock production, with fish production in some areas. Farmers generally practise mixed farming. There are about 6 million herds of large cattle, including buffalo, for meat and milk and about 2 million herds of sheep, goats and poultry. All crop production is irrigated, with a cropping intensity of about 220 percent and good yields. Major crops are maize, cotton and rice in the summer, with wheat, berseem, vegetables and beans in the winter. Rice is grown along with dry food crops mainly in the northern part. Average yields are:

- wheat: 3 tons/feddan;
- seed cotton: 1.5 tons/feddan;
- rice: 3.5 tons/feddan;
- maize: 4.5 tons/feddan.

Developing industry, expanding agricultural land and the growing population in Egypt is placing stress on the fixed Nile water supply of 55.5 billion m^3/year. Annual demand for water is estimated to reach 61.5 billion m^3 by 2025. To alleviate pressure on Nile water and on old agricultural land, the Government initiated various strategic programmes, including construction of new settlements and reclamation of desert land. The government plans to reclaim an additional 3.4 million feddans from 1997 to 2017.

The Government of Egypt has embarked on an ambitious horizontal expansion programme to increase the total irrigated land area dependent on the fixed water allocation of 55.5 billion m^3/year. Major projects are:

- The Toshka project, designed to develop 540 000 feddans of desert land in Upper Egypt for agricultural production in the next 10-20 years, taking up to 5 billion m^3/yr from Lake Nasser.
- The Salam Canal project, designed to divert 2 billion m^3/yr of drain water from the Bahr Hadus and Lower Serw drain basins in the eastern delta for 220 000 feddans of irrigated land in west Suez and 400 000 feddans of reclaimed land in Sinai. Irrigation has started in west Suez and reclamation will commence shortly in Sinai.
- The Umoum drain project, which will reuse 1 billion m^3/year of drain water from Umoum drain basin in the western Nile delta for 500 000 feddans of irrigation in Nubaria. Building is in progress.
- The Kalapsho project, designed to capture 1 billion m^3/year of drain water from the middle delta for 55 000 feddans of new land in Kalapsho.

These projects will have major impacts on the water balance of the Nile delta. Water savings are imperative. Major strategies adopted within the

[1]One feddan: approximately one acre = 0.42 ha

country include maximizing drainwater reuse and improving irrigation management in the delta.

Egypt, with a freshwater supply that will probably remain constant at 55.5 billion m^3/year faces a double challenge. It has to provide sufficient water to new reclaimed areas according to the horizontal expansion programme and increase crop production with a limited or possibly decreasing water supply in all existing irrigated areas and new lands. This latter challenge is also called vertical expansion. The IIP was designed for these purposes. After several years, the IIP should have been implemented on 250 000 feddans, but it has reached only 70 000 feddans.

The present case study describes the impact of IIP on Beni Ibeid canal command, near the city of Minya in Middle Egypt. It is based on three references: Hvidt (1997), Zaki and El-Quosy (1997) and Abou El Fatoh and Ali (1998).

The IIP

Initiated by the Egyptian Goverment and USAID, the IIP is a US$90 million project which is seen as a first step towards bringing the Egyptian irrigation system into line with the demand it will be facing by the turn of the 21st century. The IIP is introducing a broad range of improvements through institutional changes and physical improvements at macro-system and micro-system levels.

Physical improvements are:

- introduction of continuous flow, with improved canal-control structures such as automatic downstream level-control gates and renovation of delivery systems;
- introduction of single-point lifting pumps with raised, lined mesqas, or tertiary canals, or low pressure pipelines;
- construction of drainage reuse pumping stations.

Institutional changes included a demonstration programme to introduce improved on-farm irrigation techniques such as land levelling and soil improvement and to establish IASs and WUAs at mesqa and branch canal level. This latter fundamental change, introduced by the IIP, consists of delegating all decisions concerning water usage and cropping patterns to farmers through WUAs. This is in sharp contrast to the rigid state control over both factors operated prior to the IIP project. The IIP is a state-of-the-art project, especially in that it involves farmers, through WUAs, in the design, implementation and maintenance of hydraulic structures and gives responsibility for water allocation and distribution to the WUAs themselves. More specifically, the WUAs are responsible for operating and maintaining the improved mesqas, operating the single-point lift pumping plant, scheduling irrigations among water users, collecting of pumping charges, hiring pump operators, maintaining the mesqa and pumps and handling conflict among users.

Impact of IIP on Beni Ibeid command area

The Beni Ibeid command area

Beni Ibeid command area lies in one of the broader parts of the Nile valley in Upper Egypt. It is located in El Minia governorate 20 km south of El Minia on the west bank of the Nile. El Minia governorate is 250 km south of Cairo. The main water sources are fresh water from the Beni Ibeid canal, fed from the Serry canal, drainwater reuse and 20 private tubewells. The command area is 5 027 feddans, of which 4 455 feddans are cultivated.

Before IIP, the Beni Ibeid canal was operated on a rotation system in which irrigation water was delivered on a 5-days-on/10-days-off basis. Water levels in the main canals were regulated by a head gate and two intermediate sliding gates. All gates were manually operated upstream control gates.

Methodology

The results presented in this case study are based on:

- the impact of physical improvements at system level, reported by Zaki and El-Quosy (1997), based on measurements of water levels at key points along the main canal;
- the impact of institutional changes and physical improvements at mesqa level, evaluated through structured interviews undertaken by local interviewers.

A first survey was conducted in 1992 with around 40 WUA council members, by Hvidt (1997). This focused on water control and farm income. A second survey was conducted in 1997 with 60 farmers by Abou El Fatoh and Ali (1998), based on alternating from a rigid rotation system to a continuous flow system, replacing conventional sliding manually operated gates with modern automatic gates, replacing earth mesqas with elevated lined channels or buried low pressure pipelines and substituting of multi-point lifting on the mesqas by one-point lifting.

Results and discussion

Physical improvements at main canal level

The major improvement at main canal level consisted of remodelling the Beni Ibeid canal and its control structures. Three automatic downstream control gates were installed, in theory enabling the move from rotational to continuous flow irrigation, delivering water on a 24-hour basis to WUAs. Under this downstream control, each section of the main canal has at its head a constant downstream level regulator which automatically maintains the water at a fixed level. The maximum design water level is set to allow night storage of excess inflow, since mesqas are designed to deliver peak water supply in the 16 daytime hours. The performance of this control system was assessed by monitoring water levels during the 1996 irrigation season (Zaki and El-Quosy, 1997).

During the September to December period of low water requirements, water levels in the Serry canal which is upstream of the head control gate of the Beni Ibeid, were below the lower limit of the control volume. These low water levels in the Serry canal caused inadequate flows to Beni Ibeid command area, leading to a deficit that primarily affected the outlets furthest upstream.

During the March to April period of seed preparation, district engineers closed the sluice gate at the head of the canal, in case the canal should take more than its share. The Beni Ibeid canal was thus supplied with discharges accompanied with high velocities, or supercritical flows, that can cause damage to the lining.

Outside these periods, it was observed that the improved system functioned better than the traditional upstream control system. Of the farmers sampled, 85 percent prefer the modern automatic gates (Abou El Fatoh and Ali, 1998). This is mainly because of reduced tail-end losses to drains resulting from night water storage in the main canal. The main beneficiaries of this improvement are of course the water users located at the tail reach of the command area.

It should also be noted (Abou El Fatoh and Ali, 1998) that in Beni Ibeid command area, as opposed to other command areas modernized under the IIP, interference by farmers with automatic downstream control gates, such as upstream farmers closing gates manually with heavy objects, was hardly observed because WUAs organized themselves to protect automatic gates with effective fences.

Improvement of water control at mesqa level

The main results are shown in Table 3.1. Results from Abou El Fatoh and Ali (1998) are usually expressed as the percentage of farmers interviewed before and after IIP; those from Hvidt (1997) are given as the percentage of farmers who observed a change or improvement.

Table 3.1: Summary of impacts of IIP on water control at mesqa level

Indicators analysed	Before IIP	After IIP
Adequacy		
Adequacy of water supply	33%	82%
No. of days with critical water shortage	Not measured	Reduced according to 87% of interviewed farmers
Night irrigation	62%	6%
Source of irrigation water		Use of drainage water decreased
Reliability		
Reliability of water supply	95%	100%
Deviations from planned irrigations		Improved for 86% of farmers
Fairness		
Head-tail differences along mesqas		Decreased
Farmers participation		
Use of private or rent pumps	100%	20%
Use of IIP (WUA) pumps	0%	80%

The existence of continuous flow was the most important factor in securing water control, in terms of adequacy and reliability of supply. The observed decrease in irrigation time results from land levelling and application of continuous flow from an IIP single-point lifting pump operated by the WUA.

As regards organization, the strength of WUAs showed in farmer water control, particularly in the shift from privately operated to WUA-operated pumps, whose benefits reported by farmers are:

- saving time and effort involved in moving the pump from village to mesqa and back;
- reducing irrigation time by using high-capacity WUA pumps;
- saving pump rental costs, especially for small farmers who did not own their own pump before IIP.

Abou El Fatoh and Ali reported that farmers saw cooperation during irrigation time as an advantage brought by raised lined mesqas – 56 percent – and pipeline mesqas – 81 percent.

Finally, the estimated increase in yields was found to be closely associated with the adequacy of water supply.

Farm income

All these improvements observed in water control and farmer organization should have an impact on farm income. They were analysed by Hvidt (1997), whose main results are shown in Table 3.2.

Table 3.2: Summary of impacts of IIP on farm income (from Hvidt, 1997)

Type of changes	Percentage change[1]	In monetary values
Changes in recurrent costs		
Pumping	36% decrease	£E23.5→15[2]/ha per irrigatic
Labour time	50% decrease	6h 30min→3h 10 min per irrigation
Cost of labour time	50% decrease	£E150→75/ha per year
Maintenance costs		
Pumps	29% decrease	£E1.92→1.37/ha per year
Mesqas	41% decrease	£E55→32/ha per year
Changes in capital costs		
Pumps	73% decrease	£E452 000→120 000
Mesqas	Increased (no pre-project figure available)	£E65 per year (post project
Changes in income from increased yields	Increased (no pre-project figure available)	£E1 100/ha per year (post project)

[1] in percent of surveyed farmers

[2] £E1 (Egyptian pound) = US$ 0.29

These results show sizeable reductions in irrigation costs: pumping costs, irrigation times and the cost of mesqa cleaning decreased. Old pumps were sold, which provided cash income. Globally, recurrent costs decreased by around 50 percent and capital costs by around 75 percent.

In hand with this, farm income improved: one farmer estimated an increase of 13 per cent in yields following IIP improvement and a move to new crops was expected by 35 percent of the farmers.

Conclusions

Compared to other command areas where IIP has been implemented, Beni Ibeid command area is a success story. The IIP has been very well accepted and adopted by most farmers, who have observed positive impacts on their day-to-day operation and farm income. One significant though unmeasured factor in Beni Ibeid was the existing farmer organization before IIP implementation, which helped considerably in the move from traditional to WUA organization. This supports the idea that farmer participation and involvement are fundamental to any technical improvements to irrigation at system or farm level.

At main canal level, system performance has been improved except in periods where the link with the upstream main branch canal was adversely affected by inappropriate operation. This supports the idea that improvement programmes such as IIP should not be limited to isolated command areas but should be conducted on an integrated basis from main branch canals serving 10 000 ha or more down to mesqa level.

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Annex 4
Turkey case study: water savings in relation to participatory irrigation management[1]

Study area

National setting

The study area is the agricultural land all over the country where irrigation management is being carried out either by government agencies or WUAs.

The Republic of Turkey lies between 26° and 45° east longitude and 36° and 42° north latitude. It is bordered on three sides by the Mediterranean, Aegean Sea and Black Sea. Turkey's total land area is 780 600 km², of which 23 600 km² lie in Europe and 757 000 km² in Asia. The 1997 national census showed a population of 62.6 million, with an average annual growth rate of 1.8 percent; 55 percent of the population live in urban areas. Gross National Product (GNP) per capita for 1997 was US$2 500. The largest industrial and commercial centre in Turkey is the province of Istanbul and its surroundings, where 40 percent of the industries are located.

Climate

The climate of Turkey is semi-arid, with extremes in temperatures. Average annual temperatures range from 14°C to 20°C, depending on distance from the sea. There are significant temperature disparities between the inland and coastal regions. The difference in temperature between winter and summer varies from 16°C to 29°C, and is highest in the eastern part of the country. It varies between 18°C and 20°C in coastal areas.

A Mediterranean climate prevails in Turkey's Mediterranean region and western Anatolia; in the north the climate is temperate, with high precipitation in every season; inland regions have a continental climate.

Water resources

Most precipitation occurs in the winter months. Total annual rainfall is least, at 220 mm, in the low lying areas of eastern Anatolia and highest, at 2 420 mm, along the eastern Black Sea coast. Average annual rainfall for the whole country is 670 mm, with a water potential of 510 billion m^3 /year. Surface drainage accounts for 214 mm of total precipitation, or 186 billion m^3 /year, giving Turkey an average drainage coefficient of 36 percent. Evaporation, transpiration and seepage account for 352 billion m^3/year, equivalent to 69 percent of the total potential.

In some watersheds, an estimated 86 billion m^3 out of the average 166 billion m^3 cannot be used efficiently because of unsuitable topography and geology.

The existing national water potential is adequate for the distant future, provided it is supplied when and where required according to the purposes for which it will be used.

Land resources

Approximately one third of Turkey's land surface, some 28 million ha, is cultivable, of which 8.5 million ha are economically irrigable using available technology and conventional methods. This figure may be reduced because of the decrease in water availability and economic viability. So far, irrigation infrastructures serving 4.1 million ha have been developed, mainly in the public sector by the Devlet Su Isleri (DSI), or state hydraulic works, and the General Directorate of Rural Services (GDRS), with some development in private irrigation schemes.

Institutional structures in agriculture

The two government agencies responsible for water and soil resources development and management in Turkey are the DSI and the GDRS.

[1]Selmin Burak, University of Istanbul (with support of Faruk Cenap Erdogan, DSI Operation and Maintenance Department, Ankara)

DSI

The DSI, established in 1954 under the Ministry of Energy and Natural Resources (MENR), is the main investment agency responsible for planning, development and management of water and soil resources. It is therefore responsible for water supply and irrigation for large schemes, including construction of dams for flood control, irrigation, power generation, water supply and groundwater development. The DSI, based in Ankara, operates through regional directorates in 26 river basins. There are 56 sub-directorates and 14 project directorates that carry out O&M activities in irrigation through their field units.

GDRS

The GDRS was established in 1985 by the reorganization of the General Directorate of Soil and Water, the General Directorate of Roads, Water and Electricity and the General Directorate of Soil and Resettlement. The GDRS is mainly responsible for on-farm development and small irrigation works using up to 500 litres/sec. From its headquarters in Ankara, GDRS operates through 22 regional irrigation directorates. Whilst it has completed a large number of irrigation and on-farm development works, one of its main challenges is growing on-farm development requirements of large-scale schemes that have DSI irrigation infrastructures.

Background of irrigation development and transfer

The ancient hydraulic structures of Anatolia, many of which are in good condition and still in use, make it a kind of open-air museum. The first modern irrigation and drainage project, the Çumra Irrigation and Drainage Project, was designed and constructed between 1908 and 1914 under the Ottoman Empire. After the foundation of the Republic of Turkey in 1923, priority was given to swamp reclamation to fight malaria. Some small irrigation projects were subsequently implemented. After the establishment of the DSI in 1954, numerous hydraulic projects, especially irrigation schemes, were given priority, as Turkey has vast and fertile plains.

Agriculture is the major water-consuming sector, accounting for more than 70 percent of total water consumption. Water scarcity has become a major concern since the 1960s and efforts have been made to improve water management to ensure efficient use for sustainable agricultural development.

In Turkey, as in other countries, government irrigation schemes were managed either directly by the government or by local authorities and WUAs. The centralized approach constituted a financial burden on the government, because income from bills was low to zero, water consumption and wastage were high, investment costs were not being recovered and there was little farmer interest in protecting the infrastructure.

Transfer of irrigation systems to users started slowly in the early 1950s. Until 1993, small schemes were being gradually transferred to users at the rate of about 2 000 ha annually. The DSI encouraged participatory approaches by establishing irrigation groups or WUAs with limited responsibility for O&M. Central government officials, however, were reluctant to adopt a decentralized approach out of concern for losing control of management.

Forms of transfer

Full transfer

Under this scheme, all O&M activities on irrigation projects developed by the DSI are taken over by WUAs. Responsibility for O&M is transferred to WUAs by an agreement signed by them and the DSI and approved by MENR.

Participation through joint management

This type of transfer has been implemented in irrigation projects developed and operated by the DSI. Limited responsibility for O&M is taken over by WUAs by an agreement signed by them and the DSI. No MENR approval is required. No agreement is signed between WUAs and GDRS.

Informal transfer

In this system, all O&M activities in GDRS-developed irrigation projects serving a single village are managed by the farmers. No agreement is signed between WUAs and GDRS.

Of the three systems, full transfer is the preferred option. The DSI continues to monitor and evaluate O&M. Since 1993, the DSI has been collecting O&M data related to transferred schemes and a yearly evaluation report is published. Full assessment post-evaluation reports have not yet been published.

Rationale of participatory irrigation management (PIM)

PIM was adopted in 1986 in order to increase user participation and independent control of irrigation management, and to decrease O&M costs.

User participation

Farmers represent 45 percent of employment in Turkey, a significant proportion. Before the participatory process, farmers had no rights or responsibilities for irrigation management and were unable to participate in setting water tariffs, electing chairmen or making decisions. The introduction of PIM created a sense of ownership among farmers which led to improved care of facilities.

After PIM it could be said that irrigation changed from a government programme with farmer assistance to a farmer programme with government assistance.

Self control

The WUAs are established under Municipal Act no. 1 580 and operate accordingly. A governing body of a president, a general secretary and an accountant is responsible to an executive board and the general assembly. The chairman is generally the mayor of one of the communities in the service area and the general secretary must be an agricultural engineer.

At general assemblies, the chairman and the board of directors present the accounts, technical and managerial issues are discussed and the water tariff is set.

Decrease in O&M cost

Lower O&M costs mean smaller government allocations and the money saved is used for additional investment in the agriculture sector.

Introduction of accelerated transfer to user organizations

In Turkey, there are different types of user organization:

- WUAs;
- municipalities;
- village authorities;
- cooperatives.

With regard to transfer, the most effective organizations are WUAs, since they are non-profit organizations that have the right to irrigate within their district, which may vary from 300 ha to 35 000 ha. Unlike cooperatives, the WUAs have managerial, financial and technical discretion. At the time of writing, 91 percent of transfers have been made to WUAs.

In 1986, the World Bank initiated the participatory process and establishment of WUAs was accepted as a prerequisite for loan allocation to Turkey.

Before 1993, the main objective of the DSI was to transfer small and isolated schemes, since these were difficult and uneconomic to manage. This approach was limited, however, to small schemes and the DSI was reluctant to hand over to farmers the organization and management of large schemes.

The need to raise government awareness, difficulties encountered in irrigation system management by central agencies and persuasion by the World Bank led decision-makers to adopt a new system of accelerated transfer of irrigation schemes to WUAs. Following national working group meetings in 1993, DSI policy moved away from limited transfer of small schemes towards larger ones. With World Bank support, the DSI sent more than 50 senior officials to the USA and Mexico in 1993 and 1994 to investigate technical, legal and institutional aspects of the transfer of irrigation systems. These visits have further encouraged the DSI to pursue accelerated transfer.

In 1993, the DSI took the decision to launch a pilot programme of accelerated transfer in cases where WUAs were already operating efficiently. The decision was based on the following:

- the financial burden on the DSI and the government of O&M costs: cost recovery was about 40 percent;
- political awareness: the government's decentralizing approach contributed to accelerating the process;
- the National Working Group Report of November 1993: *Farmer participation in investments in agriculture and O&M activities*; satisfactory O&M results in transferred schemes.

The provinces of Antalya, Adana, Konya and Izmir were selected for the pilot programme of accelerated transfer mainly because officials in these provinces had shown interest and local farmers were more receptive. Transfer was supported with enhanced training, including seminars and workshops. Friendly regional competition in promoting successful transfer contributed positively to the process.

The pilot study, in which DSI engineers acted as promoters and worked closely with local people, municipal councils and chairmen was successful in two respects:

- engineers realized that they would not lose their jobs as a result of transfer but would have an important support role after transfer;
- more efficient O&M, involving reduced costs and improved collection rates, was implemented with assistance from WUAs.

Discussion

The decision to transfer from government to users proved correct. It highlighted the sustainability of participatory irrigation management and the success of the decentralized WUA approach. Positive and negative aspects of the process are discussed below and illustrated with recent performance figures.

Improvements after transfer to WUAs

The DSI objective is to construct irrigation facilities in the remaining 3.5 million ha of land at the rate of 120 000 ha/year. When the programme of accelerated transfer to WUAs for irrigation O&M started in 1993, the DSI planned to transfer 1.35 million ha by the end of 2000. This figure was reached, however, by the end of 1997, which reflects the efficiency of the system.

Table 4.1 shows the distribution of irrigation facilities operated under existing systems.

Table 4.1: O&M of irrigation activities by various users (in 1998)

O&M carried out by:	Irrigated land (ha)	No. per group	Percentage of irrigated land
WUAs	1 483 000	265	69
Privately owned*	15 000		1
Cooperatives (groundwater)	330 000	1 272 (DSI has ownership in 735)	15
DSI	325 000		15
Total	2 153 000		100

* The DSI implements these schemes on behalf of the owners and hands them over upon payment.

As a pilot case, the DSI Antalya Regional Directorate carried out a comparative study of the so-called "tenth transfer". Results are given in Table 4.2.

The transfer of O&M services to WUAs has had a positive impact, particularly on the technical and financial aspects. The following points are noteworthy:

- The participatory approach generated a new sense of responsibility towards better use and protection of resources and facilities.
- Water use is more reliable and equitable, with plots situated upstream or downstream of irrigated land being equally served.
- Studies to increase irrigation efficiency by modern techniques are in progress. Examples include pilot projects to compare drip irrigation, sprinkler and California systems being implemented with DSI assistance.
- The "user pays" approach has increased awareness of the need for water savings. WUAs charge interest at market rate of 12 percent for non-payment and levy fines at 40 times the standard rate for illegal connections, misuse or wastage and at 80 times the standard rate for damage caused to physical plant. There is mutual supervision among farmers which exploits social pressure to enhance efficiency.
- WUA chairpersons are obliged to provide services regardless of users' political affiliations. There is no political influence in water distribution.
- The collection rate increased from 42 percent in 1993, when the DSI controlled irrigation, to more than 80 percent in 1997, when irrigation management was transferred to WUAs.
- Energy consumption decreased following transfer by approximately 25 percent.

The results of WUA monitoring indicated that transfer was carried out successfully, although the DSI is concerned that it did not have sufficient time for post-transfer evaluation in all cases.

Constraints and required legal reforms

So far, the DSI has given technical assistance to WUAs in the form of repair and maintenance of water structures and equipment, training support and guidance on technical and administrative issues. This support continues but has decreased over the years. Unless WUAs are strengthened institutionally and technically, they will need support from central government. Experience shows that transferred schemes cannot maintain satisfactory performance and increased production from irrigated land,

Table 4.2: Comparative table for the Antalya Region

Results by the end of 1998	Regular irrigation in 1993	Transferred irrigation in 1998	Increase in efficiency %
Water saving	16 109 m^3/ha	10 684 m^3/ha	34
Energy saving	1 502 kWh/ha	1 030 kWh/ha	31
Area with high water table	8 892 ha (20%)	6 683 ha (15%)	5
Salinization: area improved	38 692 ha (89%)	39 610 (91%)	2
Increase in collection rate	71%	95%	24

particularly during the initial period, without government assistance. This is a crucial issue, since small organizations in particular may face difficulties and fail to fulfill their potential, in which case the sustainability of the PIM concept is called into doubt.

The following improvements and reforms will therefore be needed to guarantee performance and replicability.

- Urgent legal reforms are required to enable WUAs to operate within a well defined legal framework that will make PIM sustainabe. WUAs currently operate under Municipal Act no. 1 580, which is not specific to these organizations. DSI technical and advisory staff, with WUA representatives, drafted a law and submitted it to MENR in 1997.
- WUAs should be given technical assistance and guidance from the beginning of transfer until they gain sufficient experience in irrigation management.
- WUAs should be provided with O&M equipment and machinery on a cost-sharing basis.
- The Turkish Government will provide 30 percent of the finance for the five-year US$20 million World Bank project for equipment procurement. The remainder will be reimbursed by WUAs. The project was initiated in 1997 under Loan no. 4 235 TU, to improve the institutional framework, performance and sustainability of WUAs (Staff Appraisal Report no. 16 525-TU, September 18, 1997).
- The government should give priority to WUA requests for system modernization in transfer areas on a cost-sharing basis. The Uluborlu Irrigation Rehabilitation Project in Isparta province is a good example.
- Flexibility with regard to structural changes designed to implement best practice should be allowed. If regulations are inappropriate to WUA needs, low yields, inadequate water distribution, violation of rules and social unrest may occur.

Conclusion

In Turkey, WUAs have demonstrated their ability to operate and maintain facilities satisfactorily by recruiting the required staff, purchasing transport and communication equipment, assessing and collecting water fees and improving water distribution at a cost below the DSI rate.

The concepts of PIM and transfer to WUAs are recommended for replication elsewhere, bearing in mind that there is a need to improve legal structures in order to ensure a fully viable irrigation management system.

Annex 5
Tunisia case study: integrated water management in a context of scarce water resources[1]

Situated to the south of the Mediterranean, Tunisia covers 164 000 km². In 1999, the population was 9.4 million. In the north and along the coast, the climate is Mediterranean; inland and in the south it is semi-arid to arid.

The GDP maintains a steady positive balance, averaging 6 percent in the mid 1990s. Social wellbeing is reflected in greater exploitation of water resources in sanitation and intensified irrigation. Almost every city has access to drinking water and water networks are being developed in rural areas.

Geographically, Tunisia is characterized by irregular rainfall, from 500 mm to 1 000 mm in the north to an average of 150 mm in the south, and dry periods that can last for weeks, often occuring during a single season or persisting over several consecutive seasons.

Current water-management strategy in Tunisia is the result of 30 years of water resources evaluation and mobilization and socio-economic development priorities for which water is essential.

Water resources strategy

Development of water resources mobilization plan

Water resources mobilization has increased capacity by 1.5 billion m^3 in the last ten years. These water resources consist of 660 million m^3 of surface water in major dams, hill dams, lakes, flood spread and aquifer recharge basins and 355 million m^3 from exploitation of groundwater and deep aquifers.

The effort over the last ten years to mobilize more water has resulted in an increase of between 2.6 billion m^3 and 3.6 billion m^3, representing 80 percent of available water. The tenth economic plan for Tunisia in 2002 will continue this effort towards mobilizing more water. It will include implementation of a comprehensive system of large and small dams, a hydrographic and water supply network allowing for connections between surface and groundwater reservoirs within one basin and between basins to supply inland regions with water from the north. Urban water treatment plants will be constructed and there will be increased potential resources available for fodder crops.

Perception of management rules in an arid zone

Managing water in arid and semi-arid areas means dealing with hydrological irregularities – rainfall, runoff into dams, evaporation and aquifer grade lines – which render any forecast tentative whatever timeframe is considered, except those used in weather forecasting.

In semi-arid areas, water management for agriculture balances irrigation needs against water requirements for starting new crops in the following autumn.

In sub-humid or humid areas, where water resources are available and affordable, it is economically profitable to deliver the water required for agriculture without saving for the following year. In Tunisia, where irrigation is the largest water consumer, a compromise of water allocations is required but the country's integrated water-management policy has not yet found ways to achieve this.

Despite a steady increase and minimal quality constraints, urban water requirements are still far less than the quantities mobilized by agriculture. The example below considers an irrigation scheme with the following characteristics:

- irrigated area: 1 000 ha;
- equivalent continuous flow: 0.6 litres/sec/ha;
- irrigation duration during peak period: 18 hours per day.

Flows and volumes are:

- design flow for 1 000 ha: 0.8 m^3/sec;
- daily volume: 51 840 m^3.

[1] Fethi Lebdi, Professor, Institut National Agronomique de Tunisie, Tunis

Urban consumption of drinkable water averages 125 litres per day per inhabitant. If water quality is taken to be identical, the daily volume of 51 840 m^3 mentioned above would be sufficient for a population of 415 000, equivalent to one of Tunisia's large cities. Almost 80 percent of water resources are used in agriculture.

Tools for integrated management of water resources

Water transfer network

The annual compromise in water management has the objective of minimizing water loss from overflows from northern dams in rainy years or late spring storm periods. Water supplies are variable, so in order to conserve water and supply regions equitably, a network was implemented for transfer of water within a watershed or between watersheds. This network consists of natural "oueds" (temporary rivers), artificial channels and pressurized pipes and is one of the major tools of water management in Tunisia. The integrated and simultaneous use of surface water and groundwater, including the possibility of mixing water of different quality, is made possible by interconnected networks in different watersheds. During the droughts of 1987-89 and 1992-95, major dams contributed to interannual regulation and deficits in annual regulation dams were made up by water transfers from dams in the north.

Availability of hydraulic and hydrological data and processing tools

In a context of water scarcity, managers need adequate and reliable information at the right time and processing tools that integrate chronological data – models, experience and organization of data history – and assist with decisions leading to optimal management. An information system for decision support has been implemented, which includes:

- a measurement system for hydrological and hydraulic parameters of surface water and a follow-up system for watertable levels;
- an accounting system for precise evaluation of needs;
- a regularly updated data storage system structured as a water database;
- software to optimize management procedures at different stages, allowing modification of decisions to reflect data updates.

The database for the hydraulic system includes:

- hydrological and climatic data including rainfall, runoff inputs and evaporation;
- the amount of water in reservoirs;
- flow for each dam;
- flow for each oued;
- water salinity and turbidity in reservoirs and oueds upstream and downstream from them;
- chemical analysis and follow-up of hydrological parameters.

Models have been developed to optimize management procedures for flood control in the short and medium term. They are now being calibrated and validated year by year. These decision support tools help to:

- maintain water management and release instructions;
- study the impacts of those instructions on:
  - supplying drinking water needs as the first priority, with no restrictions even during dry periods;
  - minimizing water deficits in agriculture;
  - implementing agricultural water-allocation restriction programmes during drought periods;
  - minimizing water losses through overflows.

This system of information- and decision-support tools helped with decisions and predictions during the dry years of 1992-95. During this period, urban drinking water needs were met without restrictions, while agricultural needs were reduced by 50 percent at most and only locally.

Water-saving programmes

With regard to water resources, Tunisian water laws and law no. 75-16 of 31. 3. 1975 make obligatory optimal use and conservation of water resources in terms of quantity and quality. To be achievable, the objective of optimizing use of every cubic metre of water requires efforts to reduce water losses in distribution networks and at field level.

Studies to refurbish and modernize irrigation schemes are currently under way, with the aim of improving efficiency in water use.

Inappropriate management of water resources has resulted in large amounts being used and unsuitable water allocations. It has been impossible for collective networks to distribute flows in response to high demand. The balance between water resources and needs tends to be negative: some aquifers are overexploited or there is insufficient leaching and consequent soil deterioration resulting from frequent use of saline waters.

Poorly applied surface irrigation techniques, which are still the most common, result in water losses through storage in "seguias", or field canals, infiltration and overflow in seguias and deep seepage in borders, basins and furrows.

Refurbishment of networks and introduction of water-saving techniques subsidized by the government – 40 percent to 60 percent of equipment costs subsidized, depending on farm size – has helped reduce loss rates at network and field level from 50 percent to 25 percent. Water applications were shortened and adapted to field irrigation techniques – lower water allocation in more frequent applications – and cropping intensities in irrigation schemes increased to more than 1.0. This improved technical performance was brought about by:

- using water saving techniques: localized irrigation, low-pressure irrigation (drip lines) and improved surface irrigation with lined or concrete seguias;
- adapting the production system to markets and resources;
- individual water accounting being introduced to farmers;
- implementing a system to set water prices that reflects socio-economic factors and the need to save scarce water;
- giving farmers responsibility for resource and infrastructure management, thus developing awareness of water scarcity and the need to rationalize its use.

The concept of saving water appeared in every sector that uses water, especially drinking water.

Administration was decentralized and responsibilities were given to regional bodies: the CRDA drinking water district, an advanced unit of the Office National de l'Assainissement. Field measures could then be implemented that promoted water saving techniques and made treated urban wastewater available.

WUAs or Groupes d'Interêt Collectifs

Resource management at the level of irrigation schemes or rural drinking water sources has been transferred to WUAs. With their new responsibilities, users were motivated to rationalize their resource. WUAs have civil liabilities: they are financially autonomous and responsible for implementing, operating and maintaining irrigation and water-supply systems. A council composed of a president, a treasurer and members is elected to look after technical and financial matters.

WUAs are managing more than half of the public irrigation schemes. Various training programmes were made available when WUAs were created and involved in hydraulic system management. Administrative and financial skills were thus transferred, especially account management and organization, water pricing procedures and technical infrastructure maintenance.

Since then, the social concept of water has become increasingly significant in economic terms, as water is a production factor.

WUA budgets should be balanced through water sales. During off-peak periods, WUAs buy water at preferential prices – 50 percent discount – that promote irrigation for large-scale farming of cereals and fodder and enable cropping intensities in irrigation schemes of more than 100 percent.

Institutional aspects: water regulation

In Tunisia, water laws govern the water sector. The text promulgated in 1975 states the following provisions:

- water resources are the property of the State, except for some traditional water property rights that were converted to water-use rights in oases in the south;
- administration plays an integrated role in planning, management, control and follow-up of water use, whether quantitatively or qualitatively, involving diversion, consumption, irrigation schemes for water and soil conservation;
- water resources can be increased by reusing treated waste water in agriculture.

Strengths of the Tunisian experience

The Tunisian experience in water resources management is particularly effective in:

- mobilizing surface water and groundwater;
- implementing networks connecting water sources, allowing water transfer at any time;
- implementing integrated management of surface water and groundwater;

- implementing a regularly updated water database and decision-support tools;
- initiating water-saving programmes at network and field levels through following up individual water-consumption accounting promoted by the government through subsidized equipment;
- using water pricing as a parameter for managing demand and savings;
- creating and assisting WUAs, the core of water management and hydraulic infrastructure in irrigation schemes, increasing awareness of water scarcity and the need for rational use;
- taking the environment into account by allocating water to protected sites;
- increasing potential resources available for fodder crop irrigation by promoting reuse of treated wastewater through a network of wastewater treatment plants draining the main cities into the country.

Future challenges

Despite the efforts made so far, challenges remain:

- increasing water demand in a context of limited resources will result in increased competition with other sectors, such as drinking water, industry and tourism;
- globalization, with its increased competitiveness, requires optimum economic performance from the irrigation sector: reduced production costs and improved product quality, especially for export;
- research is required at some saline surface water and groundwater sources on salinity in aquifers and reservoirs and the impact of saline irrigation water on agricultural soil fertility ;
- giving responsibility to well owners for maintaining sustainable groundwater and avoiding over-exploitation of aquifers, especially those with good water quality or those regenerating in the short or medium term;
- moving from a technical to an economic approach in water resource management to help define the role of the private sector and the resulting added value expected in water-sector promotion;
- resolving land tenure difficulties and agricultural land divisions, which sometimes result in poor production, through land reform and irrigation scheme improvements;
- increasing competitiveness among participants in the water sector through training.

Conclusion

Tunisia has developed expertise in the fields of water resource mobilization and integrated management in a context of aridity, water scarcity and socio-economic constraints. This expertise has been sustained from the start by a national strategy, strong political commitment and increasing user awareness.

The water sector has developed through water-saving programmes, training, promulgation of regulations and laws, organizing information- and decision-support tools and extension techniques.

Some of the challenges mentioned above are a consequence of this development. As a whole, however, they represent the trends for short and medium term develoment, which requires reliable, sustainable procedures.

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